Handbook for Thermal and Nuclear Power Engineers

English Edition of The 6th Revision

2002

Thermal and Nuclear Power Engineering Society of Japan

TENPES

Foreword

This handbook is a version into English of the Handbook for Thermal and Nuclear Power Engineers (in Japanese) – the 6th revised edition – published in October 2000.

The handbook (in Japanese) was published first in August 1954 and reached to its 6th revised edition with the efforts to reflect the development in thermal and nuclear power generation over the years. The progress is presented in the Preface to The 6th Revised Edition.

The translation and compilation of this English Edition were performed by the Committee for Editing the English Edition of Handbook for Thermal and Nuclear Power Engineers, organized in the Thermal and Nuclear Power Engineering Society of Japan.

I should like to thank to the members of the Committee of the English Edition for their great efforts.

January, 2002

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Preface to The 6th Revised Edition

The 6th revised edition of the "Handbook for Thermal and Nuclear Power Engineers" is come to be published in this memorial year of the 50th anniversary of Thermal and Nuclear Power Engineering Society of Japan, after repeated deliberations at the general committee together with the first working group (thermal power) and the second working group (nuclear power) since October, 1998.

This handbook has a long history from the initial edition of "Handbook for Thermal Power Engineers" published in August, 1954 to the 5th edition of "Handbook for Thermal and Nuclear Power Engineers" published in March, 1993 and has been highly evaluated as an useful data book for power generation related engineers. However, more than seven years has passed since the issuance of the 5th revised edition, and remarkable technical development is attained, power business is further expanded and evolution is accomplished, together with new technologies introduction. Efficient use of energy resources including the nuclear fuel, appropriate administration and insurance of the safety in accordance with the self-liability rules by deregulation, and protection of the local and grobal environment become urgent subjects in these years, and thus acts and criteria have also been revised correspondingly. From those situations, the Handbook of the 6th revised edition has included the knowledge acquired by the latest technical development, and revised the contents to meet the demand of the new era.

In this revision, examing the previous edition thoroughly, the specifications, standards, and rules and regulations are revised to the latest, and the unit system used is altered to SI (International System of Units). In order to incorporate the newly progressed technologies, new information is added on such subjects as: combined cycle power generation, pressurized fluidized bed combustion, coal-gasifier, improved nuclear reactors, maintenance activities of nuclear power plants, various newly developing power generation systems, and important environmental measures nowadays.

Moreover, it was tried to add subsections on general information to many chapters, to improve the structure of chapters for easy understanding of the contents. In the chapter on laws and standards, the systems of laws and regulations and whole outline for each technical standard are tried to describe in charts as much as possible.

Committee members who participated for the revision of the Handbook were in charge of study and writing concentrating their abundant information and experiences obtained in the front of their business as engineers or researchers. It is expected for the Handbook to be used by many engineers of thermal and nuclear power industries to make evolution of the power generation field.

At the end, I wish to express my gratitude sincerely to the Committee members who have made self-sacrificing from beginning to end, the concerned authorities and business firms who have offered a great deal of information, and the survey division members of the Society who have exerted for editing of huge information over the long period of time.

October, 2000

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1-1 System of Units(Refer to JIS Z 8203-1985)

As for SI Units

SI is an abbreviation for the International System of Units (Le Système International d'Unitès in French) which is a coherent system of units adopted and recommended by the General Conference of International Weights and Measures. SI Units are composed of base units, supplementary units and derived units that are built up out of these two unit groups, and their multiples in teger powers of base 10.

Base Units

Quantity	Name of unit	Unit symbol	Definition
Length	meter	m	The meter is the length equal to the distance where light travels in vacuum in the fraction $\frac{1}{299,792,458}$ of second.
Mass	kilogram	kg	The kilogram is the unit of mass (being neither that of weight nor force) ; it is equal to the mass of the inter- national prototype of the kilogram.
Time	second	s	The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the Cesium-133 atom.
Electric current	ampere	A	The ampere is that constant electric current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.
Thermodynamic temperature	kelvin	K	The kelvin is the fraction $\frac{1}{273.16}$ of the thermodynamic temperature of the triple point of water.
Amount of substance	mole	mol	The mole is the amount of substance of a system or a group of elementary entities (¹) that contains as many atoms in 0.012 kilogram of carbon 12 (for the group the composition has to be specified), and to be used by specifying the elementary entities or the group thereof.
Luminous intensity	candela	cd	The candela is the luminous intensity in a given direction of a source which emits monochromatic radiation of frequency 540×10^{12} hertz and of which the radiant intensity in that direction is $\frac{1}{683}$ watt per steradian.

Note: (¹) The elementary entities referred to are atoms, molecules, ions, electrons or other particles.

Supplementary Units

Quantity	Name of unit	Unit symbol	Definition
Plane angle	radian	rad	The radian is a plane angle between two radii of a circle which cuts off on the circumference an arc equal in length to the radius.
Solid angle	steradian	sr	The steradian is the solid angle which, having its vertex in the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square sides of length equal to the radius of the sphere.

Comprehensive list of SI units and derived units

	Quantity	Name of unit	Unit symbol	Remark
(1) Space and time	Plane angle and angle	radian	rad	1° (degree) $=\frac{\pi}{180}$ rad. 1′ (min) = $\left(\frac{1}{60}\right)^{\circ}$ 1″ (sec) = $\left(\frac{1}{60}\right)'$
	Solid angle	steradian	sr	
	Length	meter	m	1nautical mile =1852 m 1 Å (angstrom) $=10^{-10}$ m
	Area	square meter	m^2	1a $=10^2 m^2$ 1ha(hectare) $=10^4 m^2$
	Volume and capacity	cubic meter	m^3	1 ℓ (liter) $=10^{-3} m^3$
	Time	second	s	1min(min)=60s 1h(hour)=60min 1d(day)=24h
	Angular velocity	radian per second	rad/s	
	Velocity and speed	meter per second	m/s	1 knot =1852m/h
	Acceleration	meter per second per second	m/s^2	
(2) Periodic and related phenomena	Frequency and cyclic frequency	hertz	Hz	1 Hz= 1 s^{-1}
	Rotating speed and speed of rotation	revolution per second	s^{-1}	min^{-1} (r/min) $=60s^{-1}$
(3) Mechanics	Mass	kilogram	kg	1 t(ton) $=10^3$ kg
	Density	kilogram per cubic meter	kg/m^3	
	Linear density	kilogram per meter	kg/m	1 tex $=10^{-6}$ kg/m
	Momentum	kilogram meter per second	kg•m/s	
	Moment of momentum and angular momentum	kilogram square meter per second	$kg•m^2/s$	
	Moment of inertia	kilogram square meter	$kg•m^2$	
	Force	newton	N	1N=1kg•m/s^2 1 kgf =9.80665N 1dyn→10^{-5}N
	Moment of force	newton meter	N•m	
(3) Mechanics (continued)	Pressure	pascal	Pa	1Pa=1N/m^2 1bar(bar) $=10^5$ Pa 1Torr=1mmHg → $\frac{101325}{760}$ Pa
	Stress	pascal or newton per square meter	Pa or N/m^2	1kgf/cm^2= 9.80665×10^4 Pa ≒0.1MPa =1bar
	Viscosity	pascal second	Pa•s	1P(poise) =0.1Pa•s
	Kinematic viscosity	square meter per second	m^2/s	1St(stokes) $=10^{-4} m^2/s$
	Surface tension	newton per meter	N/m	
	Work, energy	joule	J	1J=1N•m, 1 eV(electron volt)=1.60207 ×10^{-19}J 1erg=10^{-7}J
	Power	watt	W	1 W=1J/s =1N•m/s
	Mass flow rate	kilogram per second	kg/s	
	Flow rate	cubic meter per second	m^3/s	
(4) Heat	Thermodynamic temperature	kelvin	K	"°" mark shouldnot be attached, inspite that °K is used hitherto."
	Celsius temperature	celsius degree	℃	0 ℃=273.15K
	Temperature interval and difference of temperature	kelvin	K	"℃ can be used for temperature interval or temperature difference, but not use a letter of"deg."
	Linear expansion coefficient	per kelvin	1) K^{-1}	
	Quantity of heat and heat	joule	J	1J=1N•m 1cal=4.1868J
	Heat flow rate	watt	W	1W=J/s
	Thermal conductivity	watt per meter per kelvin	1) W/(m•K)	
	Heat transfer coefficient	watt per square meter per kelvin	1) W/(m^2•K)	
(4) Heat	Heat capacity	joule per kelvin	2) J/K	
	Specific heat capacity and specific heat	joule per kilogram per kelvin	2) J/(kg•K)	
	Entropy	joule per kelvin	J/K	
	Mass entropy and specific entropy	joule per kilogram per kelvin	J/(kg•K)	
	Specific internal energy	joule per kilogram	J/kg	
	Latent heat	joule per kilogram	J/kg	
(5) Electricity and magnetism	Electric currrent	ampere	A	
	Electric charge and quantity of electricity	coulomb	C	1C=1A•s
	Volume density of charge and charge density	coulomb per cubic meter	C/m^3	
	Surface density of charge	coulomb per square meter	C/m^2	
	Electric field strength	volt per meter	V/m	
	Electric potential, potential difference (voltage) and electromotive force	volt	V	1V=1W/A
	Electric flux displacement	coulomb per square meter	C/m^2	
	Electric flux and flux of displacement	coulomb	C	
	Electrostatic capacity and capacitance	farad	F	1F=1C/V
	Permittivity	farad per meter	F/m	
	Electric polarization	coulomb per square meter	C/m^2	
	Electric depole moment	coulomb meter	C•m	
	(electric) Current density	ampere per square meter	A/m^2	
	Linear current density	ampere per meter	A/m	
(5) Electricity and magnetism	ampere per meter	ampere per meter	A/m	10e→ $\frac{1000}{4\pi}$ A/m
	Magnetic potential and magnetromotive force	ampere	A	
	Magnetic flux density and magnetic induction	tesla	T	1T=1V•s/m^2 1Gs→10^{-4} T
	Magnetic flux	weber	Wb	1Wb=1V•s 1Mx→10^{-8}Wb
	Magnetic vector potential and vector potential	weber per meter	Wb/m	
	Self inductance and mutual inductance	henry	H	1H=1V•s/A
	Magnetic permeability	henry per meter	H/m	
	Magnetic moment	ampere square meter	A•m^2	
	Magnetization	ampere per meter	A/m	
	Magnetic polarization	tesla	T	
	Magnetic depole moment	newton square meter per ampere or weber meter	N•m^2/A or Wb•m	
	(electric) Resistance (DC)	ohm	Ω	1Ω=1V/A
	(electric) Conductance (DC)	siemens	S	1S=1A/V $=1\Omega^{-1}$
	Resistivity	ohm meter	Ω•m	
	Conductivity	siemens per meter	S/m	
	Reluctance	per henry	H^{-1}	
	Permeance	henry	H	
	(complex) Impedance, magnitude of impedance, reactance and (electric) resistance	ohm	Ω	

	Quantity	Name of unit	Unit symbol	Remark
(5) Electricity and magnetism	(complex) Admittance, magnitude of admittance, susceptance and conductance	siemens	S	
	(active) Power	watt	W	
	Reactive power	var	Var	
	Apparent power	volt ampere	VA	
	Electric energy	joule	J	1Wh=3.6kJ
(6) Optics and related electromagnetic radiations	Wavelength	meter	m	1 Å=10^{-10}m
	Radiant energy	joule	J	
	Radiant flux	watt	W	
	Radiant intensity	watt per steradian	W/sr	
	Radiance	watt per steradian per square meter	W/(sr•m^2)	
	Radiant exitance	watt per square meter	W/m^2	
	Irradiance	watt per square meter	W/m^2	
	Luminous intensity	candela	cd	
	Luminous flux	lumen	lm	
	Quantity of light	lumen second	lm•s	1lm=1cd•sr
	Luminance	candela per square meter	cd/m^2	1Sb→10^{4}cd/m^2
	Luminous exitance	lumen per square meter	lm/m^2	
	Illuminance	lux	lx	1lx=1lm/m^2 1ph→10^{4}lx
	Exposure value	lux second	lx•s	
	Luminous efficiency	lumen per watt	lm/W	
(7) Sound	Period	second	s	
	Frequency and cyclic frequency	hertz	Hz	1Hz=1s^{-1}
	Wavelength	meter	m	
	Density	kilogram per cubic meter	kg/m^3	

	Quantity	Name of unit	Unit symbol	Remark
(7) Sound	Static pressure and (instantaneous) sound pressure	pascal	Pa	
	(instantaneous) Particle velocity	meter per second	m/s	
	(instantaneous) Volumetric velocity	cubic meter per second	m^3/s	
	Sound wave velocity and speed of sound	meter per second	m/s	
	Sound energy flux and sound power	watt	W	
	Sound intensity	watt per square meter	W/m^2	
	Acoustic impedance	pascal second per cubic meter	Pa•s/m^3	
	Specific acoustic impedance	pascal second per meter	Pa•s/m	
	Mechanical impedance	newton second per meter	N•s/m	
	Sound pressure level	decibel	dB	
	Sound power level	decibel	dB	
	Reverberation time	second	s	
	Sound absorbing power and equivalent absorption area	square meter	m^2	
	Sound transmission loss	decibel	dB	
(8) Physical chemistry and molecular physics	Amount of substance	mole	mol	
	Molecular mass	kilogram per mole	kg/mol	
	Molar volume and molar capacity	cubic meter per mole	m^3/mol	
	Molar internal energy	joule per mole	J/mol	
	Molar heat capacity and molar specific heat	joule per mole per kelvin	1) J/(mol•K)	
	Molar entropy	joule per mole per kelvin	1) J/(mol•K)	
	Concentration of substance	mole per cubic meter	mol/m^3	
	Mass molar concentration	mole per kilogram	mol/kg	
	Diffusion coefficient	square meter per second	m^2/s	
	Thermal diffusion coefficient	square meter per second	m^2/s	

	Quantity	Name of unit	Unit symbol	Remark		Quantity	Name of unit	Unit symbol	Remark
(9) Radiation	Radioactivity and disintegration rate	becquerel	Bq	1Bq=1s^{-1} 1Ci(curie) =3.7×10^{10}Bq	(9) Radiation	Dose equivalent	Sievert	Sv	1Sv=1J/kg 1rem=10^{-2}Sv
	Mass energy imparted and absorbed dose	gray	Gy	1Gy=1J/kg 1rad(rad) =10^{-2}Gy		Dose exposure	coulomb per kilogram	C/kg	1R(roentgen) =2.58×10^{-4} C/kg

(Note) In the "Remark" column, ( ) = ( ) shows that the both can be used together with, and ( )→( ) shows that change should be preferable.

(Note) 1) ℃ may be used in stead of K as a symbol of temperature.

(Note) Sound loudness level is given by $L_n=20\log_{10}(P_e/P_o)_{1kHz}$ (unit : phone), where P_e is an effective sound pressure value of 1kHz sound when it is heard by a person having normal listening power who feels to be equal level of that sound, and P_o = 20 μPa.

Prefixes of the SI units

Multiples combined with unit	Name of prefix	Symbol of prefix	Multiples combined with unit	Name of prefix	Symbol of prefix	Multiples combined with unit	Name of prefix	Symbol of prefix
10^{18}	exa	E	10^2	hect	h	10^{-9}	nano	n
10^{15}	peta	P	10	daca	da	10^{-12}	pico	p
10^{12}	tera	T	10^{-1}	deci	d	10^{-15}	femto	f
10^9	giga	G	10^{-2}	centi	c	10^{-18}	atto	a
10^6	mega	M	10^{-3}	milli	m			
10^3	kilo	k	10^{-6}	micro	μ			

1-2 A Comparison List of SI Units with Customary Engineering Units for Major Quantities

Refer to JIS Z 8202- 1985,
JIS Z 8203- 1985 and
ISO- 1000- 1981

Units \ Quantity		Length	Mass	Time	Force(weight) 1)	Pressure and stress	Specific volume (capacity)
SI units		m	kg	s	N=kg•m/s^2	MPa=10^{6}N/m^2 =10bar	m^3/kg
Customary units	Metric system	m	2) kg	s	3) kgf=9.80665N	at=kgf/㎠ 3) =9.80665×10^{-2}MPa	2) m^3/kg
	Yard and pound	ft=0.3048m	2) lb=0.45359237kg	s	3) lbf=4.44822N	psi=lbf/in^2 3) =6.89476×10^{-3}MPa	ft^3/lb 2) =6.2428×10^{-2} m^3/kg

Units \ Quantity		Work (energy)	Quantity of heat	Specific enthalpy	Specific entropy
SI units		J=N•m	kJ	kJ/kg	kJ/kg•K
Customary units	Metric system	3) kgf•m=9.80665J	kcal=4.1868kJ	2) kcal/kg=4.1868kJ/kg	kcal/kg•K 2) =4.1868kJ/kg•K
	Yard and pound	3) ft•lbf=1.355818J	Btu=1.055056kJ	2) Btu/lb=2.3260kJ/kg	Btu/lb•°R 2) =4.1868kJ/kg•K

Quantity Units		Power	Viscosity	Kinematic viscosity	Thermal conductivity
SI units		kW=kJ/s	Pa•s=kg/m•s=10^{3}cP	m^2/s	W/m•K
Customary units	Metric system	PS=75kgf•m/s 3) =0.7355kW	cP=10^{-3}Pa•s	cSt=10^{-6}m^2/s	kcal/m•h•℃ =1.163W/m•K
	Yard and pound	HP=550ft•lbf/s 3) =0.7457kW	lb/ft•s 2) =1.4882Pa•s	ft^2/s=9.2903×10^{-2}m^2/s	Btu/ft•h•°F =1.7307W/m•K

Note : 1) The standard acceleration of gravity G_n=9.80665m/s^2=32.17405ft/s^2, 1 pdl= 1 lb•ft/s^2 =0.138255N.

2) kg and lb shall be used for the units of mass. (Examples : density in kg/m^3, lb/ft^3 ; specific enthalpy in kcal/kg, Btu/lb, etc.)

3) kgf and lbf shall be used for the units of force (weight). (Examples : pressure in kgf/cm^2 and lbf/in^2 ; energy in kgf•m and ft•lbf, etc.)

1-3 Conversion of Length Units

m	km	in	ft	yd	chain	mile	Nautical mile
1	0.001	39.370	3.28084	1.09361	0.04971	0.000621	0.000539
1 000	1	39 370	3 280.84	1 093.61	49.71	0.621371	0.539957
0.0254	0.000025	1	0.083332	0.027777	0.001262	0.000015	0.000013
0.3048	0.000305	12	1	0.333333	0.015151	0.000189	0.000164
0.9144	0.000914	36	3	1	0.045454	0.000568	0.000494
20.1168	0.020116	792	66	22	1	0.0125	0.010862
1 609.344	1.60931	63 360	5 280	1 760	80	1	0.868961
1 852	1.852	72 914.6	6 076.21	2 025.41	92.0641	1.1508	1

1-4 Conversion of Area Units

m^2	a	km^2	in^2	ft^2	yd^2	chain^2	acre	mile^2
1	0.01	0.000001	1 550.00	10.7639	1.19599	0.002471	0.000247	3.861×10^{-7}
100	1	0.0001	155 000	1 076.42	119.603	0.247114	0.024717	0.0000386
1 000 000	10 000	1	——	——	1 196 030	2 471.14	247.114	0.386116
0.000645	6.4516×10^{-6}	——	1	0.006944	0.000771	0.000001	——	——
0.092903	0.000929	——	144	1	0.111111	0.000229	0.0000229	——
0.836127	0.008361	0.0000008	1 296	9	1	0.002066	0.0002066	——
404.686	4.04686	0.0004046	627 264	4 356	484	1	0.1	0.0001562
4 046.86	40.468	0.004046	——	43 560	4 840	10	1	0.001562
2 589 990	25 899.9	2.58999	——	——	——	6 400	640	1

1-5 Conversion of Volume Units

m^3	*l*	in^3	ft^3	yd^3	gal(G.B.)	gal(U.S.)	bbl(U.S.) (barrel)
1	1 000	61 023.6	35.3147	1.370795	219.975	264.178	6.28982
0.001	1	61.0236	0.035315	0.001308	0.219969	0.264172	0.006290
1.63871×10^{-5}	0.016387	1	0.000578	0.000021	0.003605	0.004329	0.000103
0.028317	28.3168	1 728	1	0.037037	6.22898	7.48051	0.178107
0.764555	764.555	46 656	27	1	168.183	201.974	4.80890
0.004546	4.54609	277.427	0.160547	0.005946	1	1.201	0.028595
0.003785	3.78541	231	0.13368	0.00495	0.832699	1	0.02381
0.158987	158.987	9 702	5.61456	0.2079	34.9733	42	1

1-6 Conversion of Mass Units

kg	t	gr (grain)	oz (ounce)	lb (pound)	t (G.B.)	t (U.S.)
1	0.001	15 432	35.2740	2.20462	0.000984	0.001102
1 000	1	——	35 273.9	2 204.62	0.984204	1.1023
6.4799×10^{-5}	——	1	0.002285	0.000142	——	——
0.028349	0.000028	437.5	1	0.0625	0.000027	0.000031
0.453592	0.000453	7 000	16	1	0.000446	0.0005
1 016.05	1.01605	——	35 840	2 240	1	1.12
907.185	0.907185	——	32 000	2 000	0.892857	1

1-7 Conversion of Density Units (Refer to paragraph of 1-6 Conversion of Mass Units)

kg/m^3	g/cm^3	lb/in^3	lb/ft^3	t(G.B.)/yd^3	lb/gal(G.B.)	lb/gal(U.S.)
1	10^{-3}	3.613×10^{-5}	0.06243	7.52×10^{-4}	0.01002	8.345×10^{-3}
10^3	1	0.03613	62.43	0.752	10.02	8.345
27 680	27.680	1	1 728	20.83	277.4	231.
16.0185	0.01602	0.0005787	1	0.01205	0.1605	0.1337
1 329	1.329	0.04801	82.96	1	13.32	11.09
99.8	0.0998	0.003605	6.229	0.07508	1	0.8327
119.8	0.1198	0.004329	7.481	0.09017	1.201	1

1-8 Conversion of Force Units (Refer to paragraph of 1-6 Conversion of Mass Units)

N	Mdyn	kgf	tf(Metric system)	poundal	lbf	tf(G.B.)	tf(U.S.)
1	0.1	0.10197(3)	1.0197×10^{-4}	7.233	0.2248	1.0036×10^{-4}	1.124×10^{-4}
10	1	1.0197	1.0197×10^{-3}	72.33	2.248	1.0036×10^{-3}	1.124×10^{-3}
9.80665 *	0.980665 *	1	1×10^{-3}	70.93	2.205(1)	0.9842×10^{-3}	1.102×10^{-3}
9 806.65 *	980.665 *	1 000	1	70.93×10^{3}	2 205	0.9842	1.102
0.138255	0.01383	0.01410	0.01410×10^{-3}	1	0.03108(4)	0.01388×10^{-3}	0.01554×10^{-3}
4.44822	0.4448	0.4536(2)	0.4536×10^{-3}	32.174	1	0.4464×10^{-3}	0.5000×10^{-3}
9 964	996.4	1 016	1.016	72.07×10^{3}	2 240	1	1.120
8 896	889.6	907.2	0.9072	64.35×10^{3}	2 000	0.8929	1

(1) 1 kgf=2.2046226 lbf (2) 1 lbf=0.45359237kgf

(3) 1 N(newton) = 1 kg•m/s^2= 1 J/m=0.1Mdyn=7.233014poundal=0.10197162kgf

(4) 1 poundal= 1 lb•ft/s^2=0.01382550Mdyn=0.1382550N=0.03108065 lbf

* marks show close numerical values defined.

1-9 Conversion of Pressure Units

MPa	N/m^2	Mdyn/cm^2	kgf/cm^2	lbf/in^2	Standard atmospheric pressure	Mercurial column(0℃)		Water column(15℃)
	Pa	bar	ata.	psi	atm	mmHg	inHg	mAq
1	10^{6}	10	10.197	145.04	9.869	7 500.64	295.3	101.97
10^{-6}	1	10^{-5}	1.0197×10^{-5}	1.4504×10^{-4}	9.869×10^{-6}	0.007501	0.0002953	0.00010197
10^{-1}	10^{5}	1	1.0197	14.504	0.9869	750.064	29.53	10.197
0.0980665	98 066.5 *	0.980665 *	1	14.2233	0.9678	735.6	28.96	10.000
0.006895	6 895	0.06895	0.070307	1	0.06805	51.71	2.036	0.7031
0.101325	101 325 *	1.01325 *	1.0332	14.696	1	760.0	29.92	10.332
0.000133	133.32	0.0013332	0.00135951 *	0.01934	0.001316	1	0.03937	0.0135951 *
0.003386	3 386	0.03386	0.03453	0.4912	0.03342	25.40 *	1	0.3453
0.0098065	9 806.65 *	0.0980665 *	0.1000	1.4223	0.09678	73.56	2.896	1

* marks show close numerical values defined.

1-10 Conversion of Energy Units (Refer to paragraph of 1-13 Conversion of Power Units)

J	kgf.m	ft.lbf	kcal	Btu	kWh	PSh	HPh	MeV
1	0.101972	0.737562	2.38846×10^{-4}	9.47817×10^{-4}	2.77778×10^{-7}	3.77673×10^{-7}	3.72506×10^{-7}	6.24193×10^{12}
*9.80665	1	7.23301	2.34228×10^{-3}	9.29491×10^{-3}	2.72407×10^{-6}	3.70371×10^{-6}	3.65304×10^{-6}	6.12123×10^{13}
1.35582	0.138255	1	3.23832×10^{-4}	1.28507×10^{-3}	3.76616×10^{-7}	5.12056×10^{-7}	5.05051×10^{-7}	8.46292×10^{12}
*4186.8	426.935	3.08803×10^{3}	1	3.96832	$*1.163\times10^{-3}$	1.58124×10^{-3}	1.55961×10^{-3}	2.61337×10^{16}
1 055.06	107.586	778.169	0.251996	1	2.93071×10^{-4}	3.98466×10^{-4}	3.93015×10^{-4}	6.58558×10^{15}
$*3.6\times10^{6}$	3.67098×10^{5}	2.65522×10^{6}	859.846	3 412.14	1	1.35962	1.34102	2.24709×10^{19}
2.64779×10^{6}	$*2.7\times10^{5}$	1.95291×10^{6}	632.414	2 509.62	0.735498	1	0.9863177	1.65273×10^{19}
2.68452×10^{6}	2.73745×10^{5}	$*1.98\times10^{6}$	641.186	2 544.43	0.745700	1.0138703	1	1.67566×10^{19}
1.60207×10^{-13}	1.63366×10^{-14}	1.181626×10^{-13}	3.82648×10^{-17}	1.518469×10^{-16}	4.45020×10^{-20}	6.05059×10^{-20}	5.96781×10^{-20}	1

Remark : * marks show close numerical values defined.
G_n=9.80665m/s^2=32.174ft/s^2. 1J=10^7erg=1Nm=1Ws
1 meter horse power=1 PS=75kgf•m/s, 1 G.B. horse power=1 HP=550 ft•lbf/s, 1 kcal=4.1868kJ (Calorie in the International Steam Table, 1956)
Heat equivalent of work:A=1/426.935kcal/kgf•m=1/778.169Btu/ft•lbf. [1 cal=4.184J (Definition on thermal chemistry), but not use on this book]

1-11 Conversion of Temperaure Units

Put thermo dynamic temperature : K, Celsius temperature : C, Rankine temperature : R and Fahrenheit temperature : F, then K=C+273.15〔K〕 $C=\frac{5}{9}(F-32)$ 〔℃〕 R=(9/5)K=F+459.67〔°R〕 $F=\frac{9}{5}C+32$ 〔°F〕

1-12 Conversion of Heat Related Units

Heat flux (heat flow density)

W/m^2	kcal/m^{2}h	Btu/ft^{2}h	Btu/in^{2}h
1	0.8598	0.3170	0.002201
1.163	1	0.3687	2.560×10^{-3}
3.155	2.712	1	6.944×10^{-3}
454.3	3.906×10^{2}	144	1

Thermal conductivity

W/mK	kcal/mh℃	Btu/ft h°F	Btu/in h°F
1	0.8598	0.5778	0.04815
1.163	1	0.6720	0.05600
1.731	1.488	1	0.08333
20.77	17.86	12	1

Heat rate per volume

W/m^3	kcal/m^{3}h	Btu/ft^{3}h	Btu/in^{3}h
1	0.8598	0.09662	5.591×10^{-5}
1.163	1	0.1124	6.503×10^{-5}
10.35	8.899	1	5.787×10^{-4}
17880	1.538×10^{2}	1 728	1

Heat transfer coefficient

W/m^{2}K	kcal/m^{2}h℃	Btu/ft^2 h°F	Btu/in^2 h°F
1	0.8598	0.1761	0.001223
1.163	1	0.2048	1.422×10^{-3}
5.678	4.882	1	6.944×10^{-3}
817.7	7.031×10^{2}	144	1

1 W/m=0.8598kcal/mh=1.040Btu/fth=0.08667Btu/in h

1 kcal/m^2=0.3687Btu/ft^2, 1 Btu/ft^2=2.712kcal/m^2

1 kcal/m^3℃=0.06243Btu/ft^3°F, 1 Btu/ft^3°F=16.02kcal/m^3℃

Enthalpy, heating value, etc.: 1 kcal/kg=1.8 Btu/lb, 1 Btu/lb = 5/9 kcal/kg

Entropy, specific heat, etc.: 1 kcal/kgK = 1 Btu/lb°R, 1 kcal/kg℃=1 Btu/lb°F

1-13 Conversion of Power Units (Refer to pagagraph of 1-10 Conversion of Energy Units)

kW	PS (French Horse Power)	HP (G.B. Horse Power)	kgf•m/s	ft•lbf/s	kcal/s	Btu/s
1	1.3596	1.3410	101.97	737.6	0.2388	0.9478
0.7355	1	0.9863	*75	542.5	0.17567	0.6971
0.7457	1.01387	1	76.04	*550	0.17811	0.7068
*0.00980665	0.013333	0.01315	1	7.233	0.002342	0.009295
0.0013558	0.001843	0.001818	0.13826	1	0.0003238	0.001285
*4.1868	5.692	5.615	426.935	3088	1	3.968
1.0551	1.4345	1.4149	107.59	778.17	0.2520	1

* marks show close numerical values defined.

1-14 Conversion of Flow Rate Units (Refer to paragraph of 1-5 Conversion of Volume Units)

m^3/h	m^3/min	m^3/s	ℓ/s	ft^3/h	ft^3/min	ft^3/s	gal(G.B.)/min	gal(U.S.)/min
1	0.01667	2.778×10^{-4}	0.2778	35.31	0.5886	9.810×10^{-3}	3.667	4.403
60	1	0.01667	16.67	2 119	35.31	0.5886	220.0	264.2
3 600	60	1	1 000	1.271×10^{5}	2 119	35.31	1.320×10^{4}	1.585×10^{4}
3.6	0.06	0.001	1	127.1	2.119	0.03531	13.20	15.85
0.02832	4.719×10^{-4}	7.866×10^{-6}	7.866×10^{-3}	1	0.01667	2.778×10^{-4}	0.1038	0.1247
1.699	0.02832	4.719×10^{-4}	0.4719	60	1	0.01667	6.229	7.481
101.9	1.699	0.02832	28.32	3 600	60	1	373.7	448.8
0.2728	4.546×10^{-3}	7.577×10^{-5}	0.07577	9.632	0.1605	2.676×10^{-3}	1	1.201
0.2271	3.785×10^{-3}	6.309×10^{-5}	0.06309	8.021	0.1337	2.228×10^{-3}	0.8327	1

1-15 Conversion of Velocity and Angular Velocity Units

m/s	km/h	metric kt (knot)	ft/s	mile/h	G.B. kt (knot)	deg/s	r.p.m.	rad/s
1	3.6	1.944	3.281	2.237	1.943	1	0.1667	0.01745
0.2778	1	0.5400	0.9113	0.6214	0.5396			
0.5144	1.852	1	1.688	1.151	0.9994	6	1	0.1047
0.3048	1.097	0.5925	1	0.6818	0.5921			
0.4470	1.609	0.8690	1.467	1	0.8684	57.30	9.549	1
0.5148	1.853	1.0006	1.689	1.1515	1			

1 metric knot=1,852 m/h, 1 G.B. knot=6,080 ft/h, 1 rad=$360°/2\pi=57.296°$

1-16 Conversion of Viscosity Units

Pa•s	$kgf•s/m^2$	$lbf•s/ft^2$	P (poise)
1	0.101972	2.08854×10^{-2}	10
*9.80665	1	0.204816	98.0665
47.8803	4.88243	1	478.803
*0.1	0.0101972	2.08854×10^{-3}	1

* marks show close numerical values defined.

1-17 Conversion of Kinematic Viscosity Units

m^2/s	ft^2/s	St (stokes)
1	10.7639	10^4
9.29030×10^{-2}	1	929.030
10^{-4}	1.07639×10^{-3}	1

1-18 Major Constants

Quantity	Symbol	Numeric value	Units	Relative uncertainty (ppm)
Velocity of light (in vacuum)	c	299792458	m/s	0
Fine structure constant	α^{-1}	137.0359895		0.045
Charge of electron	e	1.60217733×10^{-19}	C	0.30
Plank's constant	h	6.6260755×10^{-34}	Js	0.60
Avogadro's number	N_A	6.0221367×10^{23}	mol^{-1}	0.59
Atomic mass unit	u	1.6605402×10^{-27}	kg	0.59
Mass of electron	m_e	9.1093897×10^{-31}	kg	0.59
Mass of proton	m_p	1.6726231×10^{-27}	kg	0.59
Specific charge of electron	e/m_e	1.75881962×10^{11}	C/kg	0.30
Mass of neutron	m_n	1.6749286×10^{-27}	kg	0.59
Faraday's constant	F	96485.309	C/mol	0.30
Josephson's frequency voltage ratio	$2e/h$	4.8359767×10^{14}	Hz/V	0.30
Rydberg's constant	R_∞	10973731.534	m^{-1}	0.0012
Bohr radius	a_0	$0.529177249\times10^{-10}$	m	0.045
Gyromagnetic ratio of proton	γ_p	26752.2128×10^{4}	Hz/T	0.30
Gas constant	R	8.314510	J/(mol•K)	8.4
Boltzmann's constant	k	1.380658×10^{-23}	J/K	8.5
Stefan-Boltzmann's constant	σ	5.67051×10^{-8}	$W/(m^2•K^4)$	34
First constant of radiation	c_1	3.7417749×10^{-16}	$W•m^2$	0.60
Second constant of radiation	c_2	0.01438769	m•K	8.4
Universal gravitation constant	G	6.67259×10^{-11}	$m^3/(s^2•kg)$	128
Standard volume of ideal gas	V_m	22.41410×10^{-3}	m^3/mol (at 0 ℃, 1 atm)	8.4
Magnetic moment of electron	μ_e	928.47701×10^{-26}	J/T	0.34

1) Recommended values by the Science and Technology Data Committee (CODATA) in 1986.

2) The value of relative uncertainty is calculated as a result of data process by the law of least squares.

2-1 Formulas of Logarithms

Put $a^n = b$, $\log_a b = n$ where $a > 1$, $b > 0$

$$\log_a 1 = 0 \qquad \log_a a = 1 \qquad \log_a 0 = -\infty \qquad \log_a \infty = \infty$$

$$\log_a(c \cdot d) = \log_a c + \log_a d \qquad \log_a\left(\frac{c}{d}\right) = \log_a c - \log_a d$$

$$\log_a(b^n) = n \log_a b \qquad \log_a \sqrt[n]{b} = \frac{1}{n}\log_a b$$

$$\log_a x = \log_a b \cdot \log_b x \qquad \log_a b \cdot \log_b a = 1$$

Logarithm which has $e = 2.718282$ as the base is called as a natural logarithm, and 10 as the base is called as a common logarithm.

$$\log_e x = \log_e 10 \cdot \log_{10} x = 2.3026 \log_{10} x$$

$$\log_{10} x = \log_{10} e \cdot \log_e x = 0.4343 \log_e x$$

2-2 Formulas of Trigonometric Functions

$$\sin^2\alpha + \cos^2\alpha = 1 \qquad \tan\alpha = \frac{\sin\alpha}{\cos\alpha} \qquad \cot\alpha = \frac{\cos\alpha}{\sin\alpha} = \frac{1}{\tan\alpha} \qquad \sec\alpha = \frac{1}{\cos\alpha}$$

$$\operatorname{cosec}\alpha = \frac{1}{\sin\alpha} \qquad 1 + \tan^2\alpha = \frac{1}{\cos^2\alpha} \qquad 1 + \cot^2\alpha = \operatorname{cosec}^2\alpha = \frac{1}{\sin^2\alpha}$$

$$\sin(\alpha \pm \beta) = \sin\alpha \cdot \cos\beta \pm \cos\alpha \cdot \sin\beta \qquad \cos(\alpha \pm \beta) = \cos\alpha \cdot \cos\beta \mp \sin\alpha \cdot \sin\beta$$

$$\tan(\alpha \pm \beta) = \frac{\tan\alpha \pm \tan\beta}{1 \mp \tan\alpha \cdot \tan\beta} \qquad \cot(\alpha \pm \beta) = \frac{\cot\alpha \cdot \cot\beta \mp 1}{\cot\beta \pm \cot\alpha}$$

$$\sin\alpha + \sin\beta = 2\sin\frac{1}{2}(\alpha+\beta)\cos\frac{1}{2}(\alpha-\beta), \quad \cos\alpha + \cos\beta = 2\cos\frac{1}{2}(\alpha+\beta)\cos\frac{1}{2}(\alpha-\beta)$$

$$\sin\alpha - \sin\beta = 2\cos\frac{1}{2}(\alpha+\beta)\sin\frac{1}{2}(\alpha-\beta), \quad \cos\alpha - \cos\beta = -2\sin\frac{1}{2}(\alpha+\beta)\sin\frac{1}{2}(\alpha-\beta)$$

$$\tan\alpha \pm \tan\beta = \frac{\sin(\alpha \pm \beta)}{\cos\alpha \cdot \cos\beta} \qquad \cot\alpha \pm \cot\beta = \frac{\sin(\beta \pm \alpha)}{\sin\alpha \cdot \sin\beta}$$

2-3 Formulas of Derivatives

u and ν are functions of x, and a and m are constants.

$$d(a+u) = du \qquad d(au) = adu \qquad d(u+\nu) = du + d\nu \qquad d(u\nu) = ud\nu + \nu du$$

$$d\left(\frac{u}{\nu}\right) = \frac{\nu du - ud\nu}{\nu^2}$$

$$d(u^m) = mu^{m-1}du \qquad d\sqrt{u} = \frac{du}{2\sqrt{u}} \qquad d(a^x) = (\log a)a^x dx$$

$$d\left(\frac{1}{u}\right) = -\frac{du}{u^2} \qquad d(e^u) = e^u du \qquad d(\log u) = \frac{du}{u} \qquad d\sin u = \cos u du$$

$$d\cos u = -\sin u\, du \qquad d\tan u = \sec^2 u\, du, \quad d\cot u = -\operatorname{cosec}^2 u\, du, \quad d\sec u = \tan u \sec u\, du$$

$$d\operatorname{cosec} u = -\cot u \operatorname{cosec} u\, du \qquad d\sin^{-1} u = \frac{du}{\sqrt{1-u^2}} \qquad d\cos^{-1} u = -\frac{du}{\sqrt{1-u^2}}$$

$$d\tan^{-1} u = \frac{du}{1+u^2} \qquad d(u^\nu) = u^\nu\left(\log u\, d\nu + \frac{\nu}{u}du\right)$$

2-4 Formulas of Integrals

u and ν are functions of x, and a and m are constants.

$$\int audx = a\int udx \qquad \int(u+\nu)dx = \int udx + \int \nu dx \qquad \int u\frac{d\nu}{dx}dx = u\nu - \int \nu\frac{du}{dx}dx$$

(Integration by parts method)

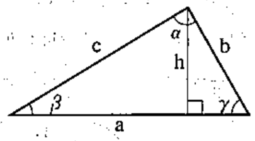
$$\int f(x)dx = \int f(\varphi(y))\frac{d\varphi}{dy}dy, \quad x = \varphi(y)$$ (Variable transformation method)

$$\int x^m dx = \frac{x^{m+1}}{m+1}(m \neq -1) \qquad \int\frac{dx}{x} = \log|x| \qquad \int a^x dx = \frac{a^x}{\log a}(a > 0) \qquad \int e^x dx = e^x$$

$$\int \sin x\, dx = -\cos x, \qquad \int \cos x\, dx = \sin x, \qquad \int\frac{dx}{\sin^2 x} = -\cot x$$

$$\int\frac{dx}{\cos^2 x} = \tan x, \qquad \int\frac{dx}{\sqrt{1-x^2}} = \sin^{-1}x = -\cos^{-1}x \qquad \int\frac{dx}{1+x^2} = \tan^{-1}x = -\cot^{-1}x$$

2-5 Area of Plane Figures



Triangle

Put $2s = a+b+c$, then

Radius of an inscribed circle

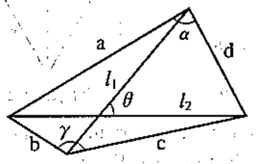
$$r = \sqrt{(s-a)(s-b)(s-c)/s}$$

Radius of a circumscribed circle

$$R = \frac{1}{2}a/\sin\alpha = \frac{1}{2}b/\sin\beta = \frac{1}{2}c/\sin\gamma$$

Area $S = \dfrac{ah}{2} = \dfrac{ab}{2}\sin\gamma = \dfrac{a^2\sin\beta\sin\gamma}{2\sin\alpha}$

$$= \frac{abc}{4R} = \sqrt{s(s-a)(s-b)(s-c)}$$



Quadrangle

Put $2s = a+b+c+d$, then

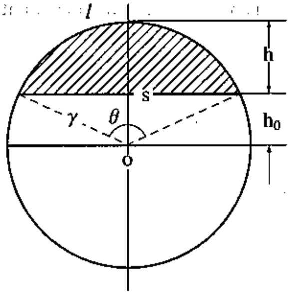
Area $S = \dfrac{1}{2}l_1 l_2 \sin\theta$

$$= \sqrt{(s-a)(s-b)(s-c)(s-d) - abcd\cos^2\frac{1}{2}(\alpha+\gamma)}$$

Circle

Put radius to r and diameter to d, then

Circumference $P = 2\pi r = \pi d$ Area $S = \pi r^2 = \dfrac{1}{4}\pi d^2$



Segment

Length of a chord $s = 2r\sin\dfrac{1}{2}\theta$, Length of an arc $l = r\theta$

Height of an arc $h = r(1 - \cos\dfrac{1}{2}\theta) = \dfrac{1}{2}s\tan\dfrac{1}{4}\theta = 2r\sin^2\dfrac{1}{4}\theta$

Area $S = \dfrac{1}{2}r^2(\theta - \sin\theta) = \dfrac{1}{2}\{r(l-s) + sh\}$

$$= r^2\{\cos^{-1}x - x\sqrt{1-x^2}\}, \quad \text{where,} \quad x = \frac{h_o}{r}$$

Ellipse

Put major axis to $2a$ and minor axis to $2b$, then

Area $S = \pi ab$

2-6 Volume and Surface Area of Solid Figures

Pyramid Put base area to S and height to h, then Volume $V = \frac{1}{3}Sh$.

Right circular cylinder Put radius to r and height to h, then Volume $V = \pi r^2 h$.

Oblique circular cylinder (Figure 1) Put radius to r and length of segment which connects between each center gravity of both base areas to l, then

Side face product $M = 2\pi rl$ Volume $V = \pi r^2 l$

Put maximum length of generating line at side face to l_1 and minimum length of that to l_2, then

$$l = \frac{1}{2}(l_1 + l_2)$$

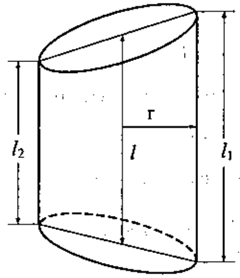


Figure 1

Circular cone Put radius of base area to r and height to h, then

Side face product $M = \pi r\sqrt{r^2+h^2}$ Volume $V = \frac{1}{3}\pi r^2 h$

Trapezoidal cone Put radii of both base areas to R and r, and height to h, then

Side face product $M = \pi(R+r)\sqrt{(R-r)^2+h^2}$

Volume $V = \frac{1}{3}\pi h(R^2+Rr+r^2)$

Sphere Put radius to r, then Volume $V = \frac{4}{3}\pi r^3$ Surface product $O = 4\pi r^2$

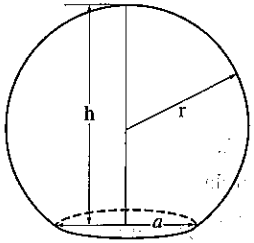


Figure 2

Spherical crown (Figure 2) Put radius to r, radius of base area to a and height to h, then

$a^2 = h(2r-h)$ Volume $V = \frac{1}{6}\pi h(3a^2+h^2) = \frac{1}{3}\pi h^2(3r-h)$

Side face product $M = 2\pi rh = \pi(a^2+h^2)$

Spherical zone (Figure 3) Put radius to r, radii of both base areas to a and b, and height to h, then

$r^2 = a^2 + (a^2-b^2-h^2)^2/4h^2$

Volume $V = \frac{1}{6}\pi h(3a^2+3b^2+h^2)$

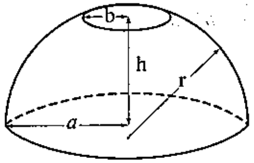


Figure 3

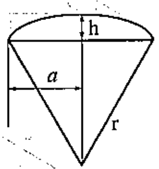


Figure 4

A part for a ball (Figure 4) Put radius of sphere to r, base radius of spherical crown to a and height to h, then Volume

$V = \frac{2}{3}\pi r^2 h$ Surface product $O = \pi r(2h+a)$

2-7 Approximation Equations

When x is extremely small compared with 1, it is convenient to calculate using an approximation equation as follows;

$$(1\pm x)^2 = 1\pm 2x \qquad (1\pm x)^n = 1\pm nx$$

$$\frac{1}{(1\pm x)^n} = 1\mp nx \qquad \sqrt{1\pm x} = 1\pm\frac{1}{2}x$$

$$n\sqrt{1\pm x} = 1\pm\frac{1}{n}x \qquad \sqrt{a(a\pm x)} = a\pm\frac{1}{2}x$$

$$\sin x = x-\frac{1}{6}x^3(x\text{ in rad}) \qquad \cos x = 1-\frac{1}{2}x^2(x\text{ in rad})$$

$$\sinh x = x+\frac{1}{6}x^3(x\text{ in rad}) \qquad \cosh x = 1+\frac{1}{2}x^2(x\text{ in rad})$$

2-8 Statistics and Probability

(1) Statistic

Mean	$\bar{x} = \frac{x_1+x_2+\cdots+x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n}$
Median	$\tilde{x}$ is a value in the center position when arranged in the order of size (in case of odd number), or an arithmetic mean of the values in the center position when arranged in the order of size (in case of even number).
Mid-range	$M = \frac{x_{\max}+x_{\min}}{2}$
Deviation sum of squares	$S = (x_1-\bar{x})^2+(x_2-\bar{x})^2+\cdots\cdots+(x_n-\bar{x})^2 = \sum_{i=1}^{n}(x_i-\bar{x})^2$
Variance	$V = \frac{S}{n-1}$
Standard deviation	$\sigma = \sqrt{V} = \sqrt{\frac{S}{n-1}}$
Range	$R = x_{\max}-x_{\min}$

(2) Two-sided confidence interval of 95% reliabilities of the statistic to population-mean, μ

As for mean-value $\bar{x}$ obtained, population-mean μ locates within the two-sided confidence interval between T_1 to T_2 by probability of 95%.

$$T_1 = \bar{x}-1.960\frac{\sigma}{\sqrt{n}}$$

$$T_2 = \bar{x}+1.960\frac{\sigma}{\sqrt{n}}$$

(3) Normal distribution (distribution of random error)

Put mean to μ and standard deviation to σ or variance to σ^2, then probability density function of normal distribution $N(\mu,\ \sigma^2)$ will become,

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma}e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

If a standardization is carried out by variable transformation using $Z = \frac{(x-\mu)}{\sigma}$ on the upper equation, it will be set to $\mu=0$ and $\sigma=1$, and then the probability density function of this standard normal distribution $N(0,\ 1^2)$ will become,

$$F(Z) = \frac{1}{\sqrt{2\pi}}e^{-\frac{Z^2}{2}}$$

The value of $\varepsilon = \frac{1}{\sqrt{2\pi}}\int_{K_\varepsilon}^{\infty} e^{-\frac{Z^2}{2}}dZ$ to the positive value of Z is shown in the normal distribution table.

And where normal distribution of mean μ and standard deviation σ,

Probability to become $\mu-\sigma \leqq x \leqq \mu+\sigma$ is 0.6826 (about 68%).
Probability to become $\mu-2\sigma \leqq x \leqq \mu+2\sigma$ is 0.9544 (about 95%).
Probability to become $\mu-3\sigma \leqq x \leqq \mu+3\sigma$ is 0.9974 (about 99.7%).

(4) Binominal distribution (distribution of the number of defective within a sample)

Put fraction defective of a population to p, then the probability that a number of defectives x in a sample size n becomes to be 0, 1, 2, ⋯⋯ n is,

$$f(x) = \frac{n!}{x!(n-x)!}p^x(1-p)^{n-x} \quad (x = 0,\ 1,\ 2,\cdots\cdots n)$$

And expectation (E) and standard deviation (D) of x and p are respectively,

$$E(x) = np, \qquad E(p) = p$$

$$D(x) = \sqrt{np(1-p)} \qquad D(p) = \sqrt{\frac{p(1-p)}{n}}$$

(5) Poisson distribution (number of flaw distribution of which an appearance probability is extremely small event.)

When appearance probability p of a certain event is extremely small for a large number of trial n and a value of $np = m$ can be set constant, the probability in which a value of number of flaw $x = 0,\ 1,\ 2,\cdots\cdots$ appears is, then

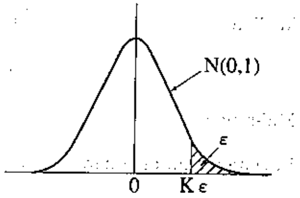
$$f(x) = e^{-m}\frac{m^x}{x!}(x = 0,\ 1,\ 2,\cdots\cdots)$$

And expectation (E) and standard deviation (D) of Poisson distribution are,

$$E(x) = m, \qquad D(x) = \sqrt{m}$$

(6) Normal distribution table

$$K\varepsilon \longrightarrow \varepsilon = Pr\{u \geqq K\varepsilon\} = \frac{1}{\sqrt{2\pi}}\int_{K\varepsilon}^{\infty} e^{-\frac{Z^2}{2}}dZ$$



K ε	∗=0	1	2	3	4	5	6	7	8	9
0.0*	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641
0.1*	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
0.2*	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
0.3*	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
0.4*	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
0.5*	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
0.6*	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
0.7*	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
0.8*	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
0.9*	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
1.0*	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
1.1*	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
1.2*	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
1.3*	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
1.4*	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
1.5*	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
1.6*	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
1.7*	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
1.8*	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
1.9*	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
2.0*	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
2.1*	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
2.2*	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
2.3*	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
2.4*	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
2.5*	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
2.6*	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
2.7*	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
2.8*	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
2.9*	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
3.0*	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010

[Example] ε to K ε =1.96 goes to the right from 1.9* of a left head line, and the value which has fallen from 6 of the upper head line, is read to be 0.0250 .

3-1 Stress in Beam

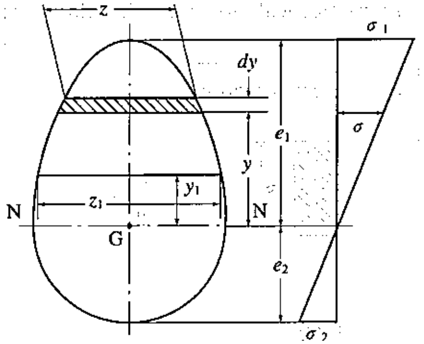
(1) Bending stress

$$\sigma = \frac{M}{I/y} = \frac{M}{Z} \quad \sigma_1 = \frac{\mathrm{M}}{I/e_1} = \frac{M}{Z_1}$$

$$\sigma_2 = \frac{-M}{I/e_2} = \frac{M}{Z_2}$$

$$Z_1 = \frac{I}{e_1} \quad Z_2 = -\frac{I}{e_2}$$

where, M is bending moment, y is distance from a neutral axis, e_1 and e_2 are maximum values of distance, I is geometrical moment of inertia, and Z_1 and Z_2 are section moduli.



(2) Shear stress

$$\tau = \frac{F}{z_1 I}\int_{y1}^{e1} zydy$$

where, F is shear force, z is width of beam cross section, and z_1 is width at the point (position of y_1) where the shear stress is obtained.

(3) Geometrical moment of inertia

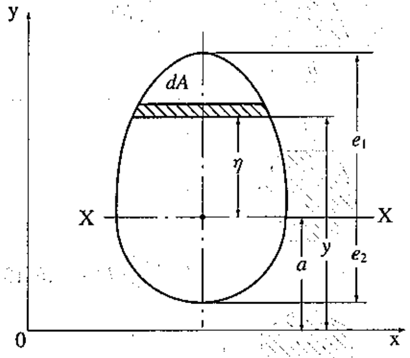
$$I_x = \int y^2 dA = Ak_x{}^2$$

$$I_y = \int x^2 dA = Ak_y{}^2$$

$$I = \int \eta^2 dA = Ak^2 = I_x - Aa^2$$

$$I_p = \int (x^2+y^2)dA = I_x + I_y$$

where, A is area of cross section, I_x is geometrical moment of inertia for axis x, I_y is geometrical moment of inertia at area for axis y, I is geometrical moment of inertia XX passed through a center of the cross section and drawn in parallel with axis x, I_p is polar moment of inertia for axis line passed through origin of axes x and y, and perpendicular to cross section xy, and kx, ky and k are radii of gyration of area for the respective axis lines.



(4) Deflection of beam by bending moment : v

$$v = -\int_0^x\left\{\int_0^x \frac{M}{EI}dx\right\}dx + c_1 x + c_2$$

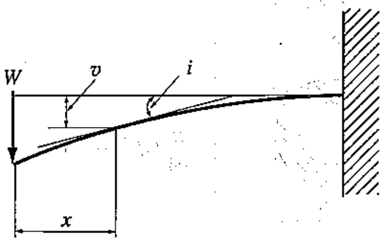
where, M is bending moment in cross section x, and E is longitudinal modulus of elasticity (Young's modulus).

(5) Slant by bending moment : i

$$\frac{1}{\rho} = \frac{d^2v}{dx^2} = -\frac{M}{EI}$$

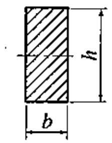
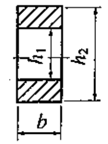
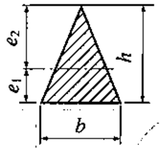
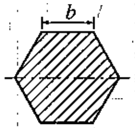
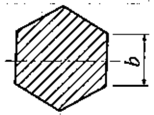
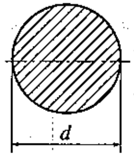
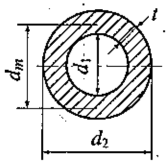
$$i \fallingdotseq \tan i = \frac{dv}{dx} = -\int_0^x \frac{M}{EI}dx + c_1$$

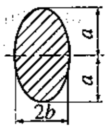
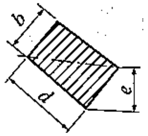
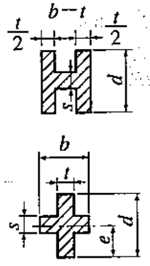
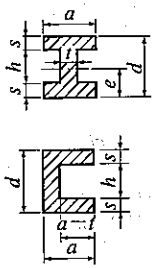
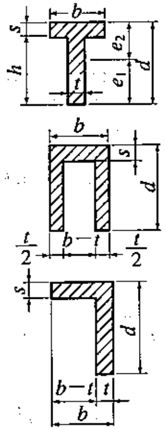
where, ρ is radius of curvature in cross section x.



3-2 Geometrical Moment of Inertia, Radius of Gyration of Area and Section Modulus

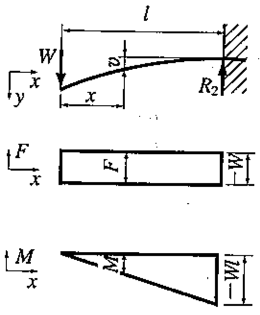
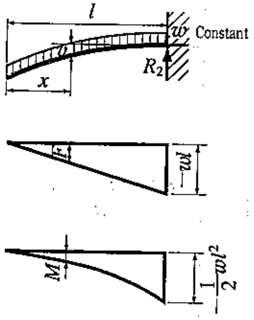
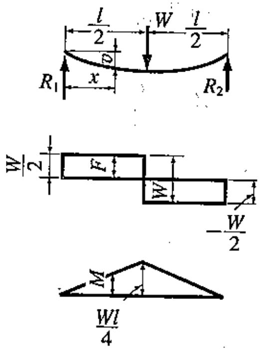
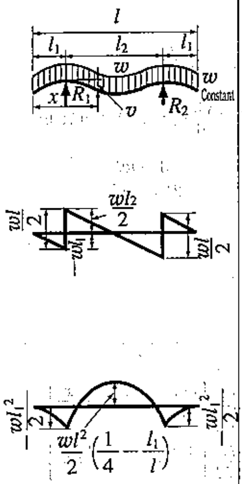
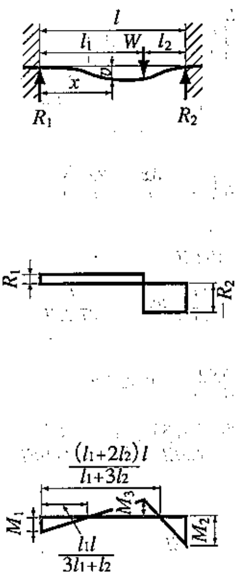
I : geometrical moment of inertia　k : radius of gyration of area　Z : section modulus

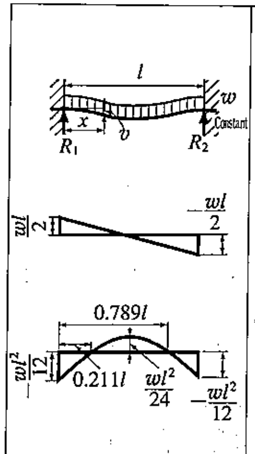
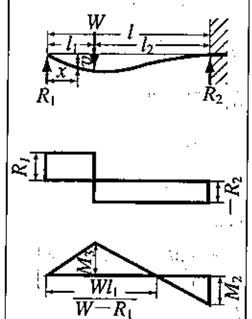
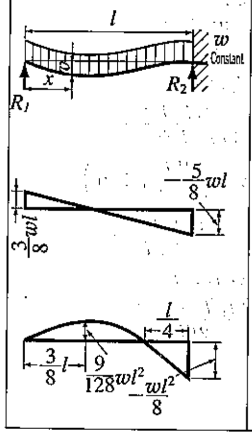
View of cross section	I	k^2	Z
	$\frac{1}{12}bh^3$	$\frac{1}{12}h^2$ $(k = 0.289h)$	$\frac{1}{6}bh^2$
	$\frac{1}{12}b(h_2^3-h_1^3)$	$\frac{1}{12}\frac{h_2^3-h_1^3}{h_2-h_1}$	$\frac{1}{6}\frac{b(h_2^3-h_1^3)}{h_2}$
	$\frac{1}{36}bh^3$	$\frac{1}{18}h^2$ $(k = 0.236h)$	$e_1 = \frac{1}{3}h,\ e_2 = \frac{2}{3}h$ $Z_1 = \frac{1}{12}bh^2,\ Z_2 = \frac{1}{24}bh^2$
	$\frac{5\sqrt{3}}{16}b^4 = 0.5413b^4$	$\frac{5}{24}b^2$ $(k = 0.456b)$	$e = \frac{\sqrt{3}}{2}b = 0.866b$ $Z = \frac{5}{8}b^3 = 0.625b^3$
			$e = b$ $\frac{5\sqrt{3}}{16}b^3 = 0.5413b^3$
	$\frac{\pi}{64}d^4$	$\frac{1}{16}d^2$	$\frac{\pi}{32}d^3$
	$\frac{\pi}{64}(d_2^4-d_1^4)$	$\frac{1}{16}(d_2^2+d_1^2)$	$\frac{\pi}{32}\frac{d_2^4-d_1^4}{d_2}$ $\fallingdotseq 0.8d_m^2t$ (when value t/d_m is small.)

View of cross section	I	k^2	Z
	$\frac{\pi}{4}a^3b$	$\frac{1}{4}a^2$	$\frac{\pi}{4}a^2b$
	$\frac{b^3d^3}{6(b^2+d^2)}$	$\frac{b^2d^2}{6(b^2+d^2)}$	$\frac{b^2d^2}{6\sqrt{b^2+d^2}}$
	$\frac{td^3+s^3(b-t)}{12}$	$\frac{td^3+s^3(b-t)}{12\{td+s(b-t)\}}$	$\frac{td^3+s^3(b-t)}{6d}$
	$\frac{ad^3-h^3(a-t)}{12}$	$\frac{ad^3-h^3(a-t)}{12\{ad-h(a-t)\}}$	$\frac{ad^3-h^3(a-t)}{6d}$
	$I = \frac{1}{3}\{te_1^3+be_2^3$ $-(b-t)(e_2-s)^3\}$ where, $e_1 = d-\frac{d^2t+s^2(b-t)}{2(bs+ht)}$ $e_2 = \frac{d^2t+s^2(b-t)}{2(bs+ht)}$	$k^2 = \frac{I}{A}$ where, $A = bs+ht$	$Z_1 = \frac{I}{e_1}$ $Z_2 = \frac{I}{e_2}$

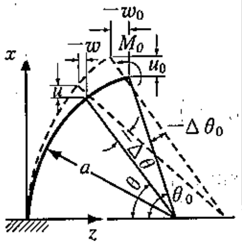
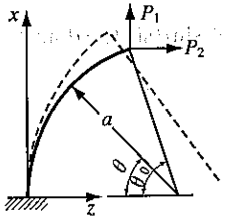
〔Source: Mechanical Engineers' Handbook, A4 (1987), The Japan Society of Mechanical Engineers〕

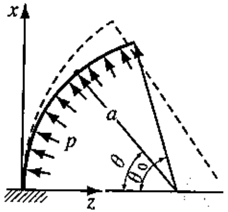
3-3 Calculation of Beam

Illustrations of load, elastic line, shear force and bending moment	Reaction force R and shear force F	Bending moment M	Deflection v and slant i
	$R_2 = W$ $F = -W$	$M = -Wx$ $x = l$:− $\|M\|_{\max} = Wl$	$v = \frac{Wl^3}{3EI}\left(1-\frac{3x}{2l}+\frac{x^3}{2l^3}\right)$ $x = 0$:− $v_{\max} = \frac{Wl^3}{3EI} = \frac{\sigma l^2}{3Ee}$ $\|i\|_{\max} = \frac{Wl^2}{2EI} = \frac{3}{2l}v_{\max}$
	$R_2 = wl$ $F = -wx$ $x = l$:− $\|F\|_{\max} = wl$	$M = -\frac{wx^2}{2}$ $x = l$:− $\|M\|_{\max} = \frac{wl^2}{2}$	$v = \frac{wl^4}{8EI}\left(1-\frac{4x}{3l}+\frac{x^4}{3l^4}\right)$ $x = 0$:− $v_{\max} = \frac{wl^4}{8EI} = \frac{\sigma l^2}{4Ee}$ $\|i\|_{\max} = \frac{wl^3}{6EI} = \frac{4}{3l}v_{\max}$
	$R_1 = R_2 = \frac{W}{2}$ $0 < x < \frac{l}{2}$:− $F = \frac{W}{2}$ $\frac{l}{2} < x < l$:− $F = -\frac{W}{2}$	$0 \leqq x \leqq \frac{l}{2}$:− $M = \frac{Wx}{2}$ $\frac{l}{2} \leqq x \leqq l$:− $M = \frac{W(l-x)}{2}$ $x = \frac{l}{2}$:− $\|M\|_{\max} = \frac{Wl}{4}$	$0 \leqq x \leqq \frac{l}{2}$:− $v = \frac{Wl^3}{48EI}\left(\frac{3x}{l}-\frac{4x^3}{l^3}\right)$ $x = \frac{l}{2}$:− $v_{\max} = \frac{Wl^3}{48EI} = \frac{\sigma l^2}{12Ee}$ $\frac{l}{2} \leqq x \leqq l$:− $v = \frac{Wl^3}{48EI}\left\{\frac{3(l-x)}{l}-\frac{4(l-x)^3}{l^3}\right\}$ $\left.\begin{matrix}x=0\\x=l\end{matrix}\right\}$:− $\|i\|_{\max} = \frac{Wl^2}{16EI} = \frac{3}{l}v_{\max}$
	$R_1 = R_2 = \frac{wl}{2}$ $0 < x < l_1$:− $F = -wx$ $l_1 < x < (l_1+l_2)$:− $F = w\left(\frac{l}{2}-x\right)$ $(l_1+l_2) < x < l$:− $F = w(l-x)$	$0 \leqq x \leqq l_1$:− $M = -\frac{wx^2}{2}$ $l_1 \leqq x \leqq (l_1+l_2)$:− $M = -\frac{w}{2}\{x(x$ $-l)+ll_1\}$ $(l_1+l_2) \leqq x \leqq l$:− $M = -\frac{w}{2}(l-x)^2$ $M_{x=l_1} = -\frac{wl_1^2}{2}$ $M_{x=l/2} = \frac{wl^2}{2}$ $\times\left(\frac{1}{4}-\frac{l_1}{l}\right)$ Put $l_1 > \left(\frac{1}{\sqrt{2}}-\frac{1}{2}\right)l$,then $\|M\|_{\max} = \|M_{x=l1}\|$ Put $l_1 < \left(\frac{1}{\sqrt{2}}-\frac{1}{2}\right)l$,then $\|M\|_{\max} = M_{x=l/2}$	$0 \leqq x \leqq l_1$:− $v = \frac{wl^4}{24EI}\left\{\left(\frac{6l_1{}^2}{l^3}-\frac{6l_1}{l^2}+\frac{1}{l}\right)x+\frac{x^4}{l^4}-\frac{l_1{}^4}{l^4}\right.$ $\left.-\frac{6l_1{}^3}{l^3}+\frac{6l_1{}^2}{l^2}-\frac{l_1}{l}\right\}$ $l_1 \leqq x \leqq (l_1+l_2)$:− $v = \frac{wl^4}{24EI}\left\{\left(1-\frac{6l_1}{l}\right)\frac{x}{l}+\frac{6l_1x^2}{l^3}-\frac{2x^3}{l^3}+\frac{x^4}{l^4}\right.$ $\left.-\frac{l_1{}^4}{l^4}-\frac{4l_1{}^3}{l^3}+\frac{6l_1{}^2}{l^2}-\frac{l_1}{l}\right\}$ $(l_1+l_2) \leqq x \leqq l$:− $v = \frac{wl^4}{24EI}\left\{\left(\frac{6l_1{}^2}{l^3}-\frac{6l_1}{l^2}+\frac{1}{l}\right)(l-x)\right.$ $\left.+\frac{(l-x)^4}{l^4}-\frac{l_1{}^4}{l^4}-\frac{6l_1{}^3}{l^3}+\frac{6l_1{}^2}{l^2}-\frac{l_1}{l}\right\}$ $v_{x=0} = \frac{wl_1}{24EI}(3l_1{}^3+6l_1{}^2l_2-l_2{}^3)$ $v_{x=l/2} = \frac{wl_2{}^2}{384EI}(5l_2{}^2-24l_1{}^2)$
	$R_1 = \frac{Wl_2{}^2(3l_1+l_2)}{l^3}$ $R_2 = \frac{Wl_1{}^2(l_1+3l_2)}{l^3}$ $0 < x < l_1$:− $F = \frac{Wl_2{}^2(3l_1+l_2)}{l^3}$ $l_1 < x < l$:− $F = -\frac{Wl_1{}^2(l_1+3l_2)}{l^3}$	$0 \leqq x \leqq l_1$:− $M = \frac{Wl_2^2}{l^2}$ $\times\left\{\frac{x(3l_1+l_2)}{l}-l_1\right\}$ $l_1 \leqq x \leqq l$:− $M = \frac{Wl_1{}^2}{l^2}\{l_1+2l_2$ $\left.-\frac{x}{l}(l_1+3l_2)\right\}$ $x = 0$:− $M_1 = -\frac{Wl_1l_2{}^2}{l^2}$ $x = l$:− $M_2 = -\frac{Wl_1{}^2l_2}{l^2}$ $x = l_1$:− $M_3 = \frac{2Wl_1{}^2l_2{}^2}{l^3}$ According to $l_1 \gtreqqless l_2$ $\|M_1\| \lesseqqgtr \|M_3\| \lesseqqgtr \|M_2\|$	$0 \leqq x \leqq l_1$:− $v = \frac{Wl_2^2x^2}{6EIl}\left\{\frac{3l_1}{l}-\frac{(3l_1+l_2)x}{l^2}\right\}$ $l_1 \leqq x \leqq l$:− $v = \frac{Wl_2^2x^2}{6EIl}\left\{\frac{3l_1}{l}-\frac{(3l_1+l_2)x}{l^2}\right\}$ $+\frac{W(x-l_1)^3}{6EI}$ $v_{x=l_1} = \frac{Wl_1{}^3l_2{}^3}{3EIl^3}$ Put $l_1 > l_2$, then $v_{\max} = \frac{2Wl_1{}^3l_2{}^2}{3EI(3l_1+l_2)^2}$ $\left(\text{Put } x \doteqdot \frac{2l_1l}{3l_1+l_2}, \text{ then}\right)$ $v_{x=l/2} = \frac{Wl_2{}^2(3l_1-l_2)}{48EI}$ Whichever $l_1 \gtreqqless l_2$ $i_{x=l_1} = \frac{Wl_1{}^2l_2{}^2(l_2-l_1)}{2EIl^3}$

	$R_1 = R_2 = \frac{wl}{2}$ $F = \frac{wl}{2} - wx$ $\left.\begin{array}{l} x = 0 \\ x = l \end{array}\right\}:-$ $\lvert F\rvert_{\max} = \frac{wl}{2}$	$M = \frac{wl^2}{2} \times\left(-\frac{1}{6}+\frac{x}{l}-\frac{x^2}{l^2}\right)$ $M_{x=l/2} = \frac{wl^2}{24}$ $\left.\begin{array}{l} x = 0 \\ x = l \end{array}\right\}:-$ $\lvert M\rvert_{\max} = \frac{wl^2}{12}$	$v = \frac{wl^4}{24EI}\left(\frac{x^2}{l^2}-\frac{2x^3}{l^3}+\frac{x^4}{l^4}\right)$ $x = \frac{l}{2}:-$ $v_{\max} = \frac{wl^4}{384EI}$ $x = l\left(\frac{1}{2}\mp\frac{\sqrt{3}}{6}\right) = 0.211l,\ 0.789l:-$ $\lvert i\rvert_{\max} = \frac{\sqrt{3}}{216}\ \frac{wl^3}{EI}$
	$R_1 = \frac{Wl_2{}^2}{2l^3}(3l_1+2l_2)$ $R_2 = \frac{Wl_1}{2l^3}(2l_1{}^2 +6l_1l_2+3l_2{}^2)$ $0 < x < l_1:-$ $F = R_1$ $l_1 < x < l:-$ $F = -R_2$	$0 \leqq x \leqq l_1:-$ $M = \frac{Wl_2{}^2(3l_1+2l_2)x}{2l^3}$ $l_1 \leqq x \leqq l:-$ $M = \frac{Wl_2{}^2(3l_1+2l_2)}{2l^3}x -W(x-l_1)$ $M_2 = -\frac{Wl_1l_2}{2l^2}(2l_1+l_2)$ $M_3 = \frac{Wl_1l_2{}^2}{2l^3}(3l_1+2l_2)$ According to $l_2 \gtreqqless \sqrt{2}\,l_1$ $\lvert M_3\rvert \gtreqqless \lvert M_2\rvert$	$0 \leqq x \leqq l_1:-$ $v = \frac{Wl_2{}^2}{12EI}\left\{\frac{3l_1x}{l}-\frac{(3l_1+2l_2)x^3}{l^3}\right\}$ $l_1 \leqq x \leqq l:-$ $v = \frac{Wl_2{}^2}{12EI}\left\{\frac{3l_1x}{l}-\frac{(3l_1+2l_2)x^3}{l^3}\right\} +\frac{W(x-l_1)^3}{6EI}$ $v_{x=l_1} = \frac{Wl_1{}^2l_2{}^3(4l_1+3l_2)}{12EIl^3}$ Position of $v_{\max}$ locates at $x \gtreqqless l_1$ when $l_2 \gtreqqless \sqrt{2}\,l_1$, and $0 \leqq x \leqq l_1:-$ $i = \frac{Wl_2{}^2}{4EI}\left\{\frac{l_1}{l}-\frac{(3l_1+2l_2)x^2}{l^3}\right\}$ $l_1 \leqq x \leqq l:-$ $i = \frac{Wl_2{}^2}{4EI}\left\{\frac{l_1}{l}-\frac{(3l_1+2l_2)x^2}{l^3}\right\} +\frac{W(x-l_1)^2}{2EI}$
	$R_1 = \frac{3wl}{8}$ $R_2 = \frac{5wl}{8}$ $F = w\left(\frac{3l}{8}-x\right)$ $x = l:-$ $\lvert F\rvert_{\max} = \frac{5wl}{8}$	$M = \frac{wlx}{2}\left(\frac{3}{4}-\frac{x}{l}\right)$ $x = l:-$ $\lvert M\rvert_{\max} = \frac{wl^2}{8}$ $M_{x=3l/8} = \frac{9wl^2}{128}$	$v = \frac{wl^4}{48EI}\left(\frac{x}{l}-\frac{3x^3}{l^3}+\frac{2x^4}{l^4}\right)$ $v_{x=l/2} = \frac{wl^4}{192EI}$ $v_{x=3l/8} = \frac{175}{32768}wl^4 = \frac{wl^4}{187.2EI}$ $x = \frac{1+\sqrt{33}}{16}l = 0.4215l:-$ $v_{\max} = \frac{39+55\sqrt{33}}{65536EI}wl^4 = \frac{wl^4}{184.6EI}$ $x = 0:-$ $\lvert i\rvert_{\max} = \frac{wl^3}{48EI}$

〔Source: Mechanical Engineers' Handbook, A4 (1987), The Japan Society of Mechanical Engineers〕

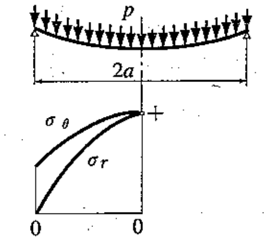
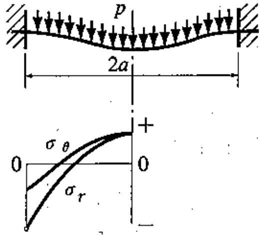
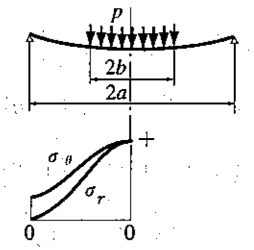
Loading form	Displacement
	$\triangle\theta = -\frac{aM_0}{EI}\theta$ $u = \frac{a^2M_0}{EI}(\sin\theta-\theta\cos\theta)$ $w = -\frac{a^2M_0}{EI}(\theta\sin\theta+\cos\theta-1)$ Displacements at loading point $\triangle\theta_0$, u_0 and w_0, equal to the one to put $\theta = \theta_0$ Put $\theta_0 = \frac{\pi}{2}$, then $\triangle\theta_0 = -\frac{\pi}{2}\ \frac{aM_0}{EI}$ $u_0 = \frac{a^2M_0}{EI}$ $w_0 = \left(1-\frac{\pi}{2}\right)\frac{a^2M_0}{EI}$ Put $\theta_0 = \pi$, then $\triangle\theta_0 = -\pi\frac{aM_0}{EI}$ $u_0 = \pi\frac{a^2M_0}{EI}$ $w_0 = 2\frac{a^2M_0}{EI}$
	$\triangle\theta = \frac{a^2P_1}{EI}(\theta\cos\theta_0-\sin\theta)$ $u = \frac{a^3P_1}{EI}\left(\frac{\theta}{2}-\frac{1}{4}\sin 2\theta-\cos\theta_0\sin\theta+\theta\cos\theta\cos\theta_0\right)$ $w = \frac{a^3P_1}{EI}\left(-\frac{1}{4}+\frac{1}{4}\cos 2\theta+\cos\theta_0\cos\theta+\theta\sin\theta\cos\theta_0-\cos\theta_0\right)$ $\triangle\theta_0 = \frac{a^2P_1}{EI}(\theta_0\cos\theta_0-\sin\theta_0)$ $u_0 = \frac{a^3P_1}{EI}\left(\theta_0-\frac{3}{4}\sin 2\theta_0+\frac{1}{2}\theta_0\cos 2\theta_0\right)$ $w_0 = \frac{a^3P_1}{EI}\left(\frac{1}{4}+\frac{3}{4}\cos 2\theta_0+\frac{\theta_0}{2}\sin 2\theta_0-\cos\theta_0\right)$ Put $\theta_0 = \frac{\pi}{2}$, then $\triangle\theta_0 = -\frac{a^2P_1}{EI}$, $u_0 = \frac{\pi}{4}\ \frac{a^3P_1}{EI}$, $w_0 = -\frac{1}{2}\ \frac{a^3P_1}{EI}$ Put $\theta_0 = \pi$, then $\triangle\theta_0 = -\pi\frac{a^2P_1}{EI}$, $u_0 = \frac{3\pi}{2}\ \frac{a^3P_1}{EI}$, $w_0 = 2\frac{a^3P_1}{EI}$

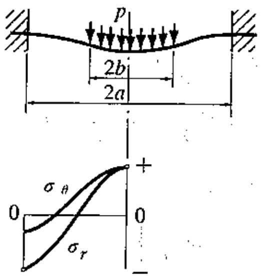
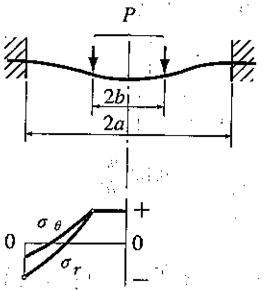
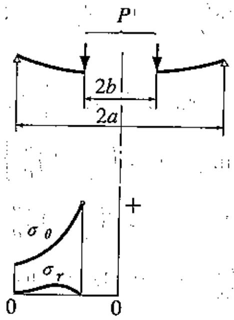
(continued)	$\triangle\theta=\frac{a^2P_2}{EI}(\theta\sin\theta_0+\cos\theta-1)$ $u=\frac{a^3P_2}{EI}\left(\frac{3}{4}+\frac{1}{4}\cos 2\theta-\sin\theta_0\sin\theta+\theta\cos\theta\sin\theta_0-\cos\theta\right)$ $w=\frac{a^3P_2}{EI}\left(\frac{1}{2}\theta+\frac{1}{4}\sin 2\theta+\sin\theta_0\sin\theta+\theta\sin\theta\sin\theta_0-\sin\theta-\sin\theta_0\right)$ $\triangle\theta_0=\frac{a^2P_2}{EI}(\theta_0\sin\theta_0+\cos\theta_0-1)$ $u_0=\frac{a^3P_2}{EI}\left(\frac{1}{4}+\frac{3}{4}\cos 2\theta_0+\frac{1}{2}\theta_0\sin 2\theta_0-\cos\theta_0\right)$ $w_0=\frac{a^3P_2}{EI}\left(\theta_0+\frac{3}{4}\sin 2\theta_0-\frac{1}{2}\theta_0\cos 2\theta_0-2\sin\theta_0\right)$ Put $\theta_0=\frac{\pi}{2}$, then $\triangle\theta_0=\left(\frac{\pi}{2}-1\right)\frac{a^2P_2}{EI}, \quad u_0=-\frac{1}{2}\frac{a^3P_2}{EI}, \quad w_0=\left(\frac{3\pi}{4}-2\right)\frac{a^3P_2}{EI}$ Put $\theta_0=\pi$, then $\triangle\theta_0=-2\frac{a^2P_2}{EI}, \quad u_0=2\frac{a^3P_2}{EI}, \quad w_0=\frac{\pi}{2}\frac{a^3P_2}{EI}$
	$\triangle\theta=-\frac{pa^3}{EI}\{\theta-\sin\theta_0+\sin(\theta_0-\theta)\}$ $u=\frac{pa^4}{EI}\left\{\frac{1}{4}\sin(\theta_0-2\theta)-\cos\theta\sin(\theta_0-\theta)+\cos\theta\sin\theta_0-\theta\cos\theta\right.$ $\left.-\frac{\theta}{2}\cos\theta_0-\frac{1}{4}\sin\theta_0+\sin\theta\right\}$ $w=\frac{pa^4}{EI}\left\{\frac{1}{4}\cos(\theta_0-2\theta)-\sin\theta\sin(\theta_0-\theta)+\sin\theta\sin\theta_0-\theta\sin\theta\right.$ $\left.-\frac{\theta}{2}\sin\theta_0-\frac{1}{4}\cos\theta_0-\cos\theta+1\right\}$ $\triangle\theta_0=-\frac{pa^3}{EI}(\theta_0-\sin\theta_0)$ $u_0=\frac{pa^4}{2EI}(\sin\theta_0+\sin 2\theta_0-3\theta_0\cos\theta_0)$ $w_0=\frac{pa^4}{2EI}(3-\cos\theta_0-\cos 2\theta-3\theta_0\sin\theta_0)$ Put $\theta_0=\pi/2$, then $\triangle\theta_0=\frac{pa^3}{EI}\left(1-\frac{\pi}{2}\right), \quad u_0=\frac{1}{2}\frac{pa^4}{EI}, \quad w_0=\left(2-\frac{3\pi}{4}\right)\frac{pa^4}{EI}$ Put $\theta_0=\pi$, then $\triangle\theta_0=-\pi\frac{pa^3}{EI}, \quad u_0=\frac{3\pi}{2}\frac{pa^4}{EI}, \quad w_0=\frac{3}{2}\frac{pa^4}{EI}$

〔Source: Ichiro Nakahara, Strength of Materials (1965), Yokendo〕

3-4 Deflection and Bending Stress of Disc

p : load per area, P: concentrated load, h: plate thickness, E: longitudinal modulus of elasticity, ν: Poisson's ratio, $D=Eh^3/12(1-\nu^2)$: bending toughness of plate, ln: natural logarithm.

No.	Load condition, deflection form and stress distribution of underside surface	Deflections w and $w_{\max}$, and stresses σ and $\sigma_{\max}$
1	Disc, perimeter simply supported and equally distributed load 	$w=\frac{pa^4}{64D}\left(1-\frac{r^2}{a^2}\right)\left(\frac{5+\nu}{1+\nu}-\frac{r^2}{a^2}\right)$ $w_{\max}=(w)_{r=0}=\frac{(5+\nu)pa^4}{64(1+\nu)D}=0.696\frac{pa^4}{Eh^3} \quad (\nu=0.3)$ $\sigma_r=\mp\frac{3pa^2}{8h^2}(3+\nu)\left(1-\frac{r^2}{a^2}\right)$ $\sigma_\theta=\mp\frac{3pa^2}{8h^2}\left\{(3+\nu)-(1+3\nu)\frac{r^2}{a^2}\right\}$ $\sigma_{\max}=(\sigma_r)_{r=0}=(\sigma_\theta)_{r=0}=\mp\frac{3(3+\nu)pa^2}{8h^2}=\mp1.24\frac{pa^2}{h^2} \quad (\nu=0.3)$
2	Disc, perimeter fixed and equally distributed load 	$w=\frac{pa^4}{64D}\left(1-\frac{r^2}{a^2}\right)^2$ $w_{\max}=(w)_{r=0}=\frac{pa^4}{64D}=0.171\frac{pa^4}{Eh^3} \quad (\nu=0.3)$ $\sigma_r=\mp\frac{3pa^2}{8h^2}\left\{(1+\nu)-(3+\nu)\frac{r^2}{a^2}\right\}$ $\sigma_\theta=\mp\frac{3pa^2}{8h^2}\left\{(1+\nu)-(1+3\nu)\frac{r^2}{a^2}\right\}$ $\sigma_{\max}=(\sigma_r)_{r=a}=\pm\frac{3pa^2}{4h^2}=\pm0.750\frac{pa^2}{h^2}$
3	Disc, perimeter simply supported and equally distributed load within concentric circle 	(i) $0\leqq r\leqq b$:− $w=\frac{pb^4}{16D}\left\{\frac{r^4}{4b^4}-\frac{4a^2-(1-\nu)b^2}{2(1+\nu)a^2}\frac{r^2}{b^2}-\left(2\frac{r^2}{b^2}+1\right)\ln\frac{a}{b}\right.$ $\left.+\frac{4(3+\nu)a^2-(7+3\nu)b^2}{4(1+\nu)b^2}\right\}$ $\sigma_r=\mp\frac{3pb^2}{8h^2}\left\{4(1+\nu)\ln\frac{a}{b}+4-(1-\nu)\frac{b^2}{a^2}-(3+\nu)\frac{r^2}{b^2}\right\}$ $\sigma_\theta=\mp\frac{3pb^2}{8h^2}\left\{4(1+\nu)\ln\frac{a}{b}+4-(1-\nu)\frac{b^2}{a^2}-(1+3\nu)\frac{r^2}{b^2}\right\}$ (ii) $b\leqq r\leqq a$:− $w=\frac{pb^4}{16D}\left[\frac{1}{2(1+\nu)}\left(1-\frac{r^2}{a^2}\right)\left\{2(3+\nu)\frac{a^2}{b^2}-(1-\nu)\right\}-\left(1+\frac{2r^2}{b^2}\right)\ln\frac{a}{r}\right]$ $\sigma_r=\mp\frac{3pb^2}{8h^2}\left\{4(1+\nu)\ln\frac{a}{r}+(1-\nu)\left(\frac{a^2}{r^2}-1\right)\frac{b^2}{a^2}\right\}$ $\sigma_\theta=\mp\frac{3pb^2}{8h^2}\left[4(1+\nu)\ln\frac{a}{r}-(1-\nu)\left\{\left(\frac{a^2}{r^2}+1\right)\frac{b^2}{a^2}-4\right\}\right]$ $w_{\max}=(w)_{r=0}=\alpha_3\frac{pa^4}{Eh^3}$ (α_3: Fig. 1) $(\nu=0.3)$ $\sigma_{\max}=(\sigma_r)_{r=0}=(\sigma_\theta)_{r=0}=\mp\beta_3\frac{pa^2}{h^2}$ (β_3: Fig. 2)$(\nu=0.3)$

4	Disc, perimeter fixed and equally distributed load within concentric circle  	(i) $0 \leqq r \leqq b$:− $w = \frac{pb^4}{16D}\left\{\frac{r^4}{4b^4}-\frac{r^2}{2a^2}+\frac{a^2}{b^2}-\left(1+\frac{2r^2}{b^2}\right)\ln\frac{a}{b}-\frac{3}{4}\right\}$ $\sigma_r = \mp\frac{3pb^2}{8h^2}\left\{(1+\nu)\left(\frac{b^2}{a^2}+4\ \ln\frac{a}{b}\right)-(3+\nu)\frac{r^2}{b^2}\right\}$ $\sigma_\theta = \mp\frac{3pb^2}{8h^2}\left\{(1+\nu)\left(\frac{b^2}{a^2}+4\ \ln\frac{a}{b}\right)-(1+3\nu)\frac{r^2}{b^2}\right\}$ (ii) $b \leqq r \leqq a$:− $w = \frac{pb^4}{16D}\left\{\left(1-\frac{r^2}{a^2}\right)\frac{a^2}{b^2}-\frac{r^2}{2a^2}-\left(1+\frac{2r^2}{b^2}\right)\ln\frac{a}{r}+\frac{1}{2}\right\}$ $\sigma_r = \mp\frac{3pb^2}{8h^2}\left\{(1+\nu)\left(4\ \ln\frac{a}{r}+\frac{b^2}{a^2}\right)+(1-\nu)\frac{b^2}{r^2}-4\right\}$ $\sigma_\theta = \mp\frac{3pb^2}{8h^2}\left\{(1+\nu)\left(4\ \ln\frac{a}{r}+\frac{b^2}{a^2}\right)-(1-\nu)\frac{b^2}{r^2}-4\nu\right\}$ $w_{\max} = (w)_{r=0} = \alpha_4\frac{pa^4}{Eh^3}$ (α_4: Fig. 1) ($\nu = 0.3$) Put $b/a < 0.569$, then $\sigma_{\max} = (\sigma_r)_{r=0} = (\sigma_\theta)_{r=0} = \mp\beta_4\frac{pa^2}{h^2}$ (β_4: Fig. 2) ($\nu = 0.3$) Put $b/a > 0.569$, then $\sigma_{\max} = (\sigma_r)_{r=a} = \pm\beta_4'\frac{pa^2}{h^2}$ (β_4': Fig. 2)($\nu = 0.3$)
5	Disc, perimeter fixed and concentric ring-type load  	(i) $0 \leqq r \leqq b$:− $w = \frac{Pa^2}{8\pi D}\left\{\frac{1}{2}\left(1-\frac{b^2}{a^2}\right)\left(1+\frac{r^2}{a^2}\right)-\frac{b^2+r^2}{a^2}\ln\frac{a}{b}\right\}$ $\sigma_r = \sigma_\theta = \mp\frac{3P}{4\pi h^2}(1+\nu)\left(\frac{b^2}{a^2}+2\ \ln\frac{a}{b}-1\right)$ (ii) $b \leqq r \leqq a$:− $w = \frac{Pa^2}{8\pi D}\left\{\frac{1}{2}\left(1+\frac{b^2}{a^2}\right)\left(1-\frac{r^2}{a^2}\right)-\frac{b^2+r^2}{a^2}\ln\frac{a}{r}\right\}$ $\sigma_r = \mp\frac{3P}{4\pi h^2}\left\{(1+\nu)\left(\frac{b^2}{a^2}+2\ \ln\frac{a}{r}\right)+(1-\nu)\frac{b^2}{r^2}-2\right\}$ $\sigma_\theta = \mp\frac{3P}{4\pi h^2}\left\{(1+\nu)\left(\frac{b^2}{a^2}+2\ \ln\frac{a}{r}\right)-(1-\nu)\frac{b^2}{r^2}-2\nu\right\}$ $w_{\max} = (w)_{r=0} = \alpha_5\frac{Pa^2}{Eh^3}$ (α_5: 図1) ($\nu = 0.3$) Put $b/a < 0.320$ then $\sigma_{\max} = (\sigma_r)_{r=0\sim b} = (\sigma_\theta)_{r=0\sim b} = \mp\beta_5\frac{P}{h^2}$ (β_5: Fig. 2) ($\nu = 0.3$) Put $b/a > 0.320$ then $\sigma_{\max} = (\sigma_r)_{r=a} = \pm\beta_5'\frac{P}{h^2}$ (β_5': Fig. 2)($\nu = 0.3$)
6	Ring disc, perimeter simply supported and ring-type load along inner circumference  	$w = \frac{Pa^2}{8\pi D}\left\{(1+A)\left(1-\frac{r^2}{a^2}\right)-\left(B+\frac{r^2}{a^2}\right)\ln\frac{a}{r}\right\}$ $\sigma_r = \mp\frac{3P}{4\pi h^2}\left\{2(1+\nu)\left(A+\ln\frac{a}{r}\right)-(1-\nu)\left(1-B\frac{a^2}{r^2}\right)\right\}$ $\sigma_\theta = \mp\frac{3P}{4\pi h^2}\left\{2(1+\nu)\left(A+\ln\frac{a}{r}\right)+(1-\nu)\left(1-B\frac{a^2}{r^2}\right)\right\}$ where $A = \frac{1-\nu}{2(1+\nu)}+\frac{b^2}{a^2-b^2}\ln\frac{a}{b}$, $B = -\frac{2(1+\nu)}{1-\nu}\ \frac{b^2}{a^2-b^2}\ln\frac{a}{b}$ $w_{\max} = (w)_{r=b} = \alpha_6\frac{Pa^2}{Eh^3}$ (α_6: Fig. 3) ($\nu = 0.3$) $\sigma_{\max} = (\sigma_\theta)_{r=b} = \mp\beta_6\frac{P}{h^2}$ (β_6: Fig. 4) ($\nu = 0.3$)

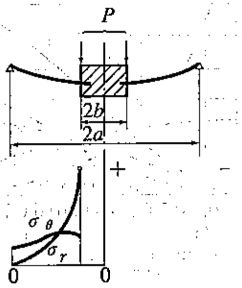
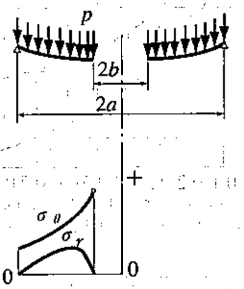
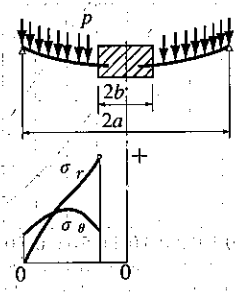
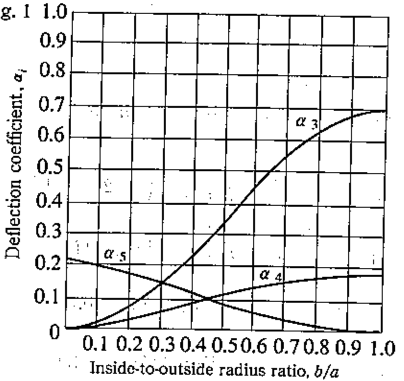
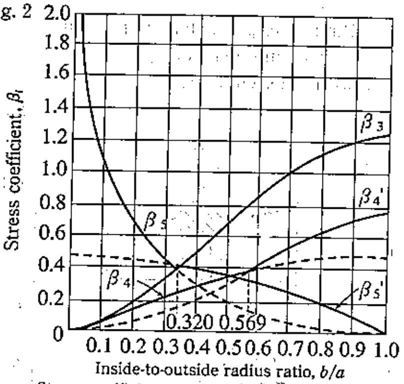
7	Ring disc, perimeter simply supported and load on piece fixed with inner circumference  	w, σ_r and σ_θ are as same as equations of No.6. where $A = \frac{1}{2}\frac{(1-\nu)a^2}{(1+\nu)a^2+(1-\nu)b^2}\left\{1-\left(1+2\ \ln\frac{a}{b}\right)\frac{b^2}{a^2}\right\}$ $B = \frac{2b^2}{(1+\nu)a^2+(1-\nu)b^2}\left\{(1+\nu)\ln\frac{a}{b}+1\right\}$ $w_{\max} = (w)_{r=b} = \alpha_7\frac{Pa^2}{Eh^3}$ (α_7: Fig. 3)($\nu = 0.3$) $\sigma_{\max} = (\sigma_r)_{r=b} = \mp\beta_7\frac{P}{h^2}$ (β_7: Fig. 4)($\nu = 0.3$)
8	Ring disc, perimeter simply supported, inner circumference free and equally distributed load  	$w = -\frac{pa^4}{64D}\left\{1-\frac{r^4}{a^4}+8(A+1)\left(1-\frac{r^2}{a^2}\right)\frac{b^2}{a^2}+4\left(B-2\frac{b^2}{a^2}\ \frac{r^2}{a^2}\right)Ln\frac{a}{r}\right\}$ $\sigma_r = \pm\frac{3pa^2}{8h^2}\left\{(3+\nu)\frac{r^2}{a^2}+4(1+\nu)\left(A+\ln\frac{a}{r}\right)\frac{b^2}{a^2}-(1-\nu)\left(\frac{2b^2}{a^2}+B\frac{a^2}{r^2}\right)\right\}$ $\sigma_\theta = \pm\frac{3pa^2}{8h^2}\left\{(1+3\nu)\frac{r^2}{a^2}+4(1+\upsilon)\left(A+\ln\frac{a}{r}\right)\frac{b^2}{a^2}+(1-\nu)\left(\frac{2b^2}{a^2}+B\frac{a^2}{r^2}\right)\right\}$ where $A = \frac{b^2}{a^2-b^2}\ln\frac{a}{b}-\frac{1}{4(1+\nu)}\left\{(1+3\nu)+(3+\nu)\frac{a^2}{b^2}\right\}$ $B = \frac{1}{1-\nu}\left\{4(1+\nu)\frac{b^2}{a^2-b^2}\ln\frac{a}{b}-(3+\nu)\right\}\frac{b^2}{a^2}$ $w_{\max} = (w)_{r=b} = \alpha_8\frac{p\alpha^4}{Eh^3}$ (α_8: Fig. 5)($\nu = 0.3$) $\sigma_{\max} = (\sigma_\theta)_{r=b} = \mp\beta_8\frac{pa^2}{h^2}$ (β_8: Fig. 6)($\nu = 0.3$)
9	Ring disc, perimeter simply supported, inner circumference fixed with movable piece and equally distributed load  	w, σ_r and σ_θ are as same as equations of No.8. where $A = -\frac{1}{4}\frac{a^2}{(1+\nu)a^2+(1-\nu)b^2}$ $\times\left[(3+\nu)\frac{a^2}{b^2}+(1-\nu)\left\{\left(4\ \ln\frac{a}{b}+3\right)\frac{b^2}{a^2}-2\right\}\right]$ $B = \frac{b^2}{(1+\nu)a^2+(1-\nu)b^2}\left[(3+\nu)-\left\{(5+\nu)+4(1+\nu)\ln\frac{a}{b}\right\}\frac{b^2}{a^2}\right]$ $w_{\max} = (w)_{r=b} = \alpha_9\frac{pa^4}{Eh^3}$ (α_9: Fig. 5)($\nu = 0.3$) $\sigma_{\max} = (\sigma_r)_{r=b} = \mp\beta_9\frac{pa^2}{h^2}$ (β_9: Fig. 6)($\nu = 0.3$)

Fig. 1



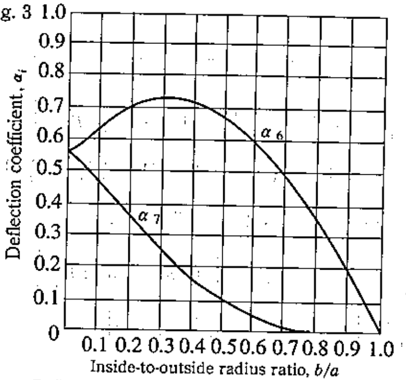
Deflection coefficients, α_3, α_4 and α_5 of disc No. 3, 4 and 5

Fig. 2



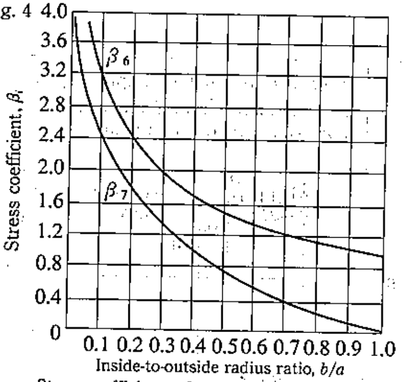
Stress coefficients, β_3, β_4, (β_4'), β_5 and (β_5') of disc No. 3, 4 and 5

Fig. 3



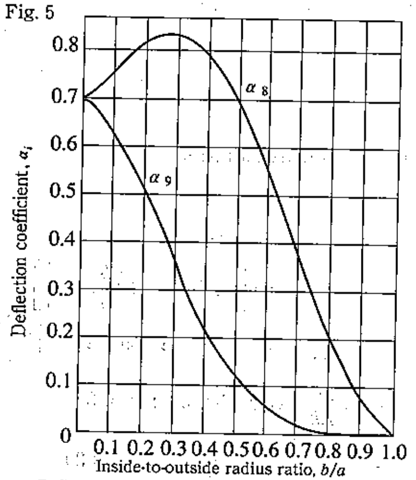
Deflection coefficients, α_6 and α_7 of disc No.6 and 7

Fig. 4



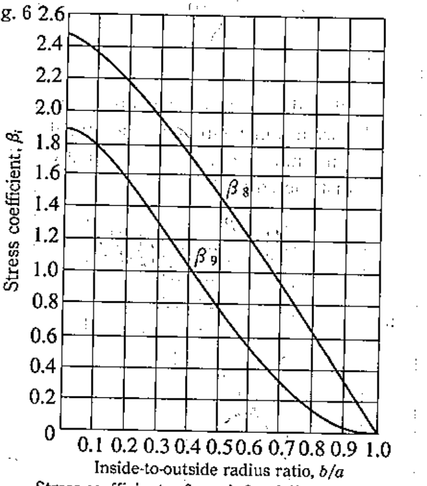
Stress coefficients, β_6 and β_7 of disc No. 6 and 7

Fig. 5



Deflection coefficients, α_8 and α_9 of disc No. 8 and 9

Fig. 6



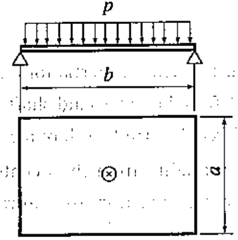
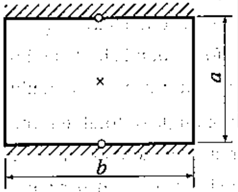
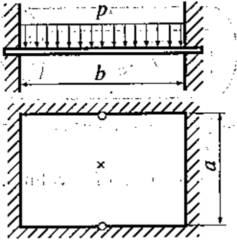
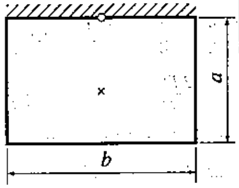
Stress coefficients, β_8 and β_9 of disc No. 8 and 9

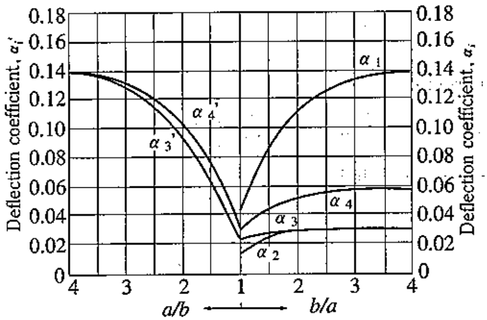
〔Source: Mechanical Engineers' Handbook, A4 (1987), The Japan Society of Mechanical Engineers〕

3-5 Deflection and Bending Stress of Rectangular Plate

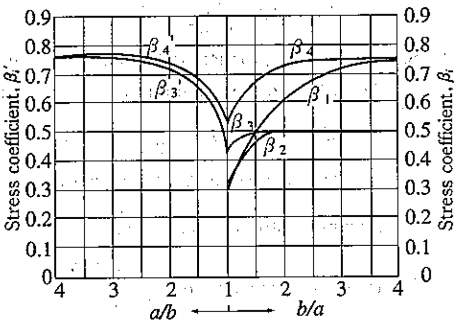
Formulas for maximum deflection $w_{\max}$, and maximum bending stress $\sigma_{\max}$ are shown below if a thin rectangular plate undergoes variable vertical loads under variable supporting conditions.
Values from α_1 to α_4 and from β_1 to β_4 are shown in the figures to put Poisson's ratio to $\nu = 0.3$.

○ Point of maximum stress × Point of maximum deflection
▨ Fixed side —— Free side

No.	Load status and support conditions	Maximum deflection, $w_{\max}$ Maximum bending stress, $\sigma_{\max}$	No.	Load status and support conditions	Maximum deflection, $w_{\max}$ Maximum bending stress, $\sigma_{\max}$
1	Equally distributed load and four-sides supported 	$w_{\max} = \alpha_1 \frac{pa^4}{Eh^3}$ $\sigma_{\max} = \beta_1 \frac{pa^2}{h^2}$	3	Equally distributed load, two facing sides fixed and two facing sides supported 	According to $b > a$ and $a > b$ $w_{\max} = \alpha_3 \frac{pa^4}{Eh^3}$ $w_{\max} = \alpha_3' \frac{pb^4}{Eh^3}$ $\sigma_{\max} = \beta_3 \frac{pa^2}{h^2}$ $\sigma_{\max} = \beta_3' \frac{pb^2}{h^2}$
2	Equally distributed load and four-sides fixed 	$w_{\max} = \alpha_2 \frac{pa^4}{Eh^3}$ $\sigma_{\max} = \beta_2 \frac{pa^2}{h^2}$	4	Equally distributed load, one side fixed and three facing sides supported 	According to $b > a$ and $a > b$ $w_{\max} = \alpha_4 \frac{pa^4}{Eh^3}$ $w_{\max} = \alpha_4' \frac{pb^4}{Eh^3}$ $\sigma_{\max} = \beta_4 \frac{pa^2}{h^2}$ $\sigma_{\max} = \beta_4' \frac{pb^2}{h^2}$



Ratio of both sides
Maximum deflection coefficients of rectangular plate, α_i and α_i'



Ratio of both sides
Maximum stress coefficients of rectangular plate, β_i and β_i'

〔Source: Mechanical Engineers' Handbook, A4 (1987), The Japan Society of Mechanical Engineers〕

3-6 Shaft

(1) A shaft acting only bending moment, M

Bending stress $\sigma_{\max} = \dfrac{M}{Z}$

$\sigma_{\max} = \dfrac{32}{\pi} \cdot \dfrac{M}{d^3}$ ……………………Round shaft (not hollow)

Design of diameter $d = \sqrt[3]{\dfrac{32}{\pi} \dfrac{M}{\sigma_W}}$ ……………………Round shaft (not hollow), where σ_W is a maximum allowable bending stress.

$\dfrac{{d_2}^4 - {d_1}^4}{d_2} = \dfrac{32}{\pi} \dfrac{M}{\sigma_W}$ ………………Hollow round shaft

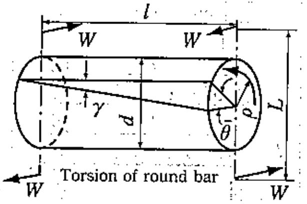
(2) A shaft acting only torsion moment, T

where, d : diameter of a round shaft, l : length of a round shaft, I_p : polar moment of inertia for a shaft center [$I_p = \pi d^4/32$ for a round shaft (no-hollow) and, $I_p = \pi(d^4 - {d_0}^4)/32$ for a hollow round shaft with inner diameter of d_0], G: transverse modulus of elasticity, W : couple of force, L : arm length of a couple of force, $\bar{\theta}$: torsion of angle of total length, θ : specific torsion of angle, ρ : radius from shaft center to a point, γ : shear strain at a radius ρ , $\gamma_{\max}$: maximum shear strain at perimeter, τ : shear stress at radius ρ , $\tau_{\max}$: maximum shear stress at perimeter, T : torsion moment, Z_p : polar modulus of section

$$T = WL \qquad \gamma_{\max} = \tau_{\max}/G \qquad \tau = 2\rho\tau_{\max}/d = \frac{T}{I_p}\rho$$

$$\tau_{\max} = \frac{T}{I_p}\frac{b}{2} = \frac{T}{Z_p} = \frac{16T}{\pi d^3} = G\theta\frac{d}{2}$$

$$\bar{\theta} = \frac{Tl}{GI_p} = \frac{32Tl}{\pi d^4 G} \qquad \theta = \frac{\bar{\theta}}{l} = \frac{T}{GI_p}$$



Torsion of round bar

When power $P(W)$ is transferred by a round shaft, then (where, n (rpm) is a number of revolution and τ_a $(Pa)$is allowable shear stress of shaft material.)

$$T = 0.15915\frac{W}{n}(\mathrm{N \cdot m})$$

$$d = 0.93239\sqrt[3]{\frac{W}{n\tau_a}}\,(\mathrm{m})$$

(3) Shaft undergoing torsion and bending moment

According to the maximum principal strain criterion,

$M_e = \dfrac{(1-\nu)}{2}M + \dfrac{(1+\nu)}{2}\sqrt{M^2 + (\alpha T)^2}$, where, $\nu = \dfrac{1}{m}$ and $\alpha = \dfrac{1}{1.3}\dfrac{\sigma_b}{\tau}$

$M_e = 0.35M + 0.65\sqrt{M^2 + (0.43T)^2}$ ……………………Mild steel

Maximum stress $\sigma_{\max} = \dfrac{M_e}{Z}$

Design of diameter $d = \sqrt[3]{\dfrac{32}{\pi} \dfrac{M_e}{\sigma_W}}$

〔Reference: Mechanical Engineers' Handbook, A4 (1987), The Japan Society of Mechanical Engineers〕

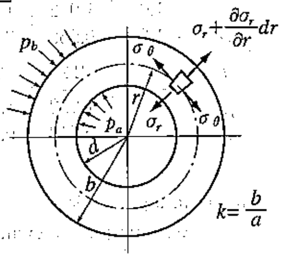
3-7 Cylinder, Sphere and Rotating Disc

(1) Cylinder and sphere

where, t : wall thickness, a : inside radius, b : outside radius, p_a : internal pressure, p_b : external pressure, $k = b/a$, $R = r/a$ and ν: Poisson's ratio

In case that a cylinder with inside radius a and outside radius b undergoes internal pressure P_a and external pressure P_b , the elastic stress distributions are shown in the table below.

Stress		Internal pressure	External pressure
Radius stress σ_r		$-\dfrac{k^2/R^2-1}{k^2-1}p_a$	$-\dfrac{k^2-k^2/R^2}{k^2-1}p_b$
Circumferential stress σ_θ		$\dfrac{k^2/R^2+1}{k^2-1}p_a$	$-\dfrac{k^2+k^2/R^2}{k^2-1}p_b$
Axial stress σ_z	Both ends closed	$\dfrac{1}{k^2-1}p_a$	$-\dfrac{k^2}{k^2-1}p_b$
	Plane-strain	$\dfrac{2\nu}{k^2-1}p_a$	$-\dfrac{2\nu k^2}{k^2-1}p_b$
	Both ends opened	0	0



Thin-wall cylinder undergoing internal pressure : circumferential stress

$$\sigma_\theta = \frac{a}{t}p$$

Thin-wall sphere undergoing internal pressure : circumferential stress

$$\sigma_t = \frac{1}{2}\frac{pa}{t}$$

(2) Thermal stress of cylinder

(a) For a hollow cylinder having a uniform temperature change (with both ends supported or fixed)

T : temperature ascent value, E : longitudinal modulus of elasticity, ν : Poisson's ratio and α : coefficient of linear expansion. Bending stress to axis at fixed end :

$$\sigma_z = \pm\alpha ET\sqrt{3/(1-\nu^2)}$$
$$= \pm 1.816\alpha ET \quad (\text{where } \nu = 0.3)$$

(where, + is for outer surface, and − is for inner surface.)

Circumferential stress at fixed end:

$$\sigma_\theta = -\alpha ET(1 \pm \sqrt{3}\,\nu/\sqrt{1-\nu^2}) = -1.545\alpha ET$$

(Maximum absolute value where $\nu = 0.3$)

(b) For a hollow cylinder having temperature gradient to radius

Thermal stress at a point far-off from fixed end

$$\sigma_\theta = \sigma_z = \pm\frac{1}{2}\alpha E(T_1 - T_2)/(1-\nu)$$
$$= \pm 0.714\alpha E(T_1 - T_2) \quad (\text{where, } \nu = 0.3)$$

(where, + is for outer surface, and − is for inner surface.)

If both ends of a pipe are free, circumferential stress on the outer surface of the pipe becomes maximum.

$$(\sigma_\theta)_{\max} = (1 - \nu + \sqrt{1-\nu^2}/\sqrt{3})\alpha E(T_1 - T_2)/2(1-\nu)$$
$$= 0.893\alpha E(T_1 - T_2) \qquad (\text{where, } \nu = 0.3)$$

(c) For a hollow cylinder having temperature gradient to axis

When the temperature of a circular tube with initial temperature T_0 descends linearly from a certain cross section to the end of distance l and is set to T_1, the maximum bending stress occurs at the cross section where temperature starts to descend.

$$\sigma_z = \pm\frac{\sqrt[4]{3}}{4}\frac{\alpha E(T_0 - T_1)}{(1-\nu^2)^{3/4}}\frac{\sqrt{rh}}{l}$$

$$= \pm 0.353\alpha E(T_0 - T_1)\sqrt{rh}/l \qquad (\text{where, } \nu = 0.3)$$

r : average radius of pipe and h : wall thickness of pipe

(d) Thermal stress in case that thick-wall cylinder has a tempereature gap between inside and outside

The absolute value of stress $\sigma_\theta = \sigma_{\theta 1}$ is always maximum at the inside circumference where $r=a$, and the next one is $\sigma_\theta = \sigma_{\theta 2}$ at the perimeter where $r=b$.

$$\sigma_{\theta 1} = \left\{\alpha E/2(1-\nu)\right\}(T_2 - T_1)\beta_1$$

$$\sigma_{\theta 2} = \left\{\alpha E/2(1-\nu)\right\}(T_2 - T_1)\beta_2$$

$$\beta_1 = 2k^2/(k^2-1) - 1/\log_e k, \quad \beta_2 = 2 - \beta_1$$

β_1 and β_2 are Bio's coefficients and these values are shown in the table below. (where, $k=b/a$)

k	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
β_1	1.0	1.032	1.061	1.087	1.111	1.134	1.154	1.174	1.192	1.208	1.224
β_2	1.0	0.968	0.939	0.913	0.889	0.866	0.846	0.826	0.808	0.792	0.776
k	—	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0
β_1	—	1.252	1.278	1.301	1.321	1.340	1.357	1.372	1.387	1.400	1.412
β_2	—	0.748	0.722	0.699	0.679	0.660	0.643	0.628	0.613	0.600	0.588

(3) Rotating cylinder

Assuming that a cylinder has an axial uniform strain, which is a plane-strain in the broad definition caused therein when the length of cylinder is far longer than the diameter, the stress is calculated by the following equation at the place where it is not so close to the both ends;

a : inner radius, b : outer radius, ω : angular velocity, E : longitudinal modulus of elasticity (Young's modulus), ν : Poisson's ratio, ρ : density of material, σ_θ : circumferential stress at radius θ, σ_r : radius stress at radius r, σ_z : axial stress at radius z, ξ : radial displacement at radius r and ε_z : uniform axial strain

$$\sigma_\theta = \frac{3-2\nu}{8(1-\nu)}\rho\omega^2\left[b^2 + a^2 + \frac{a^2b^2}{r^2} - \frac{1+2\nu}{3-2\nu}r^2\right]$$

$$\sigma_r = \frac{3-2\nu}{8(1-\nu)}\rho\omega^2\left[b^2 + a^2 - \frac{a^2b^2}{r^2} - r^2\right]$$

Put $r = a$, then

$$(\sigma_\theta)_{\max} = \frac{3-2\nu}{4(1-\nu)}\rho\omega^2\left[b^2 + \frac{1-2\nu}{3-2\nu}a^2\right]$$

Put $r = \sqrt{ab}$, then

$$(\sigma_r)_{\max} = \frac{3-2\nu}{8(1-\nu)}\rho\omega^2(b-a)^2$$

$$\sigma_z = \nu(\sigma_r + \sigma_\theta) + E\varepsilon_z$$

$$\xi = r[\{(1-\nu^2)/E\}\{\sigma_\theta - \nu\sigma_r/(1-\nu)\} - \nu\varepsilon_z]$$

(a) For no-axial force ($\int_a^b \sigma_z 2\pi r dr = 0$): –

$$\varepsilon_z = -\frac{\nu}{2}\frac{\rho\omega^2}{E}(a^2 + b^2)$$

$$\sigma_z = \frac{\nu}{4(1-\nu)}\rho\omega^2(b^2 + a^2 - 2r^2)$$

$$\xi = \frac{1}{8(1-\nu)}\frac{\rho\omega^2}{E}r[(3-5\nu)(a^2+b^2) + (3-2\nu)(1+\nu)a^2b^2/r^2 - (1+\nu)(1-2\nu)r^2]$$

(b) For no-axial strain ($\varepsilon_z = 0$): –

$$\sigma_z = \frac{\nu(3-2\nu)}{4(1-\nu)}\rho\omega^2\left[(a^2+b^2) - \frac{2}{3-2\nu}r^2\right]$$

$$\xi = \frac{1}{8(1-\nu)}\frac{\rho\omega^2}{E}r[(3-2\nu)(1+\nu)(1-2\nu)(a^2+b^2) + (3-2\nu)(1+\nu)a^2b^2/r^2 - (1+\nu)(1-2\nu)r^2]$$

(4) Rotating disc

(a) Uniform thickness rotating disc with center hole

$$\sigma_r = \frac{\rho\omega^2}{8}(3+\nu)\left(b^2 + a^2 - \frac{b^2a^2}{r^2} - r^2\right)$$

$$\sigma_\theta = \frac{\rho\omega^2}{8}\left\{(3+\nu)(b^2 + a^2 + \frac{b^2a^2}{r^2}) - (1+3\nu)r^2\right\}$$

$$\sigma_{r\max} = (\sigma_r)_{r=\sqrt{ba}} = \frac{\rho\omega^2}{8}(3+\nu)(b-a)^2$$

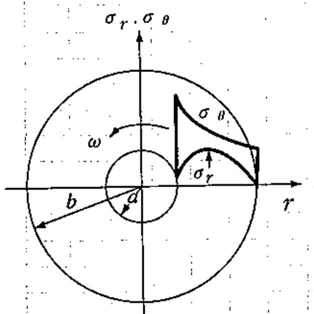
$$\sigma_{\theta\max} = (\sigma_\theta)_{r=a} = \frac{\rho\omega^2}{4}\{(3+\nu)b^2 + (1-\nu)a^2\}$$

(b) Uniform thickness rotating disc without center hole

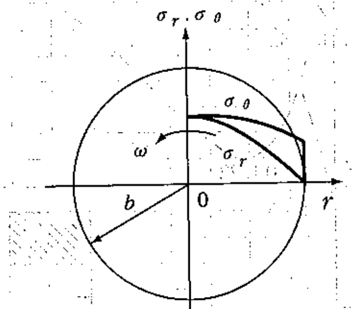
$$\sigma_r = \frac{\rho\omega^2}{8}(3+\nu)(b^2 - r^2)$$

$$\sigma_\theta = \frac{\rho\omega^2}{8}\{(3+\nu)b^2 - (1+3\nu)r^2\}$$

$$\sigma_{\max} = (\sigma_r)_{r=0} = (\sigma_\theta)_{r=0} = \frac{\rho\omega^2}{8}(3+\nu)b^2$$



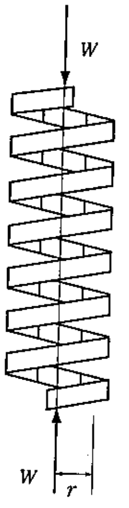
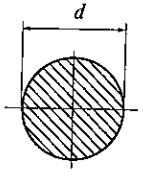
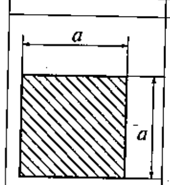
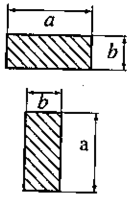
(a) Disc with center hole

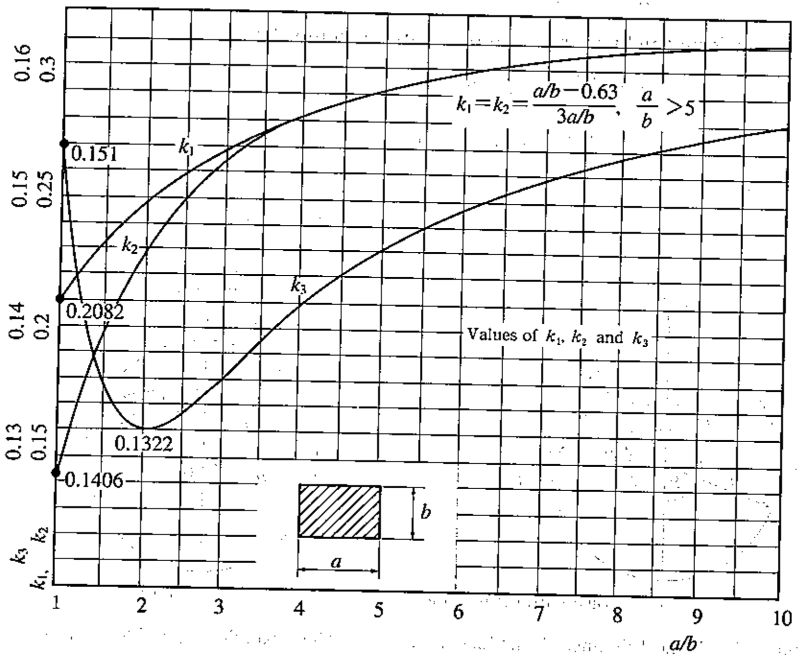


(b) Disc without center hole

(Source: Mechanical Engineers' Handbook, A4 (1987), The Japan Society of Mechanical Engineers)

3-8 Cylindrical Coil Spring

	Cross section of wire	Maximum torsional stress τ	Load W	Deflection δ	Energy per area
		$\frac{16rW}{\pi d^3}$ $=\frac{dG\delta}{4\pi ir^2}$	$\frac{d^4G}{64ir^3}\delta$ $=\frac{\pi d^3\tau}{16r}$	$\frac{16ir^3W}{d^4G}$ $=\frac{4\pi ir^2\tau}{dG}$	$\frac{1}{4}\frac{\tau^2}{G}$
		$\frac{rW}{0.2082a^3}$ $=\frac{aG\delta}{2.96\pi ir^2}$	$\frac{a^4G}{14.23\pi ir^3}\delta$ $=\frac{0.2082a^3\tau}{r}$	$\frac{14.23\pi ir^3W}{a^4G}$ $=\frac{2.96\pi ir^2\tau}{aG}$	$0.154\frac{\tau^2}{G}$
i : effective number of turn G : transverse modulus of elasticity		$\frac{rW}{k_1ab^2}$ $=\frac{k_2bG\delta}{2\pi k_1ir^2}$	$\frac{k_2ab^3G}{2\pi ir^3}\delta$ $=\frac{k_1ab^2\tau}{r}$	$\frac{2\pi ir^3W}{k_2ab^3G}$ $=\frac{2\pi k_1ir^2\tau}{k_2bG}$	$k_3\frac{\tau^2}{G}$
			k_1, k_2 and k_3 are torsion coefficients.		



3-9 Buckling

(1) Buckling of long column

A longer column is buckled when the axial load reaches to a certain value, although a shorter column is broken by compression stress caused by the axial load.

Buckling load : $p_k=\frac{n\pi^2}{l^2}\cdot EI$

Buckling stress : $\sigma_k=\frac{n\pi^2E}{\lambda^2}=\pi^2\mathrm{E}/\left(\frac{l'}{k}\right)^2=\pi^2E/\lambda'^2$

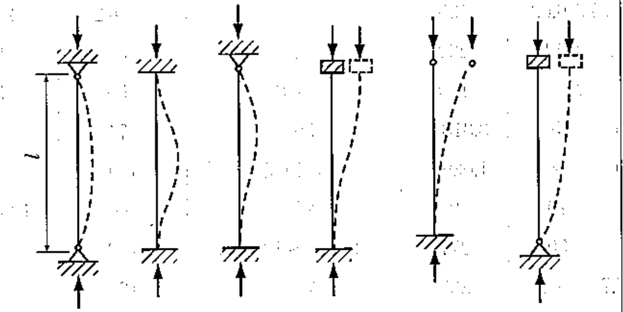
where, E : longitudinal modulus of elasticity, l : length, A : area of cross section, I : geometrical moment of inertia, k : radius gyration of area $(=\sqrt{I/A})$, λ : fineness ratio $(=\frac{l}{k})$ and n : coefficient determined in terms of end conditions of the column

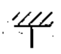
$l'=l/\sqrt{n}$: To be called as buckling length and it means a length between inflection points of deflection curve of the buckled column,

$\lambda'=l'/k$: equivalent fineness ratio

Values l' of buckling length for typical end conditions are shown in the table below.

The SSRC in U.S.A. recommends design buckling lengths, since ideal boundary conditions can't be obtained in practical use.

End condition and buckling form						
l'						
Ideal value	1.0 l	0.5 l	0.7 l	1.0 l	2.0 l	2.0 l
SSRC recommended value	1.0 l	0.65 l	0.80 l	1.2 l	2.10 l	2.0 l

Symbol	Rotation	Motion
	Free	Fixed
	Fixed	Fixed
	Free	Free
	Fixed	Free

(2) Buckling of thin plate

When a slender and rectangular thin plate of $(a\times b\times t,\ a>b)$ having the shorter sides supported and having the longer sides compressed uniformly,

Buckling stress : $\sigma=k\times\frac{\pi^2E}{12(1-\nu^2)}\times\left(\frac{t}{b}\right)^2$

where, k : coefficient according to stress distribution, shape of plate and circumference condition.

t : plate thickness

ν : Poisson's ratio

(Source: Mechanical Engineers' Handbook, A4 (1987), The Japan Society of Mechanical Engineers)

4-1 Physical Properties of Pure Metals

Element symbol	Density (20℃) kg/ℓ	Melting point ℃	Specific heat (20℃) J/(kg•K)	Linear expansion coefficient (20°~40℃) ×10⁻⁶K	Thermal conductivity (20℃) W/(m•K)	Electric resistance μ Ω/cm
Ag	10.49	960.5 ±0.0	235	19.7 (0° ~100°C)	428	1.59 (20℃)
Aℓ	2.699	660.2 ±1.0	903	23.9	220	2.655(20℃)
Au	19.32	1, 063.0 ±0.0	131	14.2	300	2.19 (0℃)
C	2.22	3, 700 ±100	691	0.6~4.3(20°~100°C)	24	1,375 (0℃)
Ca	1.55	850 ±20	626	22	130	3.43 (0℃)
Nb	8.57	2,415 ±15	273	7.1	52.5	13.1 (18℃)
Co	8.9	1,495 ±1	416	12.3	69	6.24 (20℃)
Cr	7.19	1,890 ±10	462	6.5~8.5	67	14.1 (28℃)
Cu	8.96	1,083.0 ±0.1	399	16.5	400	1.673(20℃)
Fe	7.87	1,539 ±3	462	11.7	76	9.71 (20℃)
Ga	5.91	29.78±0.02	332	18	30	53.4 (0℃)
Hg	13.55	38.87±0.02	139		8.2	94.1 (0℃)
In	7.31	156.4 ±0.1	239	33	86	8.37 (0℃)
Ir	22.5	2.454 ±3	129	6.8	59	5.3 (20℃)
Li	0.53	186 ±5	3,318	56	71	8.55 (0℃)
Mg	1.74	650 ±2	1,029	26(40°C)	154	4.46 (20℃)
Mn	7.43	1.245 ±10	483	22	—	185 (20℃)
Mo	10.2	2.625 ±50	277	4.9(20°~100°C)	143	5.17 (0℃)
Na	0.97	97.7 ±0.2	239	71	134	4.2 (0℃)
Ni	8.90	1,455 ±1	411	13.3 (0°~100°C)	83	6.84 (20℃)
Pb	11.34	327.4 ±0.1	129	29.3 (20°~100°C)	35	20.65 (20℃)
Pd	12.0	155.4 ±1	245	11.8	70.6	10.8 (20℃)
Pt	21.45	1,773.5 ±1	132	8.9	69.3	9.83 (0℃)
Se	4.81	220 ±5	353	37	0.3~0.7	——
Si	2.33	1,430 ±20	680	2.8~7.3	84	10.5 (0℃)
Sn	7.298	231.9 ±0.1	227	23	63	11.5 (20℃)
Ti	4.507	1,670 ±20	521	8.2	22	54.98 (20℃)
U	18.7	1,180	117	——	27	60 (18℃)
V	6.0	1,735 ±50	498	7.8	31	26 (20℃)
W	19.3	3,410 ±20	134	4.3	201	5.5 (20℃)
Zn	7.133	419.46	384	39.7	113	5.916(20℃)

4-2 Physical Properties of Alloys

Name	Chemical composition %	Density kg/ℓ	Melting point ℃	Thermal conductivity W/(m•K)(20℃)	Linear expansion coefficient ×10⁶/K(20℃)	Specific heat J/(kg•K)(20℃)
Mild steel	C 0. 12~0. 20	7. 855~7. 863	1, 470~1, 490	50~61	11.16~11.28	476~480
Semi-hard steel	C 0. 30~0. 45	7. 836~7. 854	1, 420~1, 450	43~51	10.73~10.92	485~489
High-carbon steel	C 0. 8~1. 6	7. 810~7. 833	1, 335~1, 540	38~44	9.58~10.87	507~519
Silicon steel	C<0. 08 Si 0. 8~4. 3 Mn<0. 35	7. 8~7. 6	1, 430~1, 530	0. 6~1. 4 (longitudinal) 0. 015~0. 016 (cross)	12~15	—
Ni-Cr steel	C 0. 25~0. 55 Ni 1. 0~5. 0 Cr 0. 03~2. 0	7. 8	1, 450~1, 510	34~42	13.3 (20~400℃) 14.8 (20~700℃)	—
Ni steel	C 0. 08~0. 25 Ni 1. 5~5. 0	7. 87 (Ni 3%)	—	42~45 42~44 (Ni 1. 07~1. 93)	10.354×10⁶+0.00523t	487~490 (Ni 1.07~1.93)
Cr-Mo steel	C 0. 35 Cr 0. 9 Mo 0. 2	7. 85	—	43	17.2	511
13%Cr stainless steel	C<0.2 Mn<0.5 Cr 11~15 Ni<1. 0	7. 6~7. 75	1, 510~1, 532	25 (200℃)	11.0	461
18-8 stainless steel	C<0. 08 Si<1.0 Ni 8~11 Cr 17~19	7. 91	1, 400~1, 420	17	17.1	503
Gray cast iron	C 2. 8~3. 8	7. 05~7. 30	1, 145~1, 275	32~56	9.2~11.8	540~566
Ni-Cr-Fe alloy	Ni 76 Cr 15. 5 Fe 7	8. 51	1, 390~1, 430	—	11.5 (38~ 93℃)	457
9-1 brass	Cu 90 Zn 10	8. 8	1, 045	—	18.2 (25~300℃)	377
7-3 brass	Cu 69~72 Zn remaining	8. 54	950	112	19	377
Gunmetal	Cu 88 Sn 10 Zn 2	8. 7	—	48	18.3	—
Al-bronze	Aℓ 9~10 Mn<0. 6 Fe<0. 25 Cu remaining	7. 6	1, 040	—	17	436
70-30 cupronickel	Cu 70 Ni 30	8. 94	1, 170~1, 240	—	16.2	377
German silver	Cu 60~65 Ni 12~22 Zn 18~23	8. 3~8. 7	950~1, 180	250~419	18~21	398~444
Phosphor bronze	Sn <10 P<0. 5 Cu remaining	8. 9~8. 95	—	80	16.8	—
White metal	Sn80~90 Sb4~10 Cu2~7	7. 38	240~355	—	Approx. 20	—

4-3 Notation of Metal Symbols (abridged from the "Table of JIS Material Symbols," JIS Handbook of Steels, edited by Japanese Standards Association, 1999)

(1)

A	Aluminum	FV	Ferrovanadium
AB	Aluminum bronze	FW	Ferrotungsten
B	Bronze	HBs	High-strength brass
BeCu	Beryllium copper	MC	Cast magnet
Bs	Brass	MCr	Metal chromium
CaSi	Calcium silicon	MF	Forged magnet
DCu	Deoxidation copper	MMn	Metal manganese
Fe	Iron	MP	Sintered magnet
FB	Ferroboron	MSi	Metal silicon
FCr	Ferrochrome	NBs	Naval brass
FMn	Ferromanganese	NS	German silver
FMo	Ferromolybudenum	PB	Phosphor bronze
FNb	Ferroniobium	S	Steel
FNi	Ferronickel	SiCr	Silicochromium
FP	Ferrophosphor	SiMn	Silicomanganese
FSi	Ferrosilicon	SP	Spiegeleisen
FTi	Ferrotitanium	TCu	Tough pitch copper

(2)

FCD	Spheroidal Graphite Iron Castings	SCW	Steel castings for welded structure
FCMB	Blackheart Malleable Iron Castings	SF	Carbon steel Forgings for General Use
FCMP	Pearlitic Malleable Iron Castings	SFVA	Alloy Steel Forgings for Pressure Vessels for High-Temperature Service
FCMW	Whiteheart Malleable Iron Castings	SFVC	Carbon steel Forgings for Pressure Vessels
NCF-B	Corrosion-resisting and heat-resisting superalloy bars	SGP	Carbon Steel Pipes for Ordinary Piping
N,CF-P	Corrosion-resisting and heat-resisting superalloy plates and sheets	SGV	Carbon Steel Plates for Pressure Vassels for Intermediate and Moderate Temperature Service
NCF-TB	Seamless nickel-chromium-iron alloy heat exchanger tubes	SL-N	Nickel Steel Plates for Pressure Vessels for Low Temperature Service
		SLA	Carbon Steel Plates for Pressure Vessels for Low Temperature Service
NCF-TP	Seamless nickel-chromium-iron alloy pipes	SM	Rolled Steels for welded structure
S-C	Carbon steels for Machine Structural Use	SMA	Hot-Rolled Atmospheric Corrosion Resisting Steels for Welded Structure
SACM	Aluminum Chromium Molybdenum Steels	SNB	Alloy Steel Bolting Materials for High Temperature Services Alloy Steel Bars for Special Application Bolting Materials
SB SB-M	Carbon Steel and Molybdenum Alloy Steel Plates for Boilers and Other Pressure Vessels	SNC	Nickel Chromium Steels
SBV	Alloy steel plates for boilers and pressure vessels	SNCM	Nickel Chromium Molybdenum Steels
SCH	Heat resisting steel castings	SPV	Steel Plates for Pressure Vessels for Intermediate Temperature Service
SCM	Chromium Molybdenum Steels	SQV	Tempered manganese molybdenum steels and manganese-molybdenum nickel steel plates for pressure vessels
SCMV	Chromium Molybdenum Alloy Steel Plates for Boilers and Pressure Vessels		
SCMnH	High manganese Steel castings	SS	Rolled Steel for General structure
SCPH	Steel castings for high temperature and high pressure service	STB	Carbon Steel Boiler and Heat Exchanger Tubes
SCPL	Steel Casting for low temperature and high pressure service	STBA	Alloy Steel Boiler and Heat Exchanger Tubes
SCr	Chromium Steels	STBL	Steel Heat Exchanger Tubes for Low Temperature Service
SCS	Stainless steel castings	STK	Carbon Steel Tubes for General Structure Purposes
SCr-TK SCM-TK	Alloy Steel Tubes for Machine Purposes	STPY	Arc welded carbon steel pipes
STPA	Alloy Steel Pipes	STS	Carbon steel pipes for high-pressure piping
STPG	Carbon steel pipes for pressure Service	SUH	Heat resistant steels
STPL	Steel pipes for low temperature Service	SUS	Stainless steel
STPT	Carbon steel pipes for high temperature Service	SUS-TB	Stainless steel Boiler and Heat Exchanger Tubes
		SUS-TP	Stainless Steel Pipes

(3)

A type of material is noted by minimum tensile strength and number or letter A, B or C. The type is followed by shape, manufacturing process, heat treatment and quality.

(a) Symbols representing shapes

W	Steel wire	CS	Cold-rolled strip
CP	Cold-rolled plate	HS	Hot-rolled strip
HP	Hot-rolled plate	TB	Tube for heat transfer
		TP	Pipe for piping

(b) Symbols representing manufacturing processes

-S-H	Hot-finished, seamless pipe	-B-C	Cold-finished, forge-welded steel pipe
-S-C	Cold-finished, seamless pipe	-A	Arc-welded steel pipe
-E-G	Electric resistance welded steel pipe	-A-C	Cold-finished, arc-welded steel pipe
-E-H	Hot-finished, electric resistance welded steel pipe	-D1	Drawing (9 is grade 9 of tolerance)
-E-C	Cold-finished, electric resistance welded steel pipe	-T2	Cutting (8 is grade 8 of tolerance)
-B	Forge-welded steel pipe	-G3	Grinding (7 is grade 7 of tolerance)

(c) Symbols representing heat treatments

N	Normalizing	SR	Stress relief of test piece
Q	Quenching and tempering	TMC	Thermal machining control
P	Low-temperature annealing		

(d) Symbols representing qualities

-O	Soft	-EH	Extreme hard
-OL	Light soft	-SH	Spring hard
-1／2H	Semihard	-F	As-manufactured
-H	Hard	-SR	Stress-relief material

Note: 1. The first character (1) of each metal symbol represents a material, the second one (2) is a standard name, and the third one (3) is a type.

2. For (1) is used an initial letter of an English or Roman term or symbol for a chemical element.

For (2) is used an initial letter of an English or Roman term.

For (3) is used a figure of a type number of material or a figure of minimum tensile strength.

Examples: SUS304CP : Cold-rolled stainless steel plate SUS304.

SM570Q : Hardened and sempered to rolled steel SM 57 for welding structure.

$\underset{(1)}{\underline{\text{S}}}\ \underset{(2)}{\underline{\text{TB}}}\ \underset{(3)}{\underline{\text{340}}}$-S-H: Hot-rolled finish, seamless carbon steel pipe for boiler and heat exchanger STB340.

4-4 Mechanical Properties of Metal Materials

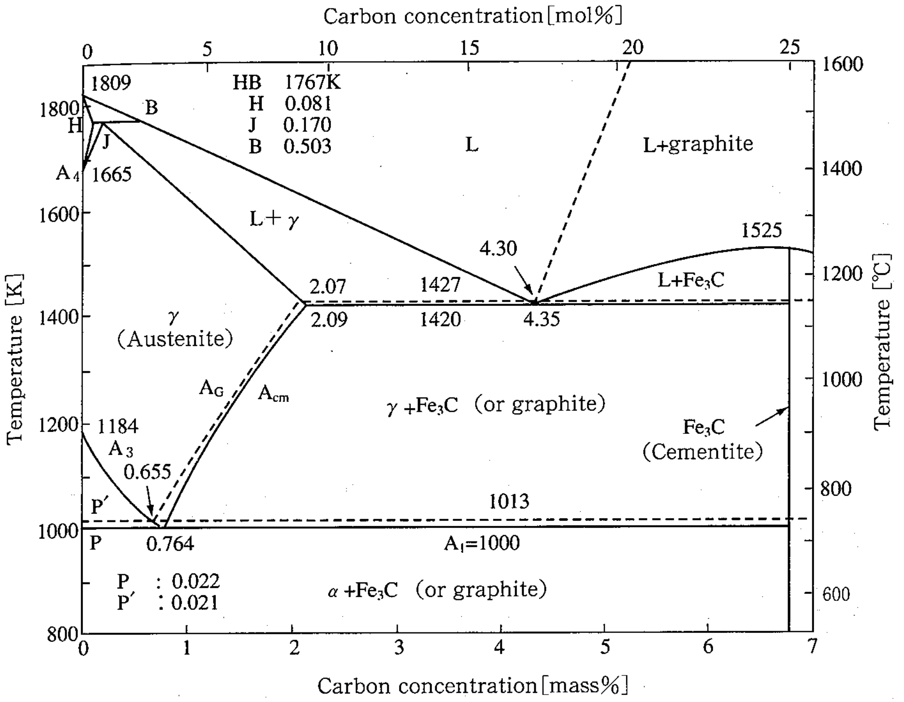
Name		Proportionality limit σ_p N/mm²	Yield point σ_s N/mm²	Tensile strength N/mm²	Young's modulus E N/cm²×10⁶	Cross modulus of elasticity G N/cm²×10⁶	Poisson's ratio 1/m
Mild steel		177～226	197～295	363～442	21	8.0	0.28～0.3
Hard steel		275～314	295～	471～569	21	8.0	
Spring steel	Without hardening	490～	–	784～	21	8.4～8.6	
	With hardening	736～	–	1,275～1,471	21	8.4～8.6	
Nickel steel (Ni 2～3%)		324～	412～	726～	21	8.3	
Brass		–	–	118	6.2	2.4	0.34
Copper		79	–	206	12.3	4.7	0.34
Gunmetal		–	–	206	8.0	2.9	0.34
Aluminum		–	–	128	7.1	2.7	
Lead		–	–	10～20	1.7	0.8	0.45

4-5 Comparison of Hardness

JIS hardness conversion table in JIS Handbook, Ferrous Materials & Metallurgy (1999), edited by Japanese Standards Association

Vickers hardness	Rockwell hardness		Shore hardness	Tensile sgtrenth	Vickers hardness	Brinell hardness (10mm,3t)		Rockwell hardness		Shore hardness	Tensile sgtrenth	Vickers hardness	Brinell hardness (10mm,3t)		Rockwell hardness		Shore hardness	Tensile sgtrenth
	B	C		N/mm²		Dia	Standard ball	B	C		N/mm²		Dia	Standard ball	B	C		N/mm²
940	–	68.0	97	–	550	–	505	–	52.3	–	1905	290	3.66	275	104.5	28.5	41	915
920	–	67.5	96	–	540	–	496	–	51.7	69	1860	285	–	270	–	27.8	–	905
900	–	67.0	95	–	530	2.77	488	–	51.1	–	1825	280	3.73	265	103.5	27.1	40	890
880	–	66.4	93	–	520	–	480	–	50.5	67	1795	275	–	261	–	26.4	–	875
860	–	65.9	92	–	510	–	473	–	49.8	–	1750	270	3.79	256	102.0	25.6	38	855
840	–	65.3	91	–	500	–	465	–	49.1	66	1705	265	3.82	252	–	24.8	–	840
820	–	64.7	90	–	490	–	456	–	48.4	–	1660	260	–	247	101.0	24.0	37	825
800	–	64.0	88	–	480	2.89	448	–	47.7	64	1620	255	–	243	–	23.1	–	805
780	–	63.3	87	–	470	2.91	441	–	46.9	–	1570	250	–	238	99.5	22.2	36	795
760	–	62.5	86	–	460	–	433	–	46.1	62	1530	245	–	233	–	21.3	–	780
740	–	61.8	84	–	450	–	425	–	45.3	–	1495	240	4.01	228	98.1	20.3	34	765
720	–	61.0	83	–	440	3.00	415	–	44.5	59	1460	230	4.08	219	96.7	18.0	33	730
700	–	60.1	81	–	430	–	405	–	43.6	–	1410	220	4.18	209	95.0	15.7	32	695
690	–	59.7	–	–	420	–	397	–	42.7	57	1370	210	4.26	200	93.4	13.4	30	670
680	–	59.2	80	–	410	3.10	388	–	41.8	–	1330	200	4.37	190	91.5	11.0	29	635
670	–	58.8	–	–	400	–	379	–	40.8	55	1290	190	4.47	181	89.5	8.5	28	605
660	–	58.3	79	–	390	–	369	–	39.8	–	1240	180	4.59	171	87.1	6.0	26	580
650	–	57.8	–	–	380	–	360	110.0	38.8	52	1205	170	4.71	162	85.0	3.0	25	545
640	–	57.3	77	–	370	3.26	350	–	37.7	–	1170	160	4.85	152	81.7	0.0	24	515
630	–	56.8	–	–	360	3.30	341	109.0	36.6	50	1130	150	4.99	143	78.7	–	22	490
620	–	56.3	75	–	350	3.35	331	–	35.5	–	1095	140	5.16	133	75.0	–	21	455
610	–	55.7	–	–	340	–	322	108.0	34.4	47	1070	130	5.33	124	71.2	–	20	425
600	–	55.2	74	–	330	3.44	313	–	33.3	–	1035	120	5.54	114	66.7	–	–	390
590	–	54.7	–	2055	320	–	303	107.0	32.2	45	1005	110	5.75	105	62.3	–	–	–
580	–	54.1	72	2020	310	–	294	–	31.0	–	980	100	–	95	56.2	–	–	–
570	–	53.6	–	1985	300	–	284	105.5	29.8	42	950	95	6.16	90	52.0	–	–	–
560	–	53.0	71	1950	295	3.63	280	–	29.2	–	935	85	6.45	81	41.0	–	–	–

4-6 Iron-Carbon Equilibrium Diagram



〔Souce: the "Handbook of Metals," 5th ed, Japan Association of Metals, 1990.〕

4-7 Extracts from Standards of Steel Pipes, Tubes, Steel and Cast and Forged Products

(for the allowable tensile stress at temperatures, see page 642 and below. See pages 51 and 52 in this section, the "New and Old Comparative Tables of JIS Symbol.)

Standard and application	Symbol	Nominal composition	Chemical composition % (Maximum)									Equivalent to ASTM No.
			C	Si	Mn	P	S	Ni	Cr	Mo	Others	
G 3101 (1995) Rolled steel for general structure (buildings, bridges, ships, vehicles and other structure)	SS330		–	–	–	0. 050	0. 050	–	–	–	–	A6-69a A36-70 A113-70 A131-69 A283-70 A284-70 A529-64
	SS400		–	–	–	0. 050	0. 050	–	–	–	–	
	SS490		–	–	–	0.050	0.050	–	–	–	–	
	SS540		0. 30	–	1. 60	0. 040	0. 040	–	–	–	–	
G 3203 (1988) Alloy steel forgings for pressure vessels for high-temperature service	SFVA F1	½Mo	0. 30	0. 35	0. 60~0. 90	0. 030	0. 030	–	–	0. 45~0. 65	–	A182F1
	SFVA F2	¾Cr, ½Mo	0. 20	0. 60	0. 30~0. 90	0. 030	0. 030	–	0. 50~0. 80	0. 45~0. 65	–	A182F2
	SFVAF12	1Cr, ½Mo	0. 20	0. 60	0. 30~0. 80	0. 030	0. 030	–	0. 80~1. 25	0. 45~0. 65	–	A182F12
	SFVA F11	1¼Cr, ½Mo	0. 20	0. 50~1. 00	0. 30~0. 80	0. 030	0. 030	–	1. 00~1. 50	0. 45~0. 65	–	A182F11
	SFVA F22	2¼Cr, 1Mo	0. 15	0. 50	0. 30~0. 60	0. 030	0. 030	–	2. 00~2. 50	0.90~1.10	–	A182F22
	SFVA F5	5Cr, ½Mo	0. 15	0. 50	0. 30~0. 60	0. 030	0. 030	–	4. 00~6. 00	0.45~0.65	–	A182F5
	SFVA F9	9Cr, 1Mo	0. 15	0. 50~1. 00	0. 30~0. 60	0. 030	0. 030	–	8. 00~10. 0	0.90~1.10	–	A182F9
G 3103 (1987) Carbon steel and molybdenum alloy steel plates for boilers and other pressure vessels	SB 410		t ≦25 0. 24 25<t≦50 0. 27 50<t≦200 0. 30	0. 15~0. 30	0. 90	0. 035	0. 040	–	–	–	–	A285 A302 A515

(Continued)

Standard and application	Symbol	Nominal composition	Chemical composition % (Maximum)									Equivalent to ASTM No.
			C	Si	Mn	P	S	Ni	Cr	Mo	Others	
G 3103 (1987) (Continued)	SB450	Steel plate	t≦25 0. 28 t≦50>25 0. 31 t≦200>50 0. 33	0. 15~0. 30	0. 90	0. 035	0. 040	–	–	–	–	
	SB480		t≦25 0. 31 t≦50>25 0. 33 t≦200>50 0. 35	0. 15~0. 30	0. 90	0. 035	0. 040	–	–	–	–	
	SB450M		t≦25 0. 18 t≦50>25 0. 21 t≦100>50 0. 23 t≦150>100 0. 25	0. 15~0. 30	0. 90	0. 035	0. 040	–	–	0. 45~0. 60	–	
	SB480M		t≦25 0. 20 t≦50>25 0. 23 t≦100>50 0. 25 t≦150>100 0. 27	0. 15~0. 30	0. 90	0. 035	0. 040	–	–	0. 45~0. 60	–	
G 3106 (1999) Rolled steels for welded structure	SM400A		t≦50 0. 23 50<t≦200 0. 25	–	2. 5×C	0. 035	0. 035	–	–	–	–	A 242-68 A 440-66
	SM400B		t≦50 0. 20 50<t≦200 0. 23	0. 35	0. 60~1. 40	0. 035	0. 035	–	–	–	–	
	SM400C		t≦100 0. 18	0. 35	1. 40	0. 035	0. 035	–	–	–	–	
	SM490A		t≦100 0. 20 100<t≦200 0. 22	0. 55	1. 50	0. 035	0. 035	–	–	–	–	
	SM490B		t≦50 0. 18 100<t≦200 0.20	0.55	1.50	0.035	0.035	–	–	–	–	

[redacted]

(Continued)

Standard and application	Symbol	Nominal composition	Chemical composition % (Maximum)									Equivalent to ASTM No.
			C	Si	Mn	P	S	Ni	Cr	Mo	Others	
G 3106 (1999) (Continued)	SM490C		t≦100 0.18	0.55	1.50	0.035	0.035	—	—	—	—	
	SM490YA		t≦100 0.20	0.55	1.60	0.035	0.035	—	—	—	—	
	SM490YB											
	SM520B		t≦100 0.20	0.55	1.60	0.035	0.035	—	—	—	—	
	SM520C											
	SM570		t≦100 0.18	0.55	1.60	0.035	0.035	—	—	—	—	
G3115 (1990) Steel plates for pressure vessels for intermediate temperature service	SPV235		t≦100 0.18 t>100 0.20	0.15～0.35	1.40	0.030	0.030	—	—	—	—	
	SPV315		0.18	0.15～0.55	1.50	0.030	0.030	—	—	—	—	
	SPV355		0.18	0.15～0.55	1.60	0.030	0.030	—	—	—	—	
	SPV450		0.18	0.15～0.75	1.60	0.030	0.030	—	—	—	—	
	SPV490		0.18	0.15～0.75	1.60	0.030	0.030	—	—	—	—	
G 3201 (1988) Carbon steel forgings for general use	SF340A		0.60	0.15～0.50	0.30～1.20	0.030	0.035	—	—	—	—	A 105-68
	SF390A											
	SF440A											
	SF490A											
	SF540A											
	SF590A											
G 5101 (1991) Carbon steel castings	SC360		0.20	—	—	0.040	0.040	—	—	—	—	A 27-65
	SC410		0.30									
	SC450		0.35									
	SC480		0.40									

(Continued)

Standard and application	Symbol	Nominal composition	Chemical composition % (Maximum)									Equivalent to ASTM No.
			C	Si	Mn	P	S	Ni	Cr	Mo	Others	
G 5151 (1991) Steel castings for high temperature and high pressure service	SCPH 1		0.25	0.60	0.70	0.040	0.040	—	—	—	—	A356-68
	SCPH 2		0.30	0.60	1.00	0.040	0.040	—	—	—	—	A217-69
	SCPH11	½Mo	0.25	0.60	0.50～0.80	0.040	0.040	—	—	0.45～0.65	—	
	SCPH21	1¼Cr、½Mo	0.20	0.60	0.50～0.80	0.040	0.040	—	1.00～1.50	0.45～0.65	—	
	SCPH22	1¼Cr、1Mo	0.25	0.60	0.50～0.80	0.040	0.040	—	1.00～1.50	0.90～1.20	—	
	SCPH23	1½Cr、1Mo¼r	0.20	0.60	0.50～0.80	0.040	0.040	—	1.00～1.50	0.90～1.20	0.15～0.25	
	SCPH32	2¼Cr、1Mo	0.20	0.60	0.50～0.80	0.040	0.040	—	2.00～2.75	0.90～1.20	—	
	SCPH61	5Cr、½Mo	0.20	0.60	0.50～0.80	0.040	0.040	—	4.00～6.50	0.45～0.65	—	
G 4109 (1987) Chromium-molybdenum alloy steel plates for boilers and pressure vessels	SCMV 1	¾Cr、½Mo	0.21	0.40	0.55～0.80	0.030	0.030	—	0.50～0.80	0.45～0.60	—	A387Cr.2
	SCMV 2	1Cr、½Mo	0.17	0.40	0.40～0.65	0.030	0.030	—	0.80～1.15	0.45～0.60	—	A387Cr.12
	SCMV 3	1¼Cr、½Mo	0.17	0.50～0.80	0.40～0.65	0.030	0.030	—	1.00～1.50	0.45～0.65	—	A387Cr.11
	SCMV 4	2¼Cr、1Mo	0.17	0.50	0.30～0.60	0.030	0.030	—	2.00～2.50	0.90～1.10	—	A387Cr.22
	SCMV 5	3Cr、1Mo	0.17	0.50	0.30～0.60	0.030	0.030	—	2.75～3.25	0.90～1.10	—	A387Cr.21
	SCMV 6	5Cr、½Mo	0.15	0.50	0.30～0.60	0.030	0.030	—	4.00～6.00	0.45～0.60	—	A387Cr.5
G 3461 (1988) Carbon steel boiler and heat exchanger tubes	STB340		0.18	0.35	0.30～0.60	0.035	0.035	—	—	—	—	A178
	STB410		0.32	0.35	0.30～0.80	0.035	0.035	—	—	—	—	A210-A1
	STB510		0.25	0.35	1.00～1.50	0.035	0.035	—	—	—	—	
Carbon steel tubes for feed water heater of power boiler specified in Article 1-2, Clause 16	KA-STB480		0.30	0.10	0.29～1.06	— 0.048	0.058	—	—	—	— — —	A556-C2
G 3462 (1988) Alloy steel boiler and heat exchanger tubes	STBA12	0.5Mo	0.10～0.20	0.10～0.50	0.30～0.80	0.035	0.035	—	—	0.45～0.65	—	A209-T1
	STBA13	0.5Mo	0.15～0.25	0.10～0.50	0.30～0.80	0.035	0.035	—	—	0.45～0.65	—	A209-T1a
	STBA20	0.75Cr.0.5Mo	0.10～0.20	0.10～0.50	0.30～0.60	0.035	0.035	—	0.50～0.80	0.40～0.65	—	A213-T2
	STBA22	1Cr、0.5Mo	0.15	0.5	0.30/0.60	0.035	0.035	—	0.80～1.25	0.40～0.65	—	A213-T12

(Continued)

Standard and application	Symbol	Nominal composition	Chemical composition % (Maximum)									Equivalent to ASTM No.
			C	Si	Mn	P	S	Ni	Cr	Mo	Others	
G 3462 (1988) (Continued)	STBA23	1.25Cr 0.75Si、0.5Mo	0.15	0.05/1.00	0.30/0.60	0.030	0.030	–	1.00~ 1.50	0.45~0.65	–	A213-T11
	STBA24	2.25Cr、1Mo	0.15	0.50	0.30/0.60	0.030	0.030	–	1.90~ 2.60	0.87~1.13		A213-T22
	STBA25	5Cr、0.5Mo	0.15	0.50	0.30/0.60	0.030	0.030	–	4.00~ 6.00	0.45~0.65		A213-T5
	STBA26	9Cr、1Mo	0.15	0.25/1.00	0.30/0.60	0.030	0.030	–	8.00~10.00	0.90~1.10		A213-T9
G 3463 (1994) Stainless steel boiler and heat exchanger tubes	SUS410TB	13Cr	0.15	1.00	1.00	0.040	0.030	–	11.50~13.50	–		A268 TP410
	SUS430TB	18Cr	0.12	0.75	1.00	0.040	0.030	–	16.00~18.00	–		A268 TP430
	SUS304TB	18Cr、8Ni	0.08	1.00	2.00	0.040	0.030	8.00~11.00	18.00~20.00	–		A213, A249 TP304
	SUS304HTB	18Cr、8Ni	0.04/0.10	0.75	2.00	0.040	0.030	8.00~11.00	18.00~20.00	–		A213, A249 TP304H
	SUS304LTB	18Cr、8Ni low C	0.03	1.00	2.00	0.040	0.030	9.00~13.00	18.00~20.00	–		A213, A249 TP304L
	SUS321TB	18Cr、8Ni、Ti	0.08	1.00	2.00	0.040	0.030	9.00~13.00	17.00~19.00	–	Ti≧5×C%	A213, A249 TP329
	SUS321HTTB	18Cr、8Ni、Ti	0.08	0.75	2.00	0.030	0.030	9.00~13.00	17.00~20.00	–	Ti 4×C%/0.06	A213, A249 TP329H
	SUS316TB	18Cr、12Ni、Mo	0.08	1.00	2.00	0.040	0.030	10.00~14.00	16.00~18.00	2.00~3.00		A213, A249 TP316
	SUS316HTB	16Cr、13Ni、Mo	0.04/1.00	0.75	2.00	0.030	0.030	11.00~14.00	16.00~18.00	2.00~3.00		A213, A249 TP316H
	SUS316LTB	18Cr、12Ni、Mo low C	0.03	1.00	2.00	0.040	0.030	12.00~16.00	16.00~18.00	2.00~3.00		A213, A249 TP316L
	SUS309TB	22Cr、12Ni	0.15	1.00	2.00	0.040	0.030	12.00~15.00	22.00~24.00	–		A249 TP309
	SUS310TB	25Cr、20Ni	0.15	1.50	2.00	0.040	0.030	19.00~22.00	24.00~26.00	–		A249 TP310
	SUS347TB	18Cr、Ni、Nb	0.08	1.00	2.00	0.040	0.030	9.00~13.00	17.00~20.00	–	Nb : Ta ≧10×C%	A213, A249 TP347
	SUS347HTB	18Cr、10Ni、Nb	0.04/1.00	1.00	2.00	0.030	0.030	9.00~13.00	17.00~20.00	–	Nb : Ta : 8×C%/1.00	A213, A249 TP347H
G 3452 (1997) Carbon steel pipes for ordinary piping	SGP		–	–	–	0.040	0.04	–	–	–		A120.
G 3454 (1988) Carbon steel pipes for pressure service	STPG370		0.25	0.35	0.30~0.90	0.040	0.040	–	–	–	–	
	STPG410		0.30	0.35	0.30~1.00	0.040	0.040	–	–	–	–	

(Continued)

(Continued)

Standard and application	Symbol	Nominal composition	Chemical composition % (Maximum)									Equivalent to ASTM No.
			C	Si	Mn	P	S	Ni	Cr	Mo	Others	
G 3455 (1988) Carbon steel pipes for high pressure service	STS370		0.25	0.10~0.35	0.30~0.90	0.035	0.035	–	–	–	–	
	STS410		0.30	0.10~0.35	0.30~1.00	0.035	0.035	–	–	–	–	
	STS480		0.33	0.10~0.35	0.30~1.00	0.035	0.035	–	–	–	–	
G 3456 (1988) Carbon steel pipes for high temperature service	STPT370		0.25	0.10~0.35	0.30~0.90	0.035	0.035	–	–	–	–	A106-A
	STPT410		0.30	0.10~0.35	0.30~1.00	0.035	0.035	–	–	–	–	A106-B
	STPT480		0.33	0.10~0.35	0.30~1.00	0.035	0.035	–	–	–	–	A106-C
G 3457 (1988) Arc welded carbon steel pipes	STPY400		0.25	–	–	0.040	0.040	–	–	–	–	
G 3458 (1988) Alloy steel pipes	STPA12	0.5Mo	0.10~0.20	0.10~0.50	0.30~0.60	0.035	0.035	–	–	0.45~0.65	–	A335-P1
	STPA20	0.5Cr 0.5Mo	0.10~0.20	0.10~0.50	0.30~0.60	0.035	0.035	–	0.50~0.80	0.40~0.65	–	A335-P2
	STPA22	1Cr 0.5Mo	0.15	0.50	0.30~0.60	0.035	0.035	–	0.80~1.25	0.45~0.65	–	A335-P12
	STPA23	1.25Cr 0.75Si 0.5Mo	0.15	0.50~1.00	0.30~0.60	0.030	0.030	–	1.00~1.50	0.45~0.15	–	A335-P11
	STPA24	2.25Cr 1Mo	0.15	0.50	0.30~0.60	0.030	0.030	–	1.10~2.60	0.87~1.13	–	A335-P22
	STPA25	5Cr 0.Mo	0.15	0.50	0.30~0.60	0.030	0.030	–	4.00~6.00	0.45~0.65	–	A335-P5
	STPA26	9Cr 1Mo	0.15	0.25~1.00	0.30~0.60	0.030	0.030	–	8.00~10.00	0.90~1.10	–	A335-P9
G 3459 (1997) Stainless steel pipes	SUS304TP	18Cr 8Ni	0.08	1.00	2.00	0.040	0.030	8.00~11.00	18.00~20.00	–	–	A312 TP304
	SUS304HTP	18Cr 8Ni	0.04~0.10	0.75	2.00	0.040	0.030	8.00~11.00	18.00~20.00	–	–	A312 TP304H
	SUS304LTP	18Cr 8Ni low C	0.03	1.00	2.00	0.040	0.030	9.00~13.00	18.00~20.00	–	–	A312 TP304L
	SUS321TP	18Cr 10Ni Ti	0.08	1.00	2.00	0.040	0.030	9.00~13.00	17.00~19.00	–	Ti: Min. 5×C% min	A312 TP321
	SUS321HTP	18Cr 10Ni Ti	0.04~0.10	0.75	2.00	0.030	0.030	9.00~13.00	17.00~20.00	–	Ti:4×C% ~0.60	A312 TP321H
	SUS316TP	18Cr 12Ni Mo	0.08	1.00	2.00	0.040	0.030	10.00~114.00	16.00~18.00	2.00~3.00	–	A312 TP316
	SUS316HTP	16Cr 13Ni Mo	0.04~0.10	0.75	2.00	0.030	0.030	11.00~14.00	16.00~18.00	2.00~3.00	–	A312 TP316H
	SUS316LTP	18Cr 12Ni Mo low C	0.03	1.00	2.00	0.040	0.030	12.00~16.00	16.00~18.00	2.00~3.00	–	A312 TP316L
	SUS309STP	22Cr 12Ni	0.15	1.00	2.00	0.040	0.030	12.00~15.00	22.00~24.00	–	–	A312 TP309

(Continued)

Standard and application	Symbol	Nominal composition	Chemical composition % (Maximum)									Equivalent to ASTM No.
			C	Si	Mn	P	S	Ni	Cr	Mo	Others	
G 3459 (1997) (Continued)	SUS310STP	25Cr 20Ni	0. 15	1. 00	2. 00	0. 040	0. 030	19. 00~22. 00	24. 00~26. 00	—	—	A312 TP310
	SUS347TP	18Cr10Ni Nb	0. 08	1. 00	2. 00	0. 040	0. 030	9. 00~13. 00	17. 00~20. 00	—	Nb : 10×C%Min.	A312 TP347
	SUS347HTP	18Cr10Ni Nb	0. 04~0. 10	1. 00	2. 00	0. 030	0. 030	9. 00~13. 00	17. 00~20. 00	—	Nb : 8×C%~1. 00	A312 TP347H
Stainless alloy steel pipes for power boiler provided in Article 1-2, Clause 1-20*	KA-SUS304 J1HTB	18Cr 9Ni 3Cu Nb N	0. 07~1. 13	0. 03	1. 00	0. 040	0. 010	7. 50~10. 50	17. 00~19. 00	—	Nb:0. 03~0. 06 N : 0. 05~0. 12 Cu:2. 50~3. 50	
	KA-SUS309 J1TB	25Cr 15Ni 1Mo N	0. 06	1. 50	2. 00	0. 040	0. 030	12. 00~16. 00	23. 00~26. 00	0. 50~1. 20		
	KA-SUS309 J2TB	22Cr 14Ni 1.5Mo N	0. 04	1. 00	2. 50~3. 50	0. 030	0. 030	12. 50~15. 50	21. 00~23. 00	1. 00~2. 00		
	KA-SUS309 J3LTB	25Cr 14Ni 0.8Mo 0.2Si N	0. 025	0. 70	2. 00	0. 040	0. 030	13. 00~16. 00	23. 00~26. 00	0. 50~1. 20	N : 0. 250 ~0. 040	
	KA-SUS310 J1TB	25Cr 20Ni Nb V	0. 10	1. 50	2. 00	0. 030	0. 030	17. 00~23. 00	23. 00~27. 00	—	Nb : 0. 20~0. 60	
	KA-SUS321 J1HTB	18Cr 10Ni Ti Nb	0. 07~0. 14	1. 00	2. 00	0. 040	0. 030	9. 00~12. 00	17. 50~19. 50	—	Ti : ≦0. 20 Nb : ≦0. 40	
	KA-SUS347 HTB	18Cr 10Ni Nb	0. 04~0. 10	0. 75	2. 00	0. 030	0. 030	9. 00~13. 00	17. 00~20. 00	—	Nb : 8×C%~1. 00	A213 TP347H
	KA-SUS410 J2TB	12Cr 1Mo W V Nb	0. 14	0. 50	0. 30~0. 70	0. 030	0. 030	—	11. 00~13. 00	0. 80~1. 20	V : 0. 20~0. 30 Nb : ≦0. 20	
Alloy steel tubes for power boiler heat exchanger provided in Article 1-2, Clause 1-18*	KA-STBA10	1.25Cr 0.3Cu	0. 10	0. 20~0. 08	0. 80	0. 020	0. 015 ~0. 030	—	1. 00~ 1. 50	—		
	KA-STBA21	1Cr 0.3Mo	0. 10~0. 20	0. 50	0. 30~0. 70	—	—	—	0. 80~ 1. 25	0. 20~0. 45	—	
	KA-STBA27	9Cr 2Mo	0. 08	0. 50	0. 30~0. 70	—	—	—	8. 00~10. 00	1. 80~2. 20	—	
	KA-STBA28	9Cr 1Mo Nb V	0. 08~0. 12	0. 20~0. 50	0. 30~0. 60	0. 020	0. 010	≦0. 40	8. 00~ 9. 50	0. 85~1. 05	V:0. 18~0. 25 N:0. 003~0. 070 Nb:0. 06~0. 10 Sol.Al:≦0. 04	A213 P91
Alloy steel pipes for piping of power plant provided in Article 1-2, Clause 1-27.*	KA-STPA21	1Cr 0.3Mo	0. 10~0. 20	0. 50	0. 30~0. 60	—	—	—	0. 80~ 1. 25	0. 20~0. 45	—	
	KA-STPA27	9Cr 2Mo	0. 08	0. 50	0. 30~0. 70	—	—	—	8. 00~10. 00	1. 80~2. 20	—	
	KA-STPA28	9Cr 1Mo Nb V	0. 08~0. 12	0. 20~0. 50	0. 30~0. 60	0. 020	0.010	≦0. 40	8. 00~ 9. 50	0. 85~1. 05	V:0. 18~0. 25 N:0. 003~0. 070 Nb:0. 06~0. 10 Sol.Al:≦0. 04	A335 P91

(Continued)

Standard and application	Symbol	Nominal composition	Chemical composition % (Maximum)									Equivalent to ASTM No.
			C	Si	Mn	P	S	Ni	Cr	Mo	Others	
G 3118 (1990) Carbon steel plates for pressure vessels for intermediate and moderate temperature service	SGV410	t≦12.5	0.21	0.15~0.30	0.85~1.20	0.035	0.040	—	—	—	—	
		12.5<t≦50	0.23									
		50<t≦100	0.25									
		100<t≦200	0.27									
	SGV450	t≦12.5	0.24	0.15~0.30	0.85~1.20	0.035	0.040	—	—	—	—	
		125<t≦50	0.26									
		50<t≦100	0.28									
		100<t≦200	0.29									
	SGV480	t≦12.5	0.27	0.15~0.30	0.85~1.20	0.035	0.040	—	—	—	—	
		12.5<t≦50	0.28									
		50<t≦100	0.30									
		100<t≦200	0.31									
G 3120 (1987) Manganese-molybdenum and manganese-molybdenum-nickel alloy steel plates quenched and tempered for pressure vessels	SQV1A SQV1B	Mn 0.5Mo	0.25	0.15~0.30	1.15~1.50	0.035	0.040	—	—	0.45~0.60	—	A533-A
	SQV2A SQV2B	Mn 0.5Ni 0.5Mo	0.25	0.15~0.30	1.15~1.50	0.035	0.040	0.40~0.70	—	0.45~0.60	—	A533-B
	SQV3A SQV3B	Mn 0.75Ni 0.5Mo	0.25	0.15~0.30	1.15~1.50	0.035	0.040	0.70~1.00	—	0.45~0.60	—	A533-C
G 3460 (1988) Steel pipes for low temperature service	STPL380		0.25	0.35	1.35	0.035	0.035	—	—	—	—	A333-Gr1
	STPL450	3.5Ni	0.18	0.10~0.35	0.30~0.60	0.030	0.030	3.20~3.80	—	—	—	A333-Gr3
G 4103 (1979) Nickel chromium molybdenum steels	SNCM240		0.38~0.43	0.15~0.35	0.70~1.00	0.030	0.030	0.40~0.70	0.40~0.65	0.15~0.30	—	
	SNCM431		0.27~0.35	0.15~0.35	0.60~0.90	0.030	0.030	1.60~2.00	0.60~1.00	0.15~0.30	—	
	SNCM439		0.36~0.43	0.15~0.35	0.60~0.90	0.030	0.030	1.60~2.00	0.60~1.00	0.15~0.30	—	
	SNCM447		0.44~0.50	0.15~0.35	0.60~0.90	0.030	0.030	1.60~2.00	0.60~1.00	0.15~0.30	—	
	SNCM625		0.20~0.30	0.15~0.35	0.35~0.60	0.030	0.030	3.00~3.25	1.00~1.50	0.15~0.30	—	
	SNCM630		0.25~0.35	0.15~0.35	0.35~0.60	0.030	0.030	2.50~3.50	2.50~3.50	0.50~0.70	—	
G 3202 (1988) Carbon steel forgings for pressure vessels	SFVC1		0.30	0.35	0.40~1.35	0.030	0.030	—	—	—	—	
	SFVC2A		0.35	0.35	0.40~1.10	0.030	0.030	—	—	—	—	

(Continued)

Standard and application	Symbol	Nominal composition	Chemical composition % (Maximum)									Equivalent to ASTM No.
			C	Si	Mn	P	S	Ni	Cr	Mo	Others	
G 3202 (1988) (Continued)	SFVC2B		0.30	0.35	0.70~1.35	0.030	0.030	–	–	–	–	
G 3214 (1991) Stainless steel forgings for pressure vessels	SUSF304	18Cr 8Ni	0.08	1.00	2.00	0.045	0.030	8.00~11.00	18.00~20.00	–	–	A182F304
	SUSF304L	18Cr 8Ni LowC	0.030	1.00	2.00	0.045	0.030	9.00~13.00	18.00~20.00	–	–	A182F304L
	SUSF316	16Cr 12Ni 2Mo	0.08	1.00	2.00	0.045	0.030	10.00~14.00	16.00~18.00	2.00~3.00	–	A182F316
	SUSF316L	16Cr 12Ni 2Mo LowC	0.030	1.00	2.00	0.045	0.030	12.00~15.00	16.00~18.00	2.00~3.00	–	A182F316L
	SUSF321	18Cr 10Ni Ti	0.08	1.00	2.00	0.045	0.030	9.00~13.00	17.00~19.00	–	Ti: Min.5×C%	A182F321
	SUSF347	18Cr 10Ni Nb	0.08	1.00	2.00	0.045	0.030	9.00~13.00	17.00~20.00	–	Nb: Min.10×C%	A182F347
G 5121 (1991) Stainless steel castings	SCS13	18Cr 8Ni	0.08	2.00	2.00	0.040	0.040	8.00~11.00	18.00~21.00	–	–	
	SCS13A	18Cr 8Ni	0.08	2.00	1.50	0.040	0.040	8.00~11.00	18.00~21.00	–	–	
	SCS14	18Cr 9Ni 2Mo	0.08	2.00	2.00	0.040	0.040	10.00~14.00	17.00~20.00	2.00~3.00	–	
	SCS14A	18Cr 9Ni 2Mo	0.08	1.50	1.50	0.040	0.040	9.00~12.00	18.00~21.00	2.00~3.00	–	
	SCS16	18Cr 12Ni 2Mo LowC	0.03	1.50	2.00	0.040	0.040	12.00~16.00	17.00~20.00	2.00~3.00	–	
	SCS16A	18Cr 12Ni 2Mo LowC	0.03	1.50	1.50	0.040	0.040	9.00~13.00	17.00~21.00	2.00~3.00	–	
	SCS19	18Cr 8Ni LowC	0.03	2.00	2.00	0.040	0.040	8.00~12.00	17.00~21.00	–	–	
	SCS19A	18Cr 8Ni LowC	0.03	2.00	1.50	0.040	0.040	8.00~12.00	17.00~21.00	–	–	
	SCS21	18Cr 10Ni Nb	0.08	2.00	2.00	0.040	0.040	9.00~12.00	18.00~21.00	–	Nb: 10×C%~1.35	
G 4304 (1991) Hot rolled stainless steel plates, steels and strips	SUS304	18Cr 8Ni	0.08	1.00	2.00	0.045	0.030	8.00~10.50	18.00~20.00	–	–	
	SUS304L	18Cr 8Ni LowC	0.03	1.00	2.00	0.045	0.030	9.00~13.00	18.00~20.00	–	–	
G 4305 (1991) Cold rolled stainless steel plates, sheets and strips	SUS316	16Cr 12Ni 2Mo	0.08	1.00	2.00	0.045	0.030	10.00~14.00	16.00~18.00	2.00~3.00	–	
	SUS316L	16Cr 12Ni 2Mo LowC	0.03	1.00	2.00	0.045	0.030	12.00~15.00	16.00~18.00	2.00~3.00	–	
	SUS321	18Cr 10Ni Ti	0.08	1.00	2.00	0.045	0.030	9.00~13.00	17.00~19.00	–	Ti: Min.5×C%	
	SUS347	18Cr 10Ni Nb	0.08	1.00	2.00	0.045	0.030	9.00~13.00	17.00~19.00	–	Nb: Min.10×C%	
	SUS405	13Cr	0.08	1.00	1.00	0.040	0.030	11.00~14.50	–	–	Al: 0.10~0.30	

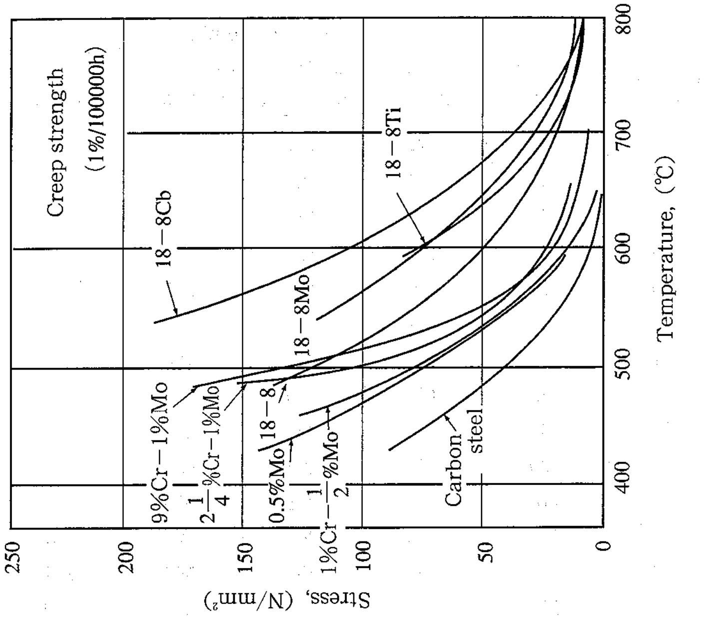
New and Old Symbol Comparative Table of JIS Symbol for Ferrous Material

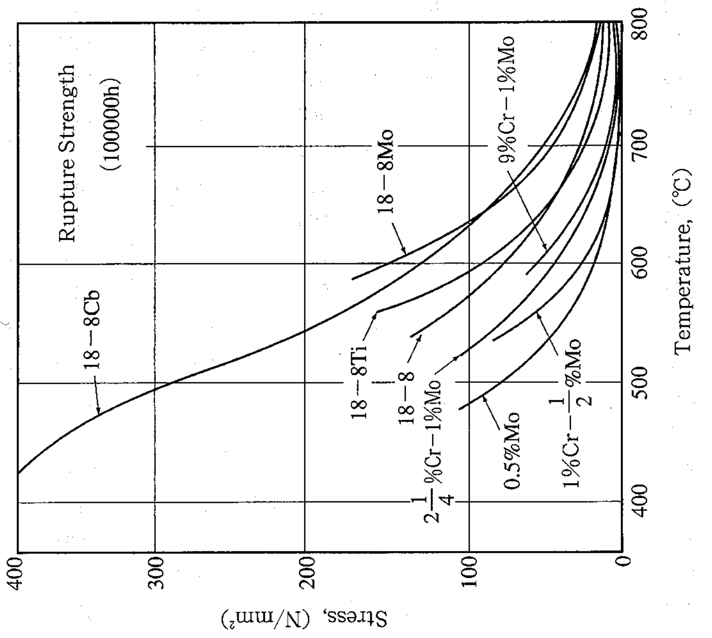
The table shows exchanged new Symble with "SI units" of Ferrous Metallurgy

Standard No.	New Symbol	Old Symbol
G3101	SS330	SS34
	SS400	SS41
	SS490	SS50
	SS540	SS55
G3103	SB410	SB42
	SB450	SB46
	SB480	SB49
	SB450M	SB46M
	SB480M	SB49M
G3104	SV330	SV34
	SV400	SV41
G3105	SBC300	SBC31
	SBC490	SBC50
	SBC690	SBC70
G3106	SM400A	SM41A
	SM400B	SM41B
	SM400C	SM41C
	SM490A	SM50A
	SM490B	SM50B
	SM490C	SM50C
	SM490YA	SM50YA
	SM490YB	SM50YB
	SM520B	SM53B
	SM520C	SM53C
	SM570	SM58
G3109	SBPR785/930	SBPR80/95
	SBPR785/1030	SBPR80/105
	SBPR930/1080	SBPR95/110
	SBPR930/1180	SBPR95/120
	SBPR1080/1230	SBPR110/125
	SBPR1080/1320	SBPR110/135
	SBPD930/1080	SBPD95/110
	SBPD1080/1220	SBPD110/125
	SBPD1275/1420	SBPD130/145
G3111	SRB330	SRB34
	SRB380	SRB39
	SRB480	SRB49
G3112	SR235	SR24
	SR295	SR30
	SD295A	SD30A
	SD295B	SD30B
	SD345	SD35
	SD390	SD40
	SD490	SD50
G3113	SAPH310	SAPH32
	SAPH370	SAPH38
	SAPH400	SAPH41
	SAPH440	SAPH45
G3104	SMA400AW	SMA41AW
	SMA400AP	SMA41AP
	SMA400BW	SMA41BW
	SMA400BP	SMA41BP
	SMA400CW	SMA41CW
	SMA400CP	SMA41CP
	SMA490AW	SMA50AW
	SMA490AP	SMA50AP
	SMA490BW	SMA50BW
	SMA490BP	SMA50BP
	SMA490CW	SMA50CW
	SMA490CP	SMA50CP
	SMA570W	SMA58W
	SMA570P	SMA58P
G3115	SPV235	SPV24
	SPV315	SPV32
	SPV355	SPV36
	SPV410	SPV42
	SPV450	SPV46
	SPV490	SPV50
G3116	SG255	SG26
	SG295	SG30
	SG325	SG33
	SG365	SG37
G3117	SRR235	SRR24
	SRR295	SRR30
	SDR235	SDR24
	SDR295	SDR30
	SDR345	SDR35
G3118	SGV410	SGV42
	SGV450	SGV46
	SGV480	SGV49
G3123	SGD290-D	SGD30-D
	SGD400-D	SGD41-D
G3124	SEV245	SEV25
	SEV295	SEV30
	SEV345	SEV35
G3126	SLA235A	SLA24A
	SLA235B	SLA24B
	SLA325A	SLA33A
	SLA325B	SLA33B
	SLA360	SLA37
	SLA410	SLA42
G3127	SL2N255	SL2N26
	SL3N255	SL3N26
	SL3N275	SL3N28
	SL3N440	SL3N45
	SL5N590	SL5N60
	SL9N520	SL9N53
	SL9N590	SL9N60
G3128	SHY685	SHY70
	SHY685N	SHY70N
	SHY685NS	SHY70NS
G3129	SH590P	SH60P
	SH590S	SH60S
G3134	SPFH490	SPFH50
	SPFH540	SPFH55
	SPFH590	SPFH60
	SPFH540Y	SPFH55Y
	SPFH590Y	SPFH60Y
G3135	SPFC340	SPFC35
	SPFC370	SPFC38
	SPFC390	SPFC40
	SPFC440	SPFC45
	SPFC490	SPFC50
	SPFC540	SPFC55
	SPFC590	SPFC60
	SPFC490Y	SPFC50Y
	SPFC540Y	SPFC55Y
	SPFC590Y	SPFC60Y
	SPFC780Y	SPFC80Y
	SPFC980Y	SPFC100Y
	SPFC340H	SPFC35H
G3201	SF340A	SF35A
	SF390A	SF40A
	SF440A	SF45A
	SF490A	SF50A
	SF540A	SF55A
	SF540B	SF55B
	SF590A	SF60A
	SF590B	SF60B
	SF640B	SF65B
G3221	SFCM590S	SFCM60S
	SFCM590R	SFCM60R
	SFCM590D	SFCM60D
	SFCM640S	SFCM65S
	SFCM640R	SFCM65R
	SFCM640D	SFCM65D
	SFCM690S	SFCM70S
	SFCM690R	SFCM70R
	SFCM690D	SFCM70D
	SFCM740S	SFCM75S
	SFCM740R	SFCM75R
	SFCM740D	SFCM75D
	SFCM780S	SFCM80S
	SFCM780R	SFCM80R
	SFCM780D	SFCM80D
	SFCM830S	SFCM85S
	SFCM830R	SFCM85R
	SFCM830D	SFCM85D
	SFCM880S	SFCM90S
	SFCM880R	SFCM90R
	SFCM880D	SFCM90D
	SFCM930S	SFCM95S
	SFCM930R	SFCM95R
	SFCM930D	SFCM95D
	SFCM980S	SFCM100S
	SFCM980R	SFCM100R
	SFCM980D	SFCM100D

Standard No.	New Symbol	Old Symbol
G3222	SFNCM690S	SFNCM70S
	SFNCM690R	SFNCM70R
	SFNCM690D	SFNCM70D
	SFNCM740S	SFNCM75S
	SFNCM740R	SFNCM75R
	SFNCM740D	SFNCM75D
	SFNCM780S	SFNCM80S
	SFNCM780R	SFNCM80R
	SFNCM780D	SFNCM80D
	SFNCM830S	SFNCM85S
	SFNCM830R	SFNCM85R
	SFNCM830D	SFNCM85D
	SFNCM880S	SFNCM90S
	SFNCM880R	SFNCM90R
	SFNCM880D	SFNCM90D
	SFNCM930S	SFNCM95S
	SFNCM930R	SFNCM95R
	SFNCM930D	SFNCM95D
	SFNCM980S	SFNCM100S
	SFNCM980R	SFNCM100R
	SFNCM980D	SFNCM100D
	SFNCM1030S	SFNCM105S
	SFNCM1030R	SFNCM105R
	SFNCM1030D	SFNCM105D
	SFNCM1080S	SFNCM110S
	SFNCM1080R	SFNCM110R
	SFNCM1080D	SFNCM110D
G3223	SFT590	SFT60
G3302	SGH340	SGH35
	SGH400	SGH41
	SGH440	SGH45
	SGH490	SGH50
	SGH540	SGH55
	SGC340	SGC35
	SGC400	SGC41
	SGC440	SGC45
	SGC490	SGC50
	SGC570	SGC58
G3312	CGC340	CGC35
	CGC400	CGC41
	CGC440	CGC45
	CGC490	CGC50
	CGC570	CGC58
G3350	SSC400	SSC41
G3353	SWH400	SWH41
	SWH400L	SWH41L
G3443	STW290	STW30
	STW370	STW38
	STW400	STW41
G3444	STK290	STK30
	STK400	STK41
	STK500	STK51
	STK490	STK50
	STK540	STK55
G3454	STPG370	STPG38
	STPG410	STPG42
G3455	STS370	STS38
	STS410	STS42
	STS480	STS49
G3456	STPT370	STPT38
	STPT410	STPT42
	STPT480	STPT49
G3457	STPY400	STPY41
G3460	STPL380	STPL39
	STPL450	STPL46
	STPL690	STPL70
G3461	STB340	STB35
	STB410	STB42
	STB510	STB52
G3464	STBL380	STBL39
	STBL450	STBL46
	STBL690	STBL70
G3465	STM-C540	STM-C55
	STM-C640	STM-C65
	STM-R590	STM-R60
	STM-R690	STM-R70
	STM-R780	STM-R80
	STM-R830	STM-R85
G3466	STKR400	STKR41
	STKR490	STKR50
G3467	STF410	STF42
G3472	STAM290GA	STAM30GA
	STAM290GB	STAM30GB
	STAM340G	STAM35G
	STAM390G	STAM40G
	STAM440G	STAM45G
	STAM440H	STAM45H
	STAM470G	STAM48G
	STAM470H	STAM48H
	STAM500G	STAM51G
	STAM500H	STAM51H
	STAM540H	STAM55H
G3473	STC370	STC38
	STC440	STC45
	STC510A	STC52A
	STC510B	STC52B
	STC540	STC55
	STC590A	STC60A
	STC590B	STC60B
G3474	STKT540	STKT55
	STKT590	STKT60
G5101	SC360	SC37
	SC410	SC42
	SC450	SC46
	SC480	SC49
G5102	SCW410	SCW42
	SCW450	SCW46
	SCW480	SCW49
	SCW550	SCW56
	SCW620	SCW63
G5201	SCW410-CF	SCW42-CF
	SCW480-CF	SCW49-CF
	SCW490-CF	SCW50-CF
	SCW520-CF	SCW53-CF
G5501	FC100	FC10
	FC150	FC15
	FC200	FC20
	FC250	FC25
	FC300	FC30
	FC350	FC35
G5502	FCD370	FCD37
	FCD400	FCD40
	FCD450	FCD45
	FCD500	FCD50
	FCD600	FCD60
	FCD700	FCD70
	FCD800	FCD80
G5702	FCMB270	FCMB28
	FCMB310	FCMB32
	FCMB340	FCMB35
	FCMB360	FCMB37
G5703	FCMW330	FCMW34
	FCMW370	FCMW38
	FCMW440	FCMW45
	FCMW490	FCMW50
	FCMW540	FCMW55
G5704	FCMP440	FCMP45
	FCMP490	FCMP50
	FCMP540	FCMP55
	FCMP590	FCMP60
	FCMP690	FCMP70
A5525	SKK440	SKK41
	SKK490	SKK50
A5526	SHK400	SHK41
	SHK400M	SHK41M
	SHK490M	SHK50M
A5528	SY295	SY30
	SY390	SY40
A5530	SKY400	SKY41
	SKY490	SKY50

4-8 Examples of Creep and Rupture Strength of Pipe Steels





4-9 Mass of Steel Plates

Thickness (mm)	Mass (kg/m²)	Mass per one plate kg					
		Width×Length(mm) 914×1829	Width×Length(mm) 1219×2438	Width×Length(mm) 1524×3048	Width×Length(mm) 1524×6096	Width×Length(mm) 1600×6000	Width×Length(mm) 1800×8000
3.2	25	42	74	117			
3.6	28	47	83	131			
4.0	31	52	93	146			
4.5	35	59	105	164	328		
5.0	39	65	117	182	365		
5.6	43	73	131	204	408		
6.0	47	78	140	219	438		
6.3	49	82	147	230	459		
7.0	54	91	163	255	510		
8.0	62	105	187	292	583		
9.0	70	118	210	328	656		
10.0	78	131	233	365	729	754	1130
11.0	86	144	257	401	802	829	1243
12.0	94	158	280	438	875	904	1356
12.7	99		296	463	926	957	1436
13.0	102		303	474	948	979	1469
14.0	110		327	510	1021	1055	1583
15.0	118		350	547	1094	1131	1696
16.0	126		373	583	1167	1206	1809
17.0	133			620	1239	1281	1921
18.0	141			656	1313	1356	2035
19.0	149			693	1386	1432	2148
20.0	157			729	1459	1507	2261
22.0	173			802	1604	1658	2487
25.0	196			911	1823	1884	2825
25.4	199				1852	1914	2871
28.0	220				2042	2110	3165
30.0	236				2188	2261	3391
32.0	251				2334	2412	3617
36.0	283				2625	2713	4069
38.0	298				2771	2864	4296
40.0	314				2917	3014	4522
45.0	353				3281	3391	5086
50.0	392				3646	3768	5652

4-10 Table of Dimensions and Mass of Steel Pipes

(as per 1988 edition)

(1) Dimension and unit mass of JIS G 3457 (1988) arc welded carbon steel pipes

Units in kg/m

Nominal dia.		Wall thickness, mm	6.0	6.4	7.1	7.9	8.7	9.5	10.3	11.1	11.9	12.7	13.1	15.1	15.9
A	B	Outside dia. mm													
350	14	355.6	51.7	55.1	61.0	67.7									
400	16	406.4	59.2	63.1	69.9	77.6									
450	18	457.2	66.8	71.1	78.8	87.5									
500	20	508.0	74.3	79.2	87.7	97.4	107	117							
550	22	558.8	81.8	87.2	96.6	107	118	129	139	150	160	171			
600	24	609.6	89.3	95.2	105	117	129	141	152	164	175	187			
650	26	660.4	96.8	103	114	127	140	152	165	178	190	203			
700	28	711.2	104	111	123	137	151	164	178	192	205	219			
750	30	762.0		119	132	147	162	176	191	206	220	235			
800	32	812.8		127	141	157	173	188	204	219	235	251	258	297	312
850	34	863.6				167	183	200	217	233	250	266	275	316	332
900	36	914.4				177	194	212	230	247	265	282	291	335	352
1000	40	1016.0				196	216	236	255	275	295	314	324	373	392
1100	44	1117.6						260	281	303	324	346	357	411	432
1200	48	1219.2						283	307	331	354	378	390	448	472
1350	54	1371.6									399	426	439	505	532
1500	60	1524.0									444	473	488	562	591
1600	64	1626.6											521	600	631
1800	72	1828.8											587	675	711
2000	80	2032.0												751	791

Remark: 1. To indicate the nominal diameter of the pipe, either the letter A or B shall be used suffixed to the figures of nomi.

2. The value of unit mass shall be calculated from the following formula assuming 1cm³ of steel to be 7.85g, and shall be rounded off to 3 significant digits in accordance with JIS Z 8401.

$$W = 0.02466t\ (D-t)$$

where, W : nunit mass of pipe (kg/m)

t : wall thckness of pipe (mm)

D : outside diameter of pipe (mm)

3. Agreement shall be made between the purchaser and the manufacturer when the dimensions not given in the above table are necessary

(2) Dimension and unit mass

JIS G 3452 carbon steel pipes for ordinary piping
JIS G 3454 carbon steel pipes for pressure service
JIS G 3455 carbon steel pipes for high-pressure service
JIS G 3456 carbon steel pipes for high-temperature piping
JIS G 3458 alloy steel pipes

□ G 3454 ⬚ G 3455, G3456, G3458

Nominal dia. (A)	Nominal dia. (B)	Outside dia. (mm)	JIS G 3452 (1997) Wall thickness (mm)	JIS G 3452 (1997) Unit mass excluding socket (kg/m)	Schedule 10 Thickness (mm)	Schedule 10 Unit mass (kg/m)	Schedule 20 Thickness (mm)	Schedule 20 Unit mass (kg/m)	Schedule 30 Thickness (mm)	Schedule 30 Unit mass (kg/m)
6	1/8	10.5	2.0	0.419						
8	1/4	13.8	2.3	0.652						
10	3/8	17.3	2.3	0.851						
15	1/2	21.7	2.8	1.31						
20	3/4	27.2	2.8	1.68						
25	1	34.0	3.2	2.43						
32	1 1/4	42.7	3.5	3.38						
40	1 1/2	48.6	3.5	3.89						
50	2	60.5	3.8	5.31			3.2	4.52		
65	2 1/2	76.3	4.2	7.47			4.5	7.97		
80	3	89.1	4.2	8.79			4.5	9.39		
90	3 1/2	101.6	4.2	10.1			4.5	10.8		
100	4	114.3	4.5	12.2			4.9	13.2		
125	5	139.8	4.5	15.0			5.1	16.9		
150	6	165.2	5.0	19.8			5.5	21.7		
175	7	190.7	5.3	24.2						
200	8	216.3	5.8	30.1			6.4	33.1	7.0	36.1
225	9	241.8	6.2	36.0						
250	10	267.4	6.6	42.4			6.4	41.2	7.8	49.9
300	12	318.5	6.9	53.0			6.4	49.3	8.4	64.2
350	14	355.6	7.9	67.7	6.4	55.1	7.9	67.7	9.5	81.1
400	16	406.4	7.9	77.6	6.4	63.1	7.9	77.6	9.5	93.0
450	18	457.2	7.9	87.5	6.4	71.1	7.9	87.5	11.1	122
500	20	508.0	7.9	97.4	6.4	79.2	9.5	117	12.7	155
550	22	558.8	—	—	6.4	87.2	9.5	129	12.7	171
600	24	609.6	—	—	6.4	95.2	9.5	141	14.3	210
650	26	660.4	—	—	7.9	127	12.7	203		

Nominal dia. (A)	Nominal dia. (B)	JIS G 3454, G 3455, G 3456, G 3458 (1988) Schedule 40 Thickness (mm)	Schedule 40 Unit mass (kg/m)	Schedule 60 Thickness (mm)	Schedule 60 Unit mass (kg/m)	Schedule 80 Thickness (mm)	Schedule 80 Unit mass (kg/m)	Schedule 100 Thickness (mm)	Schedule 100 Unit mass (kg/m)	Schedule 120 Thickness (mm)	Schedule 120 Unit mass (kg/m)	Schedule 140 Thickness (mm)	Schedule 140 Unit mass (kg/m)	Schedule 160 Thickness (mm)	Schedule 160 Unit mass (kg/m)
6	1/8	1.7	0.369	2.2	0.450	2.4	0.479								
8	1/4	2.2	0.629	2.4	0.675	3.0	0.799								
10	3/8	2.3	0.851	2.8	1.00	3.2	1.11								
15	1/2	2.8	1.31	3.2	1.46	3.7	1.64							4.7	1.97
20	3/4	2.9	1.74	3.4	2.00	3.9	2.24							5.5	2.94
25	1	3.4	2.57	3.9	2.89	4.5	3.27							6.4	4.36
32	1 1/4	3.6	3.47	4.5	4.24	4.9	4.57							6.4	5.73
40	1 1/2	3.7	4.10	4.5	4.89	5.1	5.47							7.1	7.27
50	2	3.9	5.44	4.9	6.72	5.5	7.46							8.7	11.1
65	2 1/2	5.2	9.12	6.0	10.4	7.0	12.0							9.5	15.6
80	3	5.5	11.3	6.6	13.4	7.6	15.3							11.1	21.4
90	3 1/2	5.7	13.5	7.0	16.3	8.1	18.7							12.7	27.8
100	4	6.0	16.0	7.1	18.8	8.6	22.4			11.1	28.2			13.5	33.6
125	5	6.6	21.7	8.1	26.3	9.5	30.5			12.7	39.8			15.9	48.6
150	6	7.1	27.7	9.3	35.8	11.0	41.8			14.3	53.2			18.2	66.0
175	7														
200	8	8.2	42.1	10.3	52.3	12.7	63.8	15.1	74.9	18.2	88.9	20.6	99.4	23.0	110
225	9														
250	10	9.3	59.2	12.7	79.8	15.1	93.9	18.2	112	21.4	130	25.4	152	28.6	168
300	12	10.3	78.3	14.3	107	17.4	129	21.4	157	25.4	184	28.6	204	33.3	234
350	14	11.1	94.3	15.1	127	19.0	158	23.8	195	27.8	225	31.8	254	35.7	282
400	16	12.7	123	16.7	160	21.4	203	26.2	246	30.9	286	36.5	333	40.5	365
450	18	14.3	156	19.0	205	23.8	254	29.4	310	34.9	363	39.7	409	45.2	459
500	20	15.1	184	20.6	248	26.2	311	32.5	381	38.1	441	44.4	503	50.0	565
550	22	15.9	213	22.2	294	28.6	374	34.9	451	41.3	527	47.6	600	54.0	672
600	24	17.5	256	24.6	355	31.0	442	38.9	547	46.0	639	52.4	720	59.5	807
650	26	18.9	299	26.4	413	34.0	525	41.6	635	49.1	740	56.6	84.3	64.2	944

Remark: 1. The designation of the pipe shall be based on the nominal diameter and nominal wall thickness (schedule number: Sch). However for the nominal diameter, either A or B shall be used suffixed to the figures of nominal diameter respectively for identification.

2. The value of mass shall be calculated from the following formula assuming 1 cm^3 of steel to be 7.85g and shall be rounded off to 3 significant digits in accordance with JIS Z 8401.

$$W=0.02466t\ (D-t)$$

where W: unit mass of pipe (kg/m)
t : wall thickness of pipe (mm)
D: outside diameter of pipe

3. Agreement shall be made between the purchaser and the manufacturer when the dimensions not given in the above table are necessary

(3) JIS G 3459 (1997), Dimension and unit mass of stainless steel pipes for piping

Nominal dia.		Outside dia., mm	Nominal thickness																																		
			Schedule 5S					Schedule 10S					Schedule 20S					Schedule 40					Schedule 80					Schedule 120					Schedule 160				
			Thickness, mm	Unit mass kg/m				Thickness, mm	Unit mass kg/m				Thickness, mm	Unit mass kg/m				Thickness, mm	Unit mass, kg/m				Thickness, mm	Unit mass, kg/m				Thickness, mm	Unit mass, kg/m				Thickness, mm	Unit mass, kg/m			
				Type					Type					Type					Type					Type					Type					Type			
A	B			304 304H 304L 321 321H	309 309S 310 310S 316 316H 316L 316Ti 317 317L 347 347H	329JI 329J3L 329J4L	405 409L 444		304 304H 304L 321 321H	309 309S 310 310S 316 316H 316L 316Ti 317 317L 347 347H	329JI 329J3L 329J4L	405 409L 444		304 304H 304L 321 321H	309 309S 310 310S 316 316H 316L 316Ti 317 317L 347 347H	329JI 329J3L 329J4L	405 409L 444		304 304H 304L 321 321H	309 309S 310 310S 316 316H 316L 316Ti 317 317L 347 347H	329JI 329J3L 329J4L	405 409L 444		304 304H 304L 321 321H	309 309S 310 310S 316 316H 316L 316Ti 317 317L 347 347H	329JI 329J3L 329J4L	405 409L 444		304 304H 304L 321 321H	309 309S 310 310S 316 316H 316L 316Ti 317 317L 347 347H	329JI 329J3L 329J4L	405 409L 444		304 304H 304L 321 321H	309 309S 310 310S 316 316H 316L 316Ti 317 317L 347 347H	329JI 329J3L 329J4L	405 409L 444
6	⅛	10.5	1.0	0.237	0.238	0.233	0.231	1.2	0.278	0.280	0.273	0.272	1.5	0.336	0.338	0.331	0.329	1.7	0.373	0.375	0.367	0.364	2.4	0.484	0.487	0.476	0.473	–	–	–	–	–	–	–	–	–	–
8	¼	13.8	1.2	0.377	0.379	0.370	0.368	1.65	0.499	0.503	0.491	0.488	2.0	0.588	0.592	0.578	0.575	2.2	0.636	0.640	0.625	0.621	3.0	0.807	0.812	0.794	0.789	–	–	–	–	–	–	–	–	–	–
10	⅜	17.3	1.2	0.481	0.484	0.473	0.470	1.65	0.643	0.647	0.633	0.629	2.0	0.762	0.767	0.750	0.745	2.3	0.859	0.865	0.845	0.840	3.2	1.12	1.13	1.11	1.10	–	–	–	–	–	–	–	–	–	–
15	½	21.7	1.65	0.824	0.829	0.811	0.806	2.1	1.03	1.03	1.01	1.00	2.5	1.20	1.20	1.18	1.17	2.8	1.32	1.33	1.30	1.29	3.7	1.66	1.67	1.63	1.62	–	–	–	–	–	4.7	1.99	2.00	1.96	1.95
20	¾	27.2	1.65	1.05	1.06	1.03	1.03	2.1	1.31	1.32	1.29	1.28	2.5	1.54	1.55	1.51	1.50	2.9	1.76	1.77	1.73	1.72	3.9	2.26	2.28	2.23	2.21	–	–	–	–	–	5.5	2.97	2.99	2.92	2.91
25	1	34.0	1.65	1.33	1.34	1.31	1.30	2.8	2.18	2.19	2.14	2.13	3.0	2.32	2.33	2.28	2.26	3.4	2.59	2.61	2.55	2.53	4.5	3.31	3.33	3.25	3.23	–	–	–	–	–	6.4	4.40	4.43	4.33	4.30
32	1¼	42.7	1.65	1.69	1.70	1.66	1.65	2.8	2.78	2.80	2.74	2.72	3.0	2.97	2.99	2.92	2.90	3.6	3.51	3.53	3.45	3.43	4.9	4.61	4.64	4.54	4.51	–	–	–	–	–	6.4	5.79	5.82	5.69	5.66
40	1½	48.6	1.65	1.93	1.94	1.90	1.89	2.8	3.19	3.21	3.14	3.12	3.0	3.41	3.43	3.35	3.33	3.7	4.14	4.16	4.07	4.05	5.1	5.53	5.56	5.44	5.40	–	–	–	–	–	7.1	7.34	7.39	7.22	7.17
50	2	60.5	1.65	2.42	2.43	2.38	2.36	2.8	4.02	4.05	3.96	3.93	3.5	4.97	5.00	4.89	4.86	3.9	5.50	5.53	5.41	5.38	5.5	7.54	7.58	7.41	7.37	–	–	–	–	–	8.7	11.2	11.3	11.0	11.0
65	2½	76.3	2.1	3.88	3.91	3.82	3.79	3.0	5.48	5.51	5.39	5.35	3.5	6.35	6.39	6.24	6.20	5.2	9.21	9.27	9.06	9.00	7.0	12.1	12.2	11.9	11.8	–	–	–	–	–	9.5	15.8	15.9	15.5	15.5
80	3	89.1	2.1	4.55	4.58	4.48	4.45	3.0	6.43	6.48	6.33	6.29	4.0	8.48	8.53	8.34	8.29	5.5	11.5	11.5	11.3	11.2	7.6	15.4	15.5	15.2	15.1	–	–	–	–	–	11.1	21.6	21.7	21.2	21.1
90	3½	101.6	2.1	5.20	5.24	5.12	5.09	3.0	7.37	7.42	7.25	7.20	4.0	9.72	9.79	9.56	9.51	5.7	13.6	13.7	13.4	13.3	8.1	18.9	19.0	18.6	18.4	–	–	–	–	–	12.7	28.1	28.3	27.7	27.5
100	4	114.3	2.1	5.87	5.91	5.77	5.74	3.0	8.32	8.37	8.18	8.13	4.0	11.0	11.1	10.8	10.7	6.0	16.2	16.3	15.9	15.8	8.6	22.6	22.8	22.3	22.1	11.1	28.5	28.7	28.1	27.9	13.5	33.9	34.1	33.3	33.1
125	5	139.8	2.8	9.56	9.62	9.40	9.34	3.4	11.6	11.6	11.4	11.3	5.0	16.8	16.9	16.5	16.4	6.6	21.9	22.0	21.5	21.4	9.5	30.8	31.0	30.3	30.1	12.7	40.2	40.5	39.5	39.3	15.9	49.1	49.4	48.3	48.0
150	6	165.2	2.8	11.3	11.4	11.1	11.1	3.4	13.7	13.8	13.5	13.4	5.0	20.0	20.1	19.6	19.5	7.1	28.0	28.1	27.5	27.3	11.0	42.3	42.5	41.6	41.3	14.3	53.8	54.1	52.9	52.5	18.2	66.6	67.1	65.5	65.1
200	8	216.3	2.8	14.9	15.0	14.6	14.6	4.0	21.2	21.3	20.8	20.7	6.5	34.0	34.2	33.4	33.2	8.2	42.5	42.8	41.8	41.6	12.7	64.4	64.8	63.4	63.0	18.2	89.8	90.4	88.3	87.8	23.0	111	111	109	108
250	10	267.4	3.4	22.4	22.5	22.0	21.9	4.0	26.2	26.4	25.8	25.7	6.5	42.2	42.5	41.5	41.3	9.3	59.8	60.2	58.8	58.4	15.1	94.9	95.5	93.3	92.8	21.4	131	132	129	128	28.6	170	171	167	166
300	12	318.5	4.0	31.3	31.5	30.8	30.6	4.5	35.2	35.4	34.6	34.4	6.5	50.5	50.8	49.7	49.4	10.3	79.1	79.6	77.8	77.3	17.4	131	131	128	128	25.4	185	187	182	181	33.3	237	238	233	231
350	14	355.6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	11.1	95.3	95.9	93.7	93.1	19.0	159	160	157	156	27.8	227	228	223	222	35.7	284	286	280	278
400	16	406.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	12.7	125	125	122	122	21.4	205	207	202	201	30.9	289	291	284	283	40.5	369	372	363	361
450	18	457.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	14.3	158	159	155	154	23.8	257	259	253	251	34.9	367	369	361	359	45.2	464	467	456	453
500	20	508.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15.1	185	187	182	181	26.2	314	316	309	307	38.1	446	449	439	436	50.0	570	574	561	558
550	22	558.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15.9	215	216	211	210	28.6	378	380	372	369	41.3	532	536	524	520	54.0	679	683	668	664
600	24	609.6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	17.5	258	260	254	252	31.0	447	450	439	437	46.0	646	650	635	631	59.5	815	821	802	797
650	26	660.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	18.9	302	304	297	295	34.0	531	534	522	519	49.1	748	752	735	731	64.2	953	960	938	932

Remark: 1. The designation of the pipe shall be based on the nominal diameter and nominal wall thickness (schedule number: Sch). However for the nominal diameter, either A or B shall be used suffixed to the figures of nominal diameter respectively for identification."

2. The value of mass shall be calculated from the following formulas (shown in the next page) and shall be rounded off to 3 significant digits in accordance with JIS Z 8401.

3. Agreement shall be made between the purchaser and the manufacturer when the dimensions not given in the above table are necessary.

Symbol of grade	Basic mass$^{(1)}$kg	Formula$^{(2)}$
SUS304TP, SUS304HTP, SUS304LTP, SUS321TP, SUS321HTP	7.93	$W = 0.02491t(D-t)$
SUS309TP, SUS309STP, SUS310TP, SUS310STP, SUS316TP, SUS316HTP, SUS316LTP, SUS316TiTP, SUS317TP, SUS317LTP, SUS347TP, SUS347HTP	7.98	$W = 0.02507t(D-t)$
SUS329JITP, SUS329J3LTP, SUS329J4LTP	7.80	$W = 0.02450t(D-t)$
SUS405TP, SUS409LTP, SUS444TP	7.75	$W = 0.02435t(D-t)$

Note: (1) The basic mass means the mass of stainless steel of 1 mm in thickness and 1 m^2 in area.

(2) W: unit mass of pipe (kg/m)

t: wall thickness of pipe (mm)

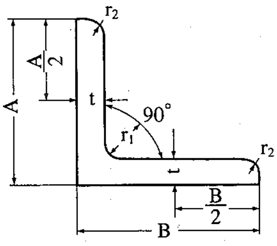
D: outside diameter of pipe (mm)

4-11 Table of Unit Mass of Round Steels and Square Steels

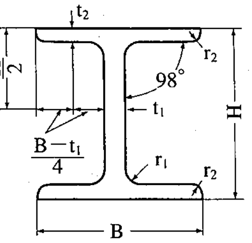
(JIS G 3191－1966)

Diameter or side (mm)	Round steel (kg/m)	Square steel (kg/m)	Diameter or side (mm)	Round steel (kg/m)	Square steel (kg/m)
6	0.222	0.283	46	13.0	16.6
7	0.302	0.385	48	14.2	18.1
8	0.395	0.502	50	15.4	19.6
9	0.499	0.636	52	16.7	21.2
10	0.617	0.785			
11	0.746	0.950	55	18.7	23.7
12	0.888	1.13	56	19.3	24.6
13	1.04	1.33	60	22.2	28.3
14	1.21	1.54	64	25.3	32.2
16	1.58	2.01	65	26.0	33.2
18	2.00	2.54	68	28.5	36.3
19	2.23	2.83	70	30.2	38.5
20	2.47	3.14	75	34.7	44.2
22	2.98	3.80	80	39.5	50.3
24	3.55	4.52	85	44.5	56.7
25	3.85	4.91	90	49.9	63.6
27	4.49	5.72	95	55.6	70.9
28	4.83	6.16	100	61.7	78.5
30	5.55	7.07	110	74.6	95.0
32	6.31	8.04	120	88.8	113
33	6.71	8.55	130	104	133
36	7.99	10.2	140	121	154
38	8.90	11.3	150	139	177
39	9.38	11.9	160	158	201
42	10.9	13.8	180	200	254
45	12.5	15.9	200	247	314

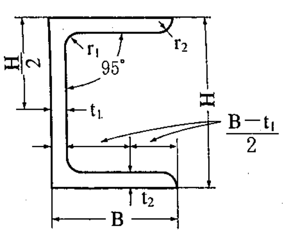
4-12 Table of Unit Mass of Shape Steels (Extracted from JIS G3192-1994)



Standard sectional dimension (mm)				Unit mass	Standard sectional dimension (mm)				Unit mass
A×B	t	r1	r2	(kg/m)	A×B	t	r1	r2	(kg/m)
40×40	3	4.5	2	1.83	90×90	6	10	5	8.28
40×40	5	4.5	3	2.95	90×90	7	10	5	9.59
45×45	4	6.5	3	2.74	90×90	10	10	7	13.3
50×50	4	6.5	3	3.06	90×90	13	10	7	17.0
50×50	6	6.5	4.5	4.43	100×100	7	10	5	10.7
60×60	4	6.5	3	3.68	100×100	10	10	7	14.9
60×60	5	6.5	3	4.55	100×100	13	10	7	19.1
65×65	6	8.5	4	5.91					
65×65	8	8.5	6	7.66					
70×70	6	8.5	4	6.38					
75×75	6	8.5	4	6.85					
75×75	9	8.5	6	9.96					
75×75	12	8.5	6	13.0					
80×80	6	8.5	4	7.32					



Standard sectional dimension (mm)					Unit mass
H×B	t1	t2	r1	r2	(kg/m)
100×75	5	8	7	3.5	12.9
125×75	5.5	9.5	9	4.5	16.1
150×75	5.5	9.5	9	4.5	17.1
150×125	8.5	14	13	6.5	36.2
180×100	6	10	10	5	23.6
200×100	7	10	10	5	26.0
200×150	9	16	15	7.5	50.4
250×125	7.5	12.5	12	6	38.3
250×125	10	19	21	10.5	55.5
300×150	8	13	12	6	48.3
300×150	10	18.5	19	9.5	65.5
300×150	11.5	22	23	11.5	76.8



Standard sectional dimension (mm)					Unit mass
H×B	t1	t2	r1	r2	(kg/m)
75×40	5	7	8	4	6.92
100×50	5	7.5	8	4	9.36
125×65	6	8	8	4	13.4
150×75	6.5	10	10	5	18.6
150×75	9	12.5	15	7.5	24.0
180×75	7	10.5	11	5.5	21.4
200×80	7.5	11	12	6	24.6
200×90	8	13.5	14	7	30.3
250×90	9	13	14	7	34.6
250×90	11	14.5	17	8.5	40.2
300×90	9	13	14	7	38.1
300×90	10	15.5	19	9.5	43.8
300×90	12	16	19	9.5	48.6

4-13 Extracts from Standards of Copper Alloy Plates and Pipes

Standard	Symbol	Old symbol	Chemical composition										Equivalent
			Cu	Pb	Fe	Sn	Zn	Aℓ	As	Mn	Ni	P	ASTM No.
Naval brass plate H 3100 (1992)	C4621P	NBsP1	61~64	≦0.20	≦0.10	0.7~1.5	Remaining	–	–	–	–	–	–
	C4640P	NBsP2	59~62	≦0.20	≦0.10	0.5~1.0							C46400 (B171)
Oxygen-free copper pipe H 3300 (1997)	C1020T	OFCuT	≧99.96	–	–	–	–	–	–	–	–	–	C10200
	C1020TS	OFCuTS											(B75)
Tough pitch copper pipe H 3300 (1997)	C1100T	TCuT1	≧99.90	–	–	–	–	–	–	–	–	–	C11000
	C1100TS	TCuT1S											(B188)
Phosphor deoxidized seamless pipe H 3300 (1997)	C1201T	DCuT1A	≧99.90	–	–	–	–	–	–	–	–	0.004~0.015	C12000
	C1201TS	DCuT1AS											(B75)
	C1220T	DCuT1B	≧99.90	–	–	–	–	–	–	–	–	0.015~0.040	C12200
	C1220TS	DCuT1BS											(B75)
Seamless brass pipe H 3300 (1997)	C2600T	BsT1	68.5~71.5	≦0.05	≦0.05	–	Remaining	–	–	–	–	–	C26000
	C2600TS	BsT1S											(B135)
	C2700T	BsT2	63.0~67.0	≦0.05	≦0.05	–		–	–	–	–	–	C27000
	C2700TS	BsT2S											(B135)
	C2800T	BsT3	59.0~63.0	≦0.01	≦0.01	–		–	–	–	–	–	C28000
	C2800TS	BsT3S											(B135)

Note: As to specify quality of any of the seamless pipes above, it shall have O, OL, 1/2H, or H suffixed after the symbol.

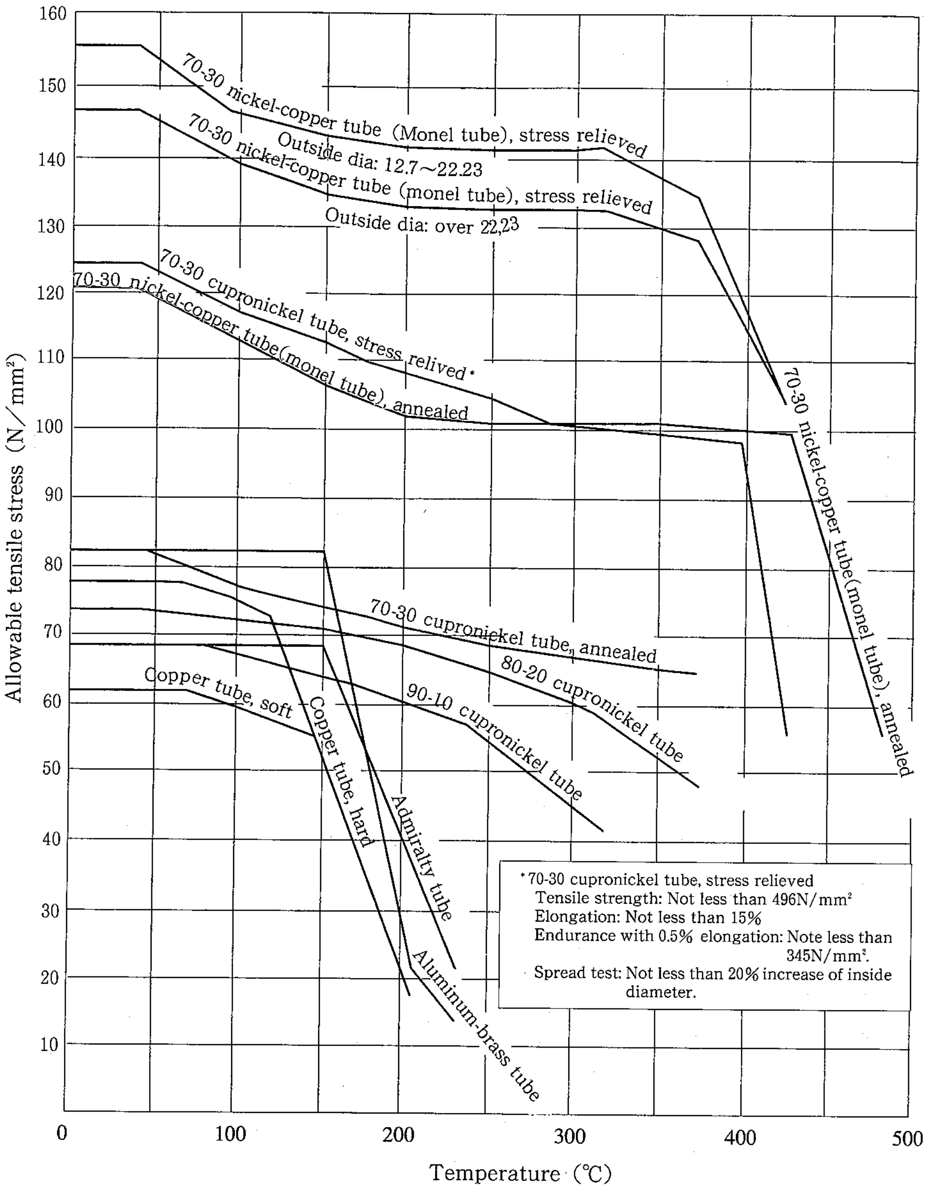
(continued)

Standard	Symbol	Old symbol	Chemical composition										Equivalent
			Cu	Pb	Fe	Sn	Zn	Aℓ	As	Mn	Ni	P	ASTM No.
Seamless brass pipe for condenser H 3300 (1997)	C4430T	BsTF1	70.0~73.0	<0.05	<0.05	0.9~1.2	Remaining	–	0.02~0.06	–	–	–	C44300
	C4430TS	BsTF1S											(B111)
	C6870T	BsTF4	76.0~79.0	〃	〃	–		1.8~2.5	〃	–	–	–	C68700
	C6870TS	BsTF4S											(B111)
	C6871T	BsTF2	76.0~79.0	〃	〃	–		〃	〃	–	–	0.20~0.50	
	C6871TS	BsTF2S											
	C6872T	BsTF3	76.0~79.0	〃	〃	–		〃	〃	<0.20	0.02~1.0	–	
	C6872TS	BsTF3S											
Seamless white copper pipe for condenser H 3300 (1997)	C7060T	CNTF1	≧99.5*	≦0.05	1.0~1.8	–	≦0.50	–	–	0.20~1.0	9.0~11.0	–	C70600
	C7060TS	CNTF1S											(B111)
	C7100T	CNTF2	〃	〃	0.5~1.0	–	〃	–	–	〃	19.0~23.0	–	C71000
	C7100TS	CNTF2S											(B111)
	C7150T	CNTF3	〃	〃	0.4~1.0	–	〃	–	–	〃	29.0~33.0	–	C71500
	C7150TS	CNTF3S											(B111)
Nickel-copper alloy pipe H 4552 (1991)	NCuT※	NCuT	28.0~34.0	–	≦2.5	–	–	–	–	≦2.0	63.0 min	≦0.5 S≦0.024 C≦0.3	UNS4400 (B165)

*(Cu+Ni+Fe+Mn) ※ The quality symbols are O and SR

NOTE: See the NOTE on the preceding page.

4-14 Allowable Tensile Stress of Copper Alloy Pipes (Tubes)

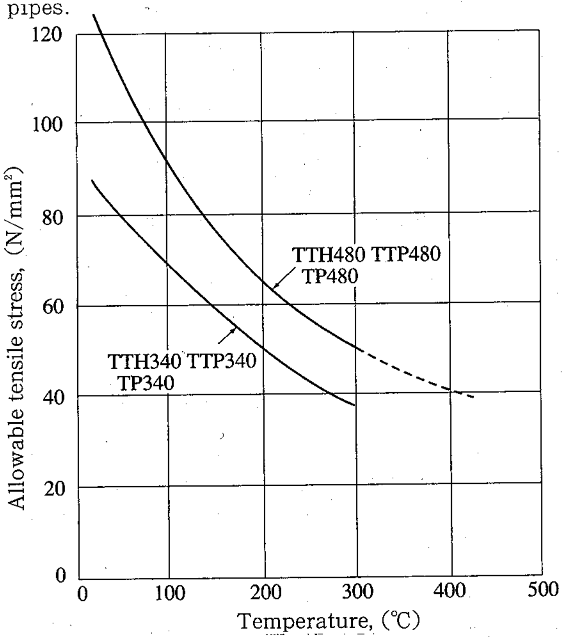


*70-30 cupronickel tube, stress relieved
Tensile strength: Not less than 496N/mm²
Elongation: Not less than 15%
Endurance with 0.5% elongation: Note less than 345N/mm².
Spread test: Not less than 20% increase of inside diameter.

4-15 Abridged Standard of Titanium Tubes, Plates, and Strips

Standard	Symbol	Chemical composition					Tensile strength (N/mm²)	Elongation (%)	Flattening test $H=\frac{(1+e)t}{e+t/D}$	Spreading test
		H	O	N	Fe	Ti				
Titanium tube for heat exchanger JIS H 4631 (1994)	TTH270	≦0.015	≦0.15	≦0.05	≦0.20	Remaining	270~410	≧27	e = 0.07	1.14D
	TTH340	〃	≦0.20	〃	≦0.25	Remaining	340~510	≧23	e = 0.07	〃
	TTH480	〃	≦0.30	≦0.07	≦0.30	Remaining	480~520	≧18	e = 0.06	〃
Titanium tube for piping JIS H 4630 (1994)	TTP270	≦0.015	≦0.15	≦0.05	≦0.20	Remaining	270~410	≧27	e = 0.07	
	TTP340	〃	≦0.20	〃	≦0.25	Remaining	340~510	≧23	e = 0.07	
	TTP480	〃	≦0.30	≦0.07	≦0.30	Remaining	480~520	≧18	e = 0.06	
Titanium tube and strip JIS H 4600 (1993)	TP270	≦0.013	≦0.15	≦0.05	≦0.20	Remaining	270~410	≧27	(Bending) 180°	
	TP340	〃	≦0.20	〃	≦0.25	Remaining	340~510	≧23	(Bending) 〃	
	TP480	〃	≦0.30	≦0.07	≦0.30	Remaining	480~520	≧18	(Bending) 〃	

Each of H4630, TTP28, TTP35 and TTP49 contains 3 types: C denotes seamless cold-drawing pipes, W denotes welded pipes and WC denotes welded cold-drawing pipes.
Each of H4630, TTP270, TTP340 and TTP480 contains 4 types: H denotes seamless hot-extrusion pipes, C denotes seamless cold-drawing pipes, W denotes welded pipes and WC which denotes welded cold-drawing pipes.
Each of H4600, TP340 and TP480 contains 2 types: H denotes hot-rolled pipes and C denotes cold-rolled pipes.



4-16 Properties of Heat Insulating Materials

〔JIS A9504, A9510, A9511(1995), R2611(1992)〕

Material standard No. and name	Type			Density kg/㎥	Max service temperature ℃	Thermal conductivity W/m•k	Others		
A9504 rock wool, heat insulating material	Rock wool	—		Max. 150	650	(Average Temperature 70±5℃) Max. 0.044	(Thickness of fiber, Max. 7μm, Content of particle,Max. 4%.)		
	Heat insulating board	No.1		Max. 100	600	Max. 0.044	—		
		No.2		Max. 160	600	Max. 0.043	—		
		No.3		Max. 300	600	Max. 0.044	—		
	Felt	—		Max. 70	400	Max. 0.049	—		
	Heat insulating cylinder	—		Max. 200	600	Max. 0.044	—		
	Heat insulating belt	No.1		Max. 100	600	Max. 0.052	—		
		No.2		Max. 160	600	Max. 0.049	—		
	Blanket	No.1		Max. 100	600	Max. 0.044	—		
		No.2		Max. 160	600	Max. 0.043	—		
A9504 glass wool, heat insulat-ing material	Glass wool	No.2		—	400	(Average Temperature70±5℃) Max. 0.042			
		No.3		—	400	Max. 0.049			
	Heat insulating board	NO.2	24k	24(±2)	250	Max. 0.049	—		
		NO.2	32k	32(±4)	300	Max. 0.046			
		NO.2	40k	40(+4, −3)	350	Max. 0.044			
		NO.2	48k	48(+4, −3)	350	Max. 0.043			
		NO.2	64k	64(±6)	400	Max. 0.042			
		NO.2	80k	80(±7)	400	Max. 0.042			
		NO.2	96k	96(+9, −8)	400	Max. 0.042			
		NO.2	120k	120(±12)	400	Max. 0.042			
		NO.3	80k	80(±7)	400	Max. 0.047			
		NO.3	96k	96(+9, −8)	400	Max. 0.047			
		NO.3	120k	120(±12)	400	Max. 0.047			
	Blanket	a		Min. 24	350	Max. 0.048			
		b		Min. 40	400	Max. 0.043			
	Heat insulating belt	a		Min. 22	300	Max. 0.052			
		b		Min. 37	350	Max. 0.052			
		c		Min. 58	400	Max. 0.052			
	Heat insulating cylinder	—		Min. 45	350	Max. 0.043			
	Waveform heat insulating board			Min. 37	350	Max. 0.052			
A9510 calcium silicate heat insulat-ing material						(Average Temperature 70±5℃)	Bending strength, N/cm²	Linear shrinkage percentage, %	Water repellent percentage, %
	Heat insulating board No.1-13			Max. 135	1000	Max. 0.049	Min. 20	Max. 2.0 To be free from cracks and warping	Min. 98.0
	Heat insulating cylinder No.1-13			Max. 135	1000	Max. 0.049			
	Heat insulating board No.2-17			Max. 170	650	Max. 0.055			
	Heat insulating cylinder No.2-17			Max. 170	650	Max. 0.055			
	Heat insulating board No.1-22			Max. 220	1000	Max. 0.062	Min. 30		
	Heat insulating cylinder No.1-22			Max. 220	1000	Max. 0.062			
	Heat insulating board No.2-22			Max. 220	650	Max. 0.062			
	Heat insulating cylinder No.2-22			Max. 220	650	Max. 0.062			

(Continued)

Material standard No. and name	Type		Density kg/㎥	Max service temperature ℃	Thermal conductivity W/m•k	Others		
A9511 polystyren form heat insulating material					(Average Temperature 20±5℃)	Bending strength N/cm²	(Reference)Coefficient of moisture perme-ability(PER 25mm thick), ng/m²•S•Pa	Combustibility
	Bead method	Heat insulating plate No,S	Min.27	80	Max. 0.034	Min. 35	185	Flame shall be extinguished within 3 sec-onds, shall not be continued exceeding the combustion limit line without embers.
		Heat insulating board No.1	Min.30	80	Max. 0.036	Min. 45	145	
		Heat insulating board No.2	Min.25	80	Max. 0.037	Min. 30	205	
		Heat insulating board No.3	Min.20	80	Max. 0.040	Min. 22	250	
		Heat insulating cylinder No.1	Min.35	70	Max. 0.036	Min. 30	—	
		Heat insulating cylinder No.2	Min.30	70	Max. 0.036	Min. 25	—	
		Heat insulating cylinder No.3	Min.25	70	Max. 0.037	Min. 20	—	
	Extrusion method	Heat insulating board class 1a	—	80	Max. 0.040	Min. 17	205	
		Heat insulating board class 1b	—	80	Max. 0.040	Min. 20	145	
		Heat insulating board class 2a,b	—	80	Max. 0.034	Min. 20	145	
		Heat insulating board class 3a	—	80	Max. 0.028	Min. 20	145	
		Heat insulating board class 3b	—	80	Max. 0.028	Min. 25	145	
		Heat insulating cylinder class 1	—	70	Max. 0.040	Min. 15	—	
		Heat insulating cylinder class 2	—	70	Max. 0.034	Min. 15	—	
		Heat insulating cylinder class 3	—	70	Max. 0.028	Min. 20	—	
A9510 water-repellent perlite heat insulating material					(Average Temperature 70±5℃)	Bending strength N/cm²	Linear shrinkage percentage, %	Water repellent percentage, %
		Heat insulating board No.3-25	Max.250	900	Max. 0.072	Min. 25	Max. 2.0 No cracks and warping	Min. 98
		Heat insulating board No.4-18	Max.185	650	Max. 0.056	Min. 20		
		Heat insulating cylinder No.3-25	Max.250	900	Max. 0.072	Min. 25		
		Heat insulating cylinder No.4-18	Max.185	650	Max. 0.056	Min. 20		
A9511 hard urethane form heat insulating material					(Average Temperature 20±5℃)	Bending strength N/cm²	(Reference)Coefficient of moisture perme-ability(PER 25mm thick), ng/m²•S•Pa	Combustibility
		Heat insulating board class 1No.1	Min.45	100	Max. 0.024	Min. 35	Min. 145	Burning time shall be within 120 seconds,and the length of combustion part shall be 60mm or under
		Heat insulating boad class 1 No.2	Min.35	100	Max. 0.024	Min. 25	185	
		Heat insulating boad class 1 No.3	Min.25	100	Max. 0.025	Min. 15	225	
		Heat insulating boad class 2 No.1	Min.45	100	Max. 0.023	Min. 35	40	—
		Heat insulating boad class 2 No.2	Min.35	100	Max. 0.023	Min. 25	40	
		Heat insulating boad class 2 No.3	Min.25	100	Max. 0.024	Min. 15	40	
		Heat insulating cylinder class 1 No.1	Min.45	100	Max. 0.024	Min. 35	145	Burning time shall be within 120 seconds, and the length of combustion part shall be 60mm or under
		Heat insulating cylinder class 1 No.2	Min.35	100	Max. 0.024	Min. 25	185	
		Heat insulating cylinder class 1 No.3	Min.25	100	Max. 0.025	Min. 15	225	

(Continued)

Material standard No. and name	Material	Density kg/m³	Max. service temperature ℃	Thermal conductivity W/m•K	Others
R2611 Refractory brick			Temperature, ℃, at which shrinkage is 2% or less while reheated.	(Average Temperature 350±10℃)	Compression strength, N/cm²
	Class A				
	grade 1	Max. 500	900	Max. 0.15	Min. 49
	grade 2	Max. 500	1000	Max. 0.16	Min. 49
	grade 3	Max. 500	1100	Max. 0.17	Min. 49
	grade 4	Max. 550	1200	Max. 0.19	Min. 78.5
	grade 5	Max. 600	1300	Max. 0.20	Min. 78.5
	grade 6	Max. 700	1400	Max. 0.23	Min. 98.1
	grade 7	Max. 750	1500	Max. 0.26	Min. 98.1
	Class B				
	grade 1	Max. 700	900	Max. 0.20	Min. 245.2
	grade 2	Max. 700	1000	Max. 0.21	Min. 245.2
	grade 3	Max. 750	1100	Max. 0.23	Min. 245.2
	grade 4	Max. 800	1200	Max. 0.26	Min. 245.2
	grade 5	Max. 800	1300	Max. 0.27	Min. 245.2
	grade 6	Max. 900	1400	Max. 0.31	Min. 294.2
	grade 7	Max. 1000	1500	Max. 0.36	Min. 294.2
	Class C				
	grade 1	Max. 1100	1300	Max. 0.35	Min. 490.3
	grade 2	Max. 1200	1400	Max. 0.44	Min. 686.5
	grade 3	Max. 1250	1500	Max. 0.52	Min. 980.7

4-17 Types, Properties and Applications of Refractory Materials

(1) Physical classification of refractory materials (by their morphology)

Class	Type		Definition and feature
Formed refractory material	Refractory brick	Calcined	Preformed refractory bricks to be used for structures such as ceramic furnace, etc.
		Non-calcined	
		Electro-forming	
	Refractory insulating brick		A refractory brick of low thermal conductivity
Unformed Refractory material	Refractory mortar	Thermal hardening,	Classified by the difference in pointing materials for refractory bricks and their hardening mechanism
		Atmospheric hardening	
		Hydraulic hardening	
	Castable refractory material		A refractory material having a refractory aggregate and castable cement or chemical bond mixed. It can be formed as refractory structure as being mixed with water before being poured in.
	Plastics refractory material		A refractory material made by adding a plastic material to a refactory aggregate before mixing a proper quantity of water to soil. Chemicals may be added in to harden at a relatively low temperature.
	Spraying material		A hot or cold refractory material to be sprayed onto a surface of structure using a gun.
	Ramming material		A particle refractory material that is strengthened by forming ceramic bond when subjet to heat. Refractory material of relatively poor plasticity and set by ramming.
	Sling material		A refractory material made by projecting using a slinger machine.
	Patching material		A refractory material adjusted to a proper partide size for ease of coating, having properties similar to Refractory mortar.
	Coating material		
	Light-weight castable refractory material		A refractory material made by mixing light-weight porous aggregate with castable cement. It can be formed as refractory structure as being mixed with water before being poured in.
Fibrous material for high temperature service.	Ceramic fiber		An artificial fiber refractory material, which is processed to a shape of blanket, felt or rope.

〔Source: the "Handbook of Refractory Materials," Association of Refractory Technology, 1997.〕

(2) Chemical classification, features, applications and characteristics of major refractory bricks.

Group	Type	Major compound	Features	Examples of application	JIS
Al_2O_3 bricks	Alumina brick	Corundum, β-alumina	①High fire resistance ②High mechanical strength ③High resistance to slags ④High density ⑤Relatively high thermal conductivity	Hot-blast stove, Stopper head, Sleeve Heating furnace cover, Heating furnace, Cement kiln Glass tank furnace, High-temperature calcination furnace	R 2305
	High-alumina brick	Corundum, mullite		Sliding nozzle, Alumimum melting furnace Skid rail Heating furnace floor, Cement kiln, Incinerator	R 2305
SiO_2-Al_2O_3 bricks	Chamotte brick	Mullite, cristobalite	①Wide range of components and charactristics. ②Low thermal expansion coefficient, thermal conductivity, density, and specific heat ③Low high-temperature strength ④Relatively low cost ⑤Low slag permeability ⑥Easy to form complicated shapes	Coke oven, Annealing furnace, Heating furnace Hot-blast stove, Cement kiln, Blast furnace Heating furnace high-temperature section, Soaking pit	R 2304

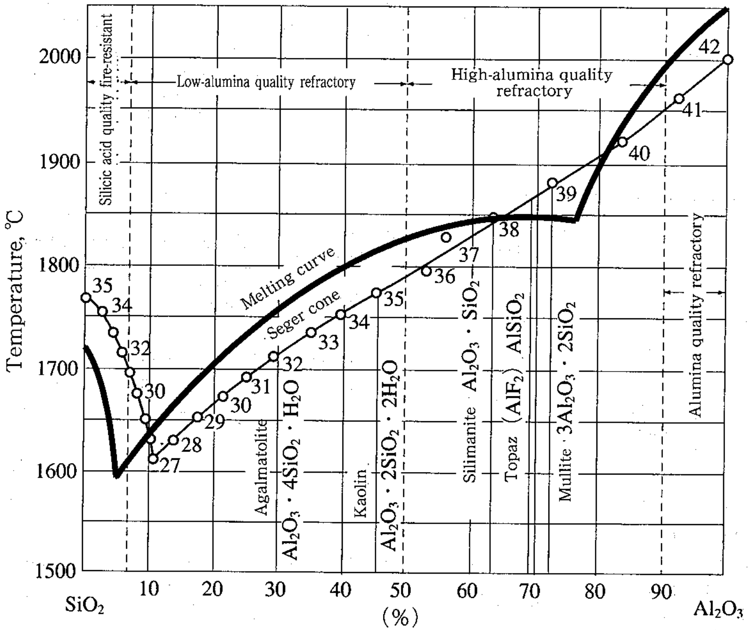
Type	Property			Chemical content, %				Fire resistance SK	Apparent specific gravity	Bulk specific gravity	Apparent porosity %	Compression strengh N/mm²	Hot linear expansion contraction coefficient at 1000℃, %	Remaining linear expansion contraction coefficient at 1500℃ for 2 hours	Load softening point
				Na_2O	Fe_2O_3	Al_2O_3	SiO_2								
Alumina brick	Calcinating				1.0~0.8	Min. 90	Max. 5	38~42	2.7~3.0	2.8~3.7	1.0~2.4	39.2~147	0.6~0.8	0~0.6	1500~1750
	Electroforming			0.1~7.0	0~0.5	93~99	Max. 1	Min. 40	3.0~3.7	2.7~3.7		19.6~294.2	0.65~0.8		Min. 1750
High-alumina brick	Calcinating				0.5~3	45~90	5~51	35~40	2.8~3.5	2.2~2.7	1.2~2.6	19.6~98.1	0.4~0.6	1.2~3.5	1400~1700
	Electroforming				0~2.5	70~80	16~25	Min. 38	3.0~3.4	2.9~3.2		196.1~392.3	0.5~0.6		Min. 1750
Chamotte brick	For structure	Medium	Heat resitance		1.5~2.0	20~30	63~75	26~32	2.5~2.6	1.8~2.1	2.0~3.0	14.7~39.2	0.4~0.7		1250~1400
		High			1.0~3.0	30~41	53~65	32~34	2.55~2.7	1.9~2.2	2.0~2.5	19.6~44.1	0.5~0.6		1350~1500
		Super			1.0~2.0	41~48	48~53	34~35	2.65~2.8	2.1~2.4	1.2~2.0	29.1~78.5	0.5~0.6		1450~1520

〔Source: the "Handbook of Refractory Materials." Association of Refractory *Technology*, 1984.〕

4-18 Seger Cone Numbers and Heat-Resistance Limit Temperatures

SK (℃)		SK (℃)		SK (℃)		SK (℃)		SK (℃)	
022	600	010a	900	3a	1,140	15	1,435	31	1,690
021	650	09a	920	4a	1,160	16	1,460	32	1,710
020	670	08a	940	5a	1,180	17	1,480	33	1,730
019	690	07a	960	6a	1,200	18	1,500	34	1,750
018	710	06a	980	7	1,230	19	1,520	35	1,770
017	730	05a	1,000	8	1,250	20	1,530	36	1,790
016	750	04a	1,020	9	1,280	21~25 not used		37	1,825
015a	790	03a	1,040	10	1,300	26	1,580	38	1,850
014a	815	02a	1,060	11	1,320	27	1,610	39	1,880
013a	835	01a	1,080	12	1,350	28	1,630	40	1,920
012a	855	1a	1,100	13	1,380	29	1,650	41	1,960
011a	880	2a	1,120	14	1,410	30	1,670	42	2,000

4-19 Relationship of Components of Silicic Acid and Alumina Mixture with Melting Temperature



Relationship between contents of SiO_2-Al_2O_3 refractory materials with melting temperature.

The characteristics of actual refractory brick is indicated by the thin curve, although the melting curve in the equilibrium diagram of the SiO_2-Al_2O_3 refractory materials is shown by the thick curve. The figures on the thin curve denote Seger cone numbers.

4-20 Castable and Plastic Refractory Materials

(1) Castable refractory materials

		Argillaceous quality for medium heat	Argillaceous quality for high heat	High-alumina quality	Superhigh-alumina	Chrome-magnesia quality	Fire-resistant, insulation quality	Insulation quality
Kind of aggregate		Chamotte	Chamotte	High-alumina quality Chamotte	Alumina	Chrome iron ore magnesia clinker	Porous Chamotte	Vermiculite and asbestos
Properties	Chemical content, % SiO_2	45~55	40~45	30~40	Max. 10		40~50	
	Al_2O_3	35~45	45~55	55~65	85~95	10~15	40~50	
	Cr_2O_3					20~25		
	Fe_2O_3					9~11		
	MgO					25~30		
	Maximum working temperature, ℃	1,000 ~1,400	1,400 ~1,500	1,500 ~1,600	1,600 ~1,700	1,500 ~1,600	1,200 ~1,400	600 ~1,000
	Hardened, dried bulk specific gravity	1.6~2.0	1.8~2.1	1.9~2.3	2.6~2.8	2.5~2.7	1.0~1.5	0.4~1.0
	Thermal conductivity at 400℃, W/mK	0.47~1.05	0.58~1.05	0.81~1.16	1.86~1.98	2.33~3.49	0.23~0.35	0.12~0.23
Major applications		Kiln		Burner tile, furnace roof	High-temperature parts of high-temperature kiln	Door lining, and fed-out steel path of open-hearth furnace door	Insulation of fire-resistant wall lining, chimney stack, flue, and other low-temperature portions	Lining of fire-resistant wall

(2) Plastic refractory materials

		Argillaceous quality for medium heat	Argillaceous quality for high heat	High-alumina quality	Chrome quality
Kind of aggregate		Chamotte	Chamotte	High-alumina quality Chamotte	Chrome iron ore
Properties	Chemical content, % SiO_2	50~55	40~50	30~40	—
	$A\ell_2O_3$	35~40	40~50	55~65	15~25
	Cr_2O_3	—	—	—	30~40
	Fe_2O_3	—	—	—	13~25
	MgO	—	—	—	10~20
	Fire resistance, SK	32	34	Min. 35	35~36
	Maximum working temperature, ℃	1,300~1,400	1,400~1,500	1,600~1,650	1,500~1,600
	Bulk specific gravity after burning	1.8~2.0	2.0~2.2	2.0~2.2	2.8~3.0
Major applications		Walls, roof, and floor of usual kiln	Boiler, melting furnace, and heating furnace	Combustion chamber, roof, walls, and burner of high-temperature kiln	Protection of stud tube, heating furnace floor, and open-hearth furnace door

〔Source : the "Handbook of Refractory Materials," Association of Refractory Technology, 1984.〕

(3) Characteristics of castable and plastic refractory materials

	Castable refractory materials	Plastic refractory materials
Common characteristics as compared with bricks	(1) Flexible design and firm structure can be made with thin wall and good heat resistant. No joint: There are no penetration of cold air, leakage of hot gas, and destruction of joint. Direct reinforcement: Structure can be strengthened as anchors are leveled. No irregular brick: A desired shape can be made, which is impossible by bricks. Little thermal expansion : No expansion margin is needed in most cases. (2) Suitable for repairing: Economical as only broken portions can be easily repaired. (3) No skilled techniques are needed to install.	
Cautions for storage	A dried place having no moisture absorbed, for six months at most.	Keep in a cold, dark place to prevent from drying up.
Cautions before use	If weathering is suspected, a test piece should be prepared to check the hardness.	Canned materials (other than clays) should be turned upside down for 2 or 3 days to have uniform moisture content
Mixing and kneading	The material should be mixed and kneaded well with pure water. Care should be taken not to add too much water for high strength. Mixing and kneading should be made by hand or a mixer.	No mixing kneading is needed. If the material becomes hard during storage, water should be added before re-kneading. If the hardness is light, it should be sprayed with water before being left for a few days. For a canned material, after opening it should be loosened well before being stamped with a dumper to be rekneaded.
Working on walls and ceiling	The material, like concrete or cement and mortar, should be waterproofed with waterproof paint in order to avoid absorbing moisture in the castable by surrounding bricks. In pouring, it should be tamped well. In vibration pouring, water should be made less, and care should be taken not to make the vibration too long. The material should be usually applied to thickness less than 50 mm with a trowel or spray. A plasterboard net should be firmly fixed on the inside more than a half of the thickness.	The material should be piled while being tamped poked well with an air hammer. A timbering should be used if necessary. The surface should be scratched to rough with a wire brush. The surface also should have groove of around 40 mm deep dented at intervals of around 1 m to collect contraction. A hole around 2/3 of the wall thickness and around 5 mm diameter should be made at intervals of 100 to 150 mm to uniformly dry.
	In any of the materials, care should be taken not to cause the heated surface to have any layer in parallel thereto.	
Curing	The material should be sprayed with water and cured for around 24 hours to keep wet if necessary. After this, it should be left at normal temperature for at least 24 hours. It should not be frozen. Care should be taken to keep it warm even in winter as the hydration heat is high.	No curing is needed. The material having a water-soluble additive should be heated to dry as soon as possible after application. Should it be left for a long time, it should have plastic film or the like covered on it to prevent drying.
Heating	In particular, the material should be gradually heated to around 300℃. After it is heated once, it can endure against quick heating and cooling.	The material should be heated as slow as possible (at around 30℃/h), particularly around 200℃ or 800℃ for the one containing clay.

〔Source: the "Handbook of Refractory Materials," Association of Refractory Technology, 1984〕

4-21 Ceramic Fibers and Sintered Ceramics

(1) Characteristics and application of ceramic fibers

		Process method	Content, %	Diameter of fiber, µ	Melting point (soffening point), ℃	Working temperature, ℃	Application
Vitreous fibers	High-silicic acid fiber	Eluting method	SiO_2	0.1~13	1660	1100	• Corrosion-resistant, insulating filter catalyst carrier for nuclear power plants and chemical plants • Insulating materials for aircraft and spacecraft equipments
	Ceramic fiber	Melting method	$A\ell_2O_3$: 37~43 SiO_2 : 51~60	1 ~ 5	1700	870 ~1100	• Insulating materials for low temperature fiber lining backup materials for ceramic furnaces and electric furnaces. etc.)
			$A\ell_2O_3$: 49~52 SiO_2 : 48~51		1750	1300	Insulating materials for usual high temperature (electric furnaces, diffusion furnaces, etc.) • Heat insulation lining for roof and walls of kiln (annealing furnaces, slow cooling furnaces, heat treating furnaces, continuous heating furnaces and non-metal dissolving furnaces)" • Heat insulation backup for roof and walls of ceramic furnaces (petroleum refining furnaces and hot-blast furnaces) • Filling for furnace • Sound absorbing materials around a burner
			$A\ell_2O_3$: 57~64 SiO_2 : 36~43		1815~1930	1400	
			SiO_2 $A\ell_2O_3$ Cr_2O_3		1760	1400	
Polycrystal fibers	Alumina fiber	Dissolving method	$A\ell_2O_3$: 94~98 SiO_2 : 2~6	2 ~ 4	2000	1500 ~1700	• Ultra-high temperature heat insulation materials. Ceramic burning furnaces (1300℃ to 1700℃) Carbon burning furnaces (1400℃ to 1550℃) Ultra-high temperature small size electric furnaces (1700℃) Non-metal dissolving furnac(1400℃ to 1600℃) • Burner block
	Mulite fiber		$A\ell_2O_3$: 72~80 SiO_2 : 20~28	2 ~ 8	1850~2000	1600	

〔Source : Toshihiro Minaki, "Kogyo-Zairyo," Vol.31, No.8, 1983〕

(2) Type and application of ceramic fiber products

Products	Morphology of products	Main application
Bulk	Fabricated with short fibers gathered and become cottony	Filling for heat insulation of furnace wall, materials for reinforcement material following product
Blanket	"Fabricated to the blanket shape (laminated fiber mats), containing no binder"	Heat insulation material for the furnace roof and wall, filter materials, fire prevention materials for construction, sound-absorbing materials
Felt	Fabricated by processing bulk with the organic binder of very small quantity and fabricated in the shape of a board	Backup insulation for the furnace roof and wall
Board	"Fabricated by processing bulk with inorganic or the organic binder, and fabricated in the shape of a board"	Lining materials for heat insulation of the furnace wall, gas seal materials
Wet felt	"Fabricated with organic binder is impregnated to blankets, keeping moist in a polyethylene bag"	Lining of the furnace (on parts which need high velocity wind resistance or wear resistance) and others
Paper	Fabricated by adding the binder to bulk and made into the shape of paper	Gasket materials for a warm water boiler and a gas heater, and others
Fiber products	"Fabricated by adding the reinforcement fiber to bulk, made yarn, and processed the shape of crossing or a rope, etc."	Covers of thermocouple read wire, heat insulation curtain and others
Molding products	"Fabricated by adding the binder to bulk, containing various form"	Insulation materials for combustion apparatus, tap entrance of an aluminum melting furnace, high temperature pipe covers and others
Block (module)	Fabricated with bulk or the blanket in the shape of a block	Lining material for heat insulation for furnace roof and wall
Non-shape products	"Fabricated by mixing bulk, aggregate, and the binde	Filler materials, surface coating, adhesion materials and others

〔Source: Energy-saving Center Industrial Furnace Handbook edited by Japan Industrial Furnace Association, 1997〕

(3) Characteristics and application of sintered ceramics

		Specific gravity	Bending strength (N/mm²)		Linear expansion coefficient, 10^{-6}/°C	Fracture toughness ($MN\cdot m^{-3/2}$)	Hv hardness	Thermal conductivity W/m•K	Application
			Room temperature	1200°C					
Oxides	Al_2O_3 Alumina	3.99	390	295	8.0	4.0	1400	17.4	Widely used in wear-resistant parts for pulverized coal feeding pipe and burner parts as cheap ceramics.
	ZrO_2 Zirconia	6.00	1,180	200	9.2	10.0	1200	3.3	Used in parts of coal feeding system as strong to mechanical shocks : coal shoot, bend pipe, etc.
Non-oxides	Si_3N_4 Silicon nitride	3.25	980	785	3.0	7.0	1500	29.1	Used for engine parts as well as wear-resistant parts as highly strong and highly tough materials: burner nozzle, gas turbine moving blade, etc.
	SiC Silicon carbide	3.10	590	540	4.3	4.5	2300	58.2	Used under severe wearing condition and in high-temperature environment as highly hard and highly heat-resistant material: CWM burner tip, gas turbine stator blade, etc.

4-22 Lubricants and Control Oils

(1) **Turbine oil** (JIS K 2213−1983)

(a) **Class 1** (without additive)

Type Item		ISO VG 32	ISO VG 46	ISO VG 68	JIS testing method
Kinematic viscosity mm²/s	(40°C)	Min. 28.8 Max. 35.2	Min. 41.4 Max. 50.6	Min. 61.2 Max. 74.8	K2283
	(100°C)	Min. 4.2	Min. 5.0	Min. 7.0	
Flash point	°C	Min. 180	Min. 185	Min. 190	K2265
Pour point	°C	Max. −7.5	Max. −5		K2269
Total acid number mgKOH/g		Max. 0.1			K2501
Thermal stability (170°C, 12h)		No deposition			K2540
Copper plate corrosion (100°C, 3h)		Max. 1			K2513
Resistance to emulsification(1) (54°C)		Max. 30min.			K2520

Note: (1) The resistance to emulsification is a time when the emulsifier amounts 3 ml.

(b) **Class 2** (with additive)

Type Item		ISO VG 32	ISO VG 46	ISO VG 68	JIS testing method
Kinematic viscosity mm²/s	(40°C)	Min. 28.8 Max. 35.2	Min. 41.4 Max. 50.6	Min. 61.2 Max. 74.8	K2283
Viscosity index		Min. 95			K2283
Flash point	°C	Min. 190	Min. 200		K2265
Pour point	°C	Max. −10	Max. −7.5		K2269
Total acid number mgKOH/g		Max. 0.3			K2501
Rust preventive performance(2) (24h)		No rust			K2510
Oxidation stability mgKOH/g(3) (Total acid number in 1000h)		Max. 1.0			K2514
Copper plate corrosion (100°C, 3h)		Max. 1			K2513
Resistance to emulsification(1) (54°C)		Max. 30min.			K2520

Note: (2) The rust preventive performance shall be tested with use of distilled water for ISO VG32 and ISO VG46 or seawater for ISO VG68.

(3) For testing the oxidation stability, the two parties, order person and manufacturer, shall be agreed there between.

(2) **Lubricant for internal-combustion engine** (JIS K 2215－1993)

Item \ Type		For land internal-combustion engine		For marine internal-combustion engine							JIS testing method
		Class 3		Class 2		Class 3		Class 4			
		No.3	No.4	No.3	No.4	No.3	No.4	No.3	No.4	No.5	
Flash point ℃		Min. 190	Min. 195	Min. 200		Min. 200		Min. 200			K2265
Kinematic viscosity (100℃), mm²/s		Min. 9.3 Max. 12.5	Min. 12.5 Max. 16.3	Min. 9.3 Max. 12.5	Min. 12.5 Max. 16.3	Min. 9.3 Max. 12.5	Min. 12.5 Max. 16.3	Min. 9.3 Max. 12.5	Min. 12.5 Max. 16.3	Min. 16.3 Max. 21.9	K2283
Viscosity index		Min. 85		Min. 70		Min. 85		Min. 50			K2283
Pour point ℃		Max. －10	Max. －7.5	Max. －7.5	Max. －5	Max. －7.5	Max. －5	Max. －7.5	Max. －5		K2269
Oxidation stability (165.5℃, 24h)	Viscosity ratio	——		Max. 2.0		——		——			K2514
	Increse of total acid number mgKOH/g	——		Max. 3.0		——		——			
Resistance to emulsification sec		——		Record		——		——			K2520
Total base number mgKOH/g		——		——		Min. 3		Min. 25			K2501
Sulfuric acid ash content %		——		——		Record		Record			K2272
Engine test (1)		Record		——		——		——			——

Note: (1) The class 3 lubricant for the land internal-combustion engine can be used in various applications. As for the engine test, testing method, acceptance criterion and other details depending on a specific application, they shall be agreed between the two parties, orderer and manufacturer.

Remark: The use classification of the lubricants for internal-combustion engines is as follows.

Lubricants for land internal-combustion engine

Class 3: Oils having an antioxidant and cleaning agent added thereto that are used in a diesel engine and a gasoline engine which is chiefly used for high load.

Lubricants for marine internal-combustion engine

Class 2: For use as system oil, having antioxidation characteristics improved.

Class 3: For use as cylinder oil and system oil, having antioxidation and cleaning characteristics improved.

Class 4: For principal use as cylinder oil, having antioxidation characteristics given and cleaning chracteristics improved sharply.

(3) **Industrial gear oils** (JIS K 2219－1993)

Type \ Item		Kinematic viscosity (40℃) mm²/s	Viscosity index	Flash point ℃	Pour point ℃	Copper plate corrosion 100℃ 3h	Rust preventive performance (distilled water or 24h)	Resistance to[1] emulsification (82℃)	Load resistance (Tongen method) kg
Class 1	ISO VG100 ISO VG150	90.0or over, up to and including110 135 〃 165	Min. 90	Min. 200	Max. －5	Max. 1	No rust	Max. 60min.	
Class 2	ISO VG150 ISO VG220	135 〃 165 198 〃 242	Min. 90	Min. 200	Max. －15 Max. －10	Max. 1	No rust	Max. 60min.	Not specified
JIS testing method		K2283	K2283	K2265	K2269	K2513	K2510	K2520	—

Note: (1) The resistance to emulsification is a time when the emulsifier amounts 3 ml.

Remark: The use classification of the gear oils are as follows

Class 1: Used for relatively light load, enclosed gears chiefly used in general machines.

Class 2: Used for intermediate and high load, enclosed gears chiefly used in general machines, such as a rolling mill.

(4) **Greases** (JIS K 2220－1993)

Item \ Type	For roller bearing Class 1 No.2
Admixture penetration	265～295
Dropping point, ℃	Min. 175
Copper plate corrosion at 100℃ in 24h	Copper plate shall have no green or black change.
Evaporation, at 99℃ in 22h%	Max. 2.0
Oil separation, %, at 100℃ in 24h	Max. 5
Oxidation stability, MPa, at 99 ℃ in 100h	Max. 0.069
Admixture stability	Max. 375

Item \ Type		For roller bearing Class 1 No.2
Impurity pcs/cm³	Min. 10 μm	Max. 5000
	Min. 25 μm	Max. 3000
	Min. 75 μm	Max. 500
	Min. 125 μm	0
Water-washing resistance, %, at 38℃in 1h		max. 10
Low-temperature torque, N•m, at－20℃	Starting torque	Max. 0.59
	Revolving torque	Max. 0.29
Humidity in 14 days		Class A

Remark: The kinematic viscosity of raw mineral oil and the kind of penetration increasing agent must be entered in a test report as needed.

Note: (1) As applicable temperature range of class 1 grease for roller bearing is －20℃ to 100℃

(2) Testing for each item shall be made in accordance with JIS K 2220.

(5) **Properties of electrically hydraulic control oils**(1) (example)

Item	Property
Color	Transparent, light yellow
Specific gravity	20℃/20℃, 1.125～1.165
Kinematic viscosity	Approx. 44 mm²/s(2) at 40℃ Approx. 5 mm²/s, 100℃
Pour point	Approx. －22℃
Total base number	0.02～0.05mgKOH/g

Item	Property
Boiling point	Approx. 350℃
Flash point	Approx. 260℃
Ignition point	Approx. 638℃
Moisture content	0.03～0.05mg/g (mass)
Volume resistivity	Approx. 10×10⁹ Ω/cm

Note: (1) The electrically hydraulic speed control methods for steam turbine includes a low-pressure type of hydraulic pressure 〔Max. 1.96Mpa (gage)〕 and a high-pressure type of hydraulic pressure 〔Min. 11.77Mpa (gage)〕. In most cases, the low-pressure type uses a turbine oil for control oil.
The high-pressure type uses an incombustible oil. The control oils are available on the market with various trademarks.

(2) See section 10-11, "Viscosity of Fuel Oil mixed."

4-23 Electric Insulation Oil, Class 1 (JISK2320－1993)

Item \ Type		No.1	No.2	No.3	No.4
Major component		Mineral oil			
Specific gravity at 15/4℃		Max. 0.91			
Kinematic viscosity, mm²/s	40℃	Max. 13			
	75℃	Max. 6			
Pour point ℃		Max. －27.5		Max. －15	Max. －27.5
Flash point, ℃, (enclosed type)		Min. 130			
Evaporation, %, at 98℃ for 5h		Max. 0.4			
Specific dispersion at 25℃		Min. 110	－	－	－
Reaction		Neutral			
Total acid number		Max. 0.02			
Corrosive sulfur		Non-corrosive			
Oxidation stability at 120℃ in 75h	Sludge	－	Max. 0.4		
	Total acid number, mgKOH/g	－	Max. 0.6		
Moisture, ppm		－	－	－	Max. 30(3) Max. 40(4)
Insulation breakdown voltage, kV (2.5mm)		Min. 40	Min. 30		Min. 40
Dielectric tangent, %, at 50 or 60 Hz at 80℃		Max. 0.1	－	－	Max. 0.1
Volume resistivity, Ω•cm, at 80℃		Min. 5×10^{13}	Min. 1×10^{13}	－	Min. 5×10^{13}

Remark: (1) Insulating oils containing no additive are specified, being classified to four kinds :

No.1: Chiefly used for oil－immersed capacitors, oil－immersed cables, etc.

No.2: Chiefly used for oil－immersed transformers, oil－immersed circuit breakers, etc.

No.3: Chiefly used for oil－immersed transformers, oil－immersed circuit breakers used in places other than severe cold ones.

No.4: Chiefly used for high－voltage, high-capacity, oil－immersed transformers.

(2) Testing for each item shall be made in accordance with JIS C 2101.

(3) For tank－cars.

(4) For drums.

5-1 Dimensions of Standard Sieves (JIS Z 8801-1994)

Sieve of metal wire cloth － Size of aperture and diameter of metal wire

Units in mm

Nominal size	Aperture size			Wire diameter	
	Reference size	Tolerance		Reference size	Tolerance (±)
		Mean (±)	Max (＋)		
125	125	2.5	3.8	8.00	1.1
106	106	2.1	3.2	6.30	0.9
90	90.0	1.8	2.7	6.30	0.9
75	75.0	1.5	2.3	6.30	0.9
63	63.0	1.3	1.9	5.60	0.8
53	53.0	1.1	1.6	5.00	0.7
45	45.0	0.9	1.3	4.50	0.6
37.5	37.5	0.8	1.3	4.50	0.6
31.5	31.5	0.6	1.3	4.00	0.5
26.5	26.5	0.6	1.1	3.55	0.40
22.4	22.4	0.55	0.90	3.55	0.40
19	19.0	0.47	0.86	3.15	0.30
16	16.0	0.40	0.80	3.15	0.30
13.2	13.2	0.33	0.70	2.80	0.20
11.2	11.2	0.28	0.56	2.50	0.15
9.5	9.50	0.23	0.47	2.24	0.15
8	8.00	0.20	0.44	2.00	0.10
6.7	6.70	0.16	0.43	1.80	0.070
5.6	5.60	0.14	0.42	1.60	0.040
4.75	4.75	0.118	0.41	1.60	0.040
4	4.00	0.100	0.37	1.40	0.040
3.35	3.35	0.100	0.32	1.25	0.030
2.8	2.80	0.084	0.28	1.12	0.030
2.36	2.36	0.070	0.24	1.00	0.030
2	2.00	0.060	0.20	0.90	0.030
1.7	1.70	0.051	0.17	0.80	0.025
1.4	1.40	0.042	0.14	0.71	0.025
1.18	1.18	0.035	0.14	0.63	0.025
1	1.00	0.030	0.14	0.56	0.025

5-2 Comparison of Various Types of Flowmeters

Methods of flow measurement		Related standards	Applicable pipe sizes	Precision	Application and Characteristics	Remark
Pressure differential type flowmeters	Orifice	JIS Z 8762	15~1500㎜	2%	Very general	Measurement of the flow rate by detecting the pressure difference between the front and the back of the restriction by applying Bernoulli's Theorem
	Nozzle				Suitable for the flow of high temperature and high speed	
	Venturi tube				Effective when lowering the pressure loss is needed	
Variable area flowmeters		JIS Z 8761	3~150㎜	1~2%	Suitable for small flow rate Straight length is unnecessary	Measurement of the flow rate by detecting the movement of the float in the vertical tube with conical bore according to the velocity of fluid
Positive displacement flowmeters			25~250㎜	0.2~0.5% of rate	For high precision uses Troublesome maitenance Improper for the fluids containing foreign matters	Measurement of the flow rate by counting the speed of rotation of gear mechanism that is proportional to the number of repetitive actions of filling and discharge of fluid
Turbine flowmeters		JIS Z 8765	6~600㎜	0.2~0.5% of rate	For high precision uses Improper for the fluids containing foreign matters	Measurement of the rotating speed of the rotor set in the liquid pass
Electromagnetic flowmeters		JIS Z 7554	2.5~2600㎜	0.5% of rate	Flow shall be conductive liquid. No pressure loss The fluid in the pipeline shall be running full"	Application of Faraday's Law
Ultrasonic flowmeters		JEMIS 032	150~3000㎜	1.5%	Low pressure loss Out of contact with measured material Easy to install on the existing pipe Turbidity is less than 5g/m³	Measurement of the flow rate by detecting the changes of sound speed influenced by the flow velocity, by radiating the ultrasonic into the fluid stream
Vortex flowmeters		JEMIS 028	15~200㎜	±1% of rate	Low pressure loss	Use of the vortices generated with a frequency proportional to the velocity of the fluid at downstream of a vortex generator
Weir flowmeters		JIS B 8302	Applicable width of weir is not less than 500mm.	About 3~4%	For open channel	Measurement of the change of head of the weir by level meter
Parshall flume type flowmeters		JIS B 7553	Sizes of throat parts are 2B~60B	About 3~4%	For open channel Pressure loss is extremely low compared to weir type	Measurement of the change of water level at the throat of parshall flume by level meter
P • B flume type flowmeters			250~1200㎜	About 3%	For cylindrical open channel	Measurement of the change of water level at the throat of P•B flume by level meter

※ The value "of rate" is the precision of the reading, and the value without "of rate" is the precision of the maximum value of the flowmeter.

5-3 Measurement of Fluid Flow by means of Pressure Differential Devices (JIS Z 8762-1995)

(1) Calculation of Flow Rate

$$q_m = \alpha\varepsilon\frac{\pi}{4}d^2\sqrt{2\triangle p\rho_1}$$

q_m : Mass flow rate (kg/s)

α : Flow coefficient [$= C\frac{1}{\sqrt{1-\beta^4}}$ where, C : Coefficient of discharge,

$\frac{1}{\sqrt{1-\beta^4}}$: Approach velocity factor]

ε : Expansion factor of gas

d : Diameter of orifice (m)

$\triangle p$: Differential pressure (Pa)

ρ_1 : Density of the fluid at inlet $(\mathrm{kg/m^3})$

(2) Shape of Orifice Plate

A : Upstream face

B : Downstream face

G : Upstream edge

H : Downstream edge

d : Diameter of orifice

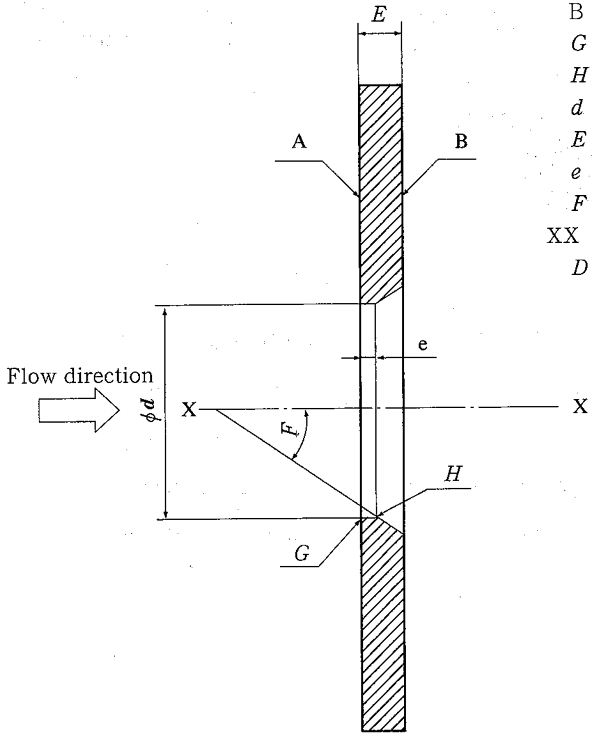
E : Thickness of orifice plate

e : Thickness of the orifice

F : Angle of bevel

XX : Axial center-line

D : Upstream internal pipe diameter



$$G < 0.0004d$$

$$0.005D \leqq e \leqq 0.02D$$

$$e \leqq E \leqq 0.05D$$

$$F = 45^\circ \pm 15^\circ$$

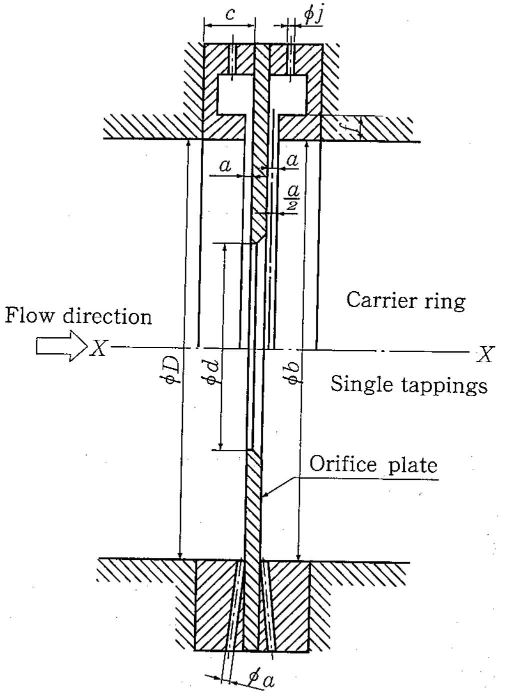
$$d \geqq 12.5mm$$

$$0.2 \leqq \beta \leqq 0.75$$

$$(\beta = d/D)$$

(3) Pressure Tappings for Orifice Plates

(a) Orifice Plate with Corner Tappings



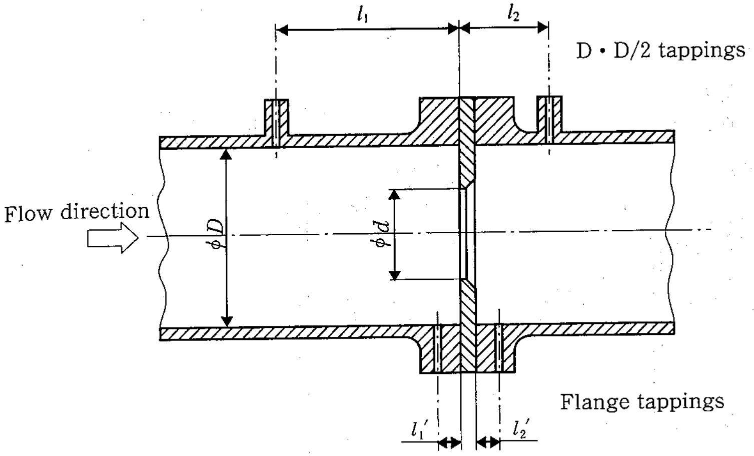
D : Internal pipe diameter
a : Width of the annular slot or diameter of single tapping
f : Thickness of the slot
j : Diameter of pressure tappings
d : Diameter of orifice
XX : Axial center-line
b : Diameter of the carrier ring
c : Length of the upstream ring

$4\text{mm} \leqq j \leqq 10\text{mm}$

For clean fluids and vapors: for $\beta \leqq 0.65$ $(\beta = d/D)$	$0.005D \leqq a \leqq 0.03D$
For clean fluids and vapors: for $\beta > 0.65$	$0.01D \leqq a \leqq 0.02D$
For clean fluids	$1\text{mm} \leqq a \leqq 10\text{mm}$
For vapors, in case of annular chambers	$1\text{mm} \leqq a \leqq 10\text{mm}$
For vapors and for liquefied gases, in case of single tappings	$4\text{mm} \leqq a \leqq 10\text{mm}$

$f \geqq 2a$

(b) Pressure Tappings for D・D/2 Tap Orifice Plate and Flange Tap Orifice Plate



(i) D・D/2 tappings :

Spacing of the upstream pressure tapping (l_1) shall be $1D \pm 0.1D$.

Spacing of the downstream pressure tapping (l_2) shall be as follows.

For $\beta \leqq 0.6$ $0.5D \pm 0.02D$
For $\beta > 0.6$ $0.5D \pm 0.01D$

l_1, l_2 spacings are measured from the upstream face of the orifice plate.

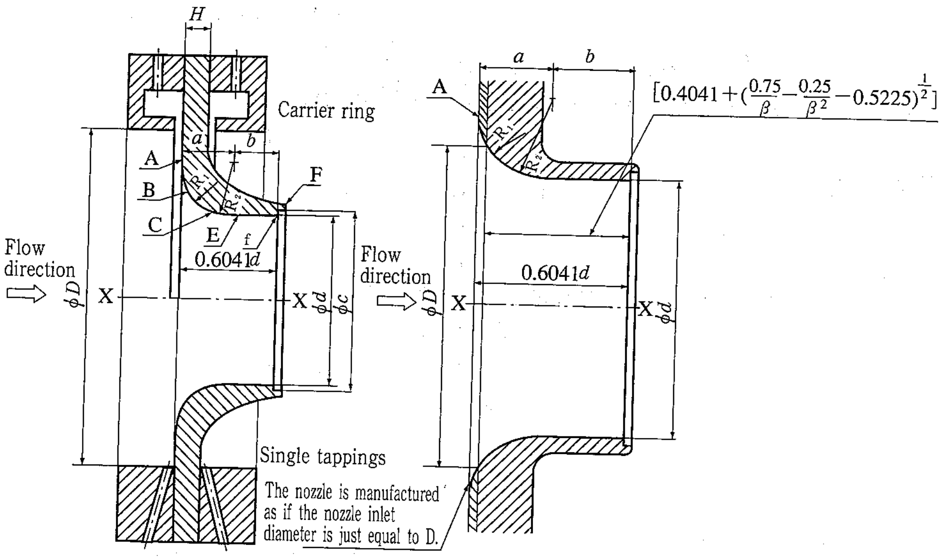
(ii) Flange tappings: spacing of the upstream pressure tapping (l_1) and spacing of the downstream pressure tapping (l_2') shall be as follows.

For $\beta \leqq 0.6$: $25.4 \pm 1\text{mm}$
For $\beta > 0.6$, $50\text{mm} \leqq D \leqq 58\text{mm}$: $25.4 \pm 1\text{mm}$
For $\beta > 0.6$, $58\text{mm} < D < 150\text{mm}$: $25.4 \pm 0.5\text{mm}$
For $\beta > 0.6$, $150\text{mm} \leqq D \leqq 1000\text{mm}$: $25.4 \pm 1\text{mm}$

The spacing l_1' is measured from the upstream face of the orifice plate, and the spacing l_2' is measured from the downstream face of the orifice plate.

(4) Shape of ISA 1932 Nozzle

(i) For $\beta \leqq \frac{2}{3}$ ($\beta = d/D$)   (ii) For $\beta > \frac{2}{3}$



$$a = \frac{12+\sqrt{39}}{60}d \fallingdotseq 0.304d$$

$$b = 0.3d$$

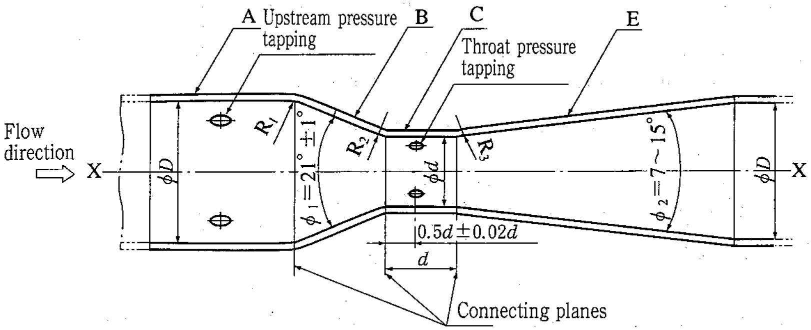
$$c \geqq 1.06d$$

Distance between the upstream tapping and downstream tapping shall be as follows.

For $\beta > 0.67$, not longer than $0.2D$

For $\beta \leqq 0.67$, not longer than $0.15D$

(5) Shape of Cone Venturi Tubes (Long Tube Type)



A : Entrance cylinder
B : Conical convergent section
C : Cylindrical throat
E : Conical divergent section
D : Internal diameter
d : Diameter of throat
XX : Axial center-line of venturi tube

5-4 Installation Requirements of Orifice Plates (JIS Z 8762-1995)

(1) General Requirements for Measurement

(a) The fluid shall be such that it can be considered as being physically and thermally homogeneous and single phase when passing through the pressure differential device.

(b) The rate of flow shall be constant.

(c) During measurement, the fluid in the pipeline and in the primary device shall be running full.

(d) If the fluid is a gas, the pressure ratio of the absolute pressure at the downstream pressure tapping to the absolute pressure at the upstream pressure tapping shall be greater than or equal to 0.75.

(e) Upstream internal pipe diameter D used for the calculation of diameter ratio shall be the mean value of the diameters between the upstream pressure tapping and the place at distance $0.5D$ from the upstream pressure tapping. The mean value is calculated to measure four diameters at three-cross sections at least. Two cross-sections shall be the cross-section at the upstream pressure tapping and the cross-section at the place of distance $0.5D$ from the pressure tapping. For orifice plate, D is the mean value of the diameters between the upstream face and the place at distance $0.5D$ from the face.

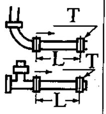
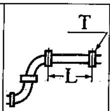
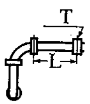
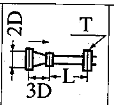
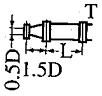
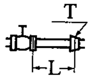
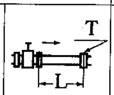
(f) The pipe bore adjacent to the primary device (the carrier ring, if the carrier ring is provided) shall be circular over the entire length of $2D$, at least. If the difference between any measured diameter and the mean value of diameters measured by (e) is less than 0.3%, the pipe bore is seemed to be circular.

(g) Over the entire length of $2D$ from the upstream face of the primary device, the downstream internal pipe diameter shall not differ 3% or more from the mean value of the upstream internal pipe diameter.

(2) Straight Lengths

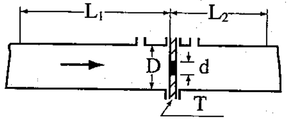
The straight lengths upstream and downstream of the primary devices shall be given in the next table.

Required minimum straight lengths (multiples of *D*) between various fittings located upstream or downstream of the primary device and the primary device itself.

	Upstream side of the primary device							Downstream side of the primary device
Diameter ratio β (d/D)	 Single 90° bend or one tee (flow from one branch only)	 2 or more 90° bends in the same plane	 2 or more 90° bends in different planes	 Reducer 2D to D over a length of 1.5 D to 3D	 Expander 0.5D to D over a length of D to 2D	 Globe valve fully open	 Full bore ball or gate valve fully open	All fittings shown at left
≦0.20	10(6)	14(7)	34(17)	5	16(8)	18(9)	12(6)	4(2)
0.25	10(6)	14(7)	34(17)	5	16(8)	18(9)	12(6)	4(2)
0.30	10(6)	16(8)	34(17)	5	16(8)	18(9)	12(6)	5(2.5)
0.35	12(6)	16(8)	36(18)	5	16(8)	18(9)	12(6)	5(2.5)
0.40	14(7)	18(9)	36(18)	5	16(8)	20(10)	12(6)	6(3)
0.45	14(7)	18(9)	38(19)	5	17(9)	20(10)	12(6)	6(3)
0.50	14(7)	20(10)	40(20)	6(5)	18(9)	22(11)	12(6)	6(3)
0.55	16(8)	22(11)	44(22)	8(5)	20(10)	24(12)	14(7)	6(3)
0.60	18(9)	26(13)	48(24)	9(5)	22(11)	26(13)	14(7)	7(3.5)
0.65	22(11)	32(16)	54(27)	11(6)	25(13)	28(14)	16(8)	7(3.5)
0.70	28(14)	36(18)	62(31)	14(7)	30(15)	32(16)	20(10)	7(3.5)
0.75	36(18)	42(21)	70(35)	22(11)	38(19)	36(18)	24(12)	8(4)
0.80	46(23)	50(25)	80(40)	30(15)	54(27)	44(22)	30(15)	8(4)

Other fittings	Required minimum upstream straight lengths	Downstream side of the primary device
Abrupt symmetrical reduction having a diameter ratio ≧0.5	30 (15)	
Thermometer pocket or well of diameter ≦0.03 *D*	5 (3)	>5 *D*
Thermometer pocket or well of diameter between 0.03 *D* and 0.13 *D*	20 (10)	>5 *D*

Remark: (1) All straight lengths in this table are measured from the upstream face of the primary device shown in this drawing, and are expressed as multiple of *D* .



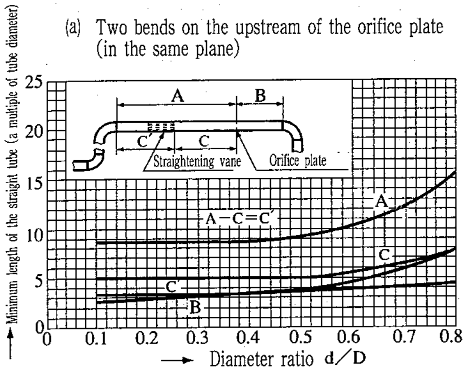
L_1 = Upstream straight length
L_2 = Downstream straight length
T = Primary device

(2) Values without parentheses are "zero additional uncertainty" values.

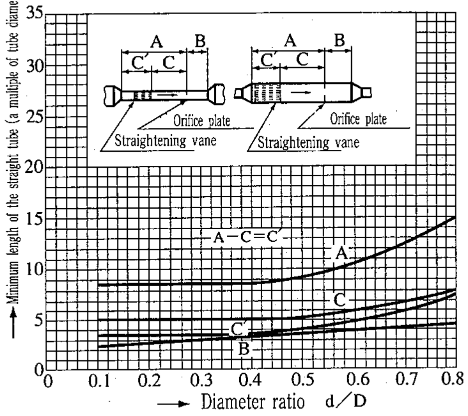
(3) Values between the values in parentheses and values without parentheses are "0.5% additional uncertainty" values.

(4) The minimum straight lengths for natural gas are shown in the next drawings. (JIS M8010-1993). In case that more higher accuracy is needed, it is recommended to use the straight length specified in paragraph(2).

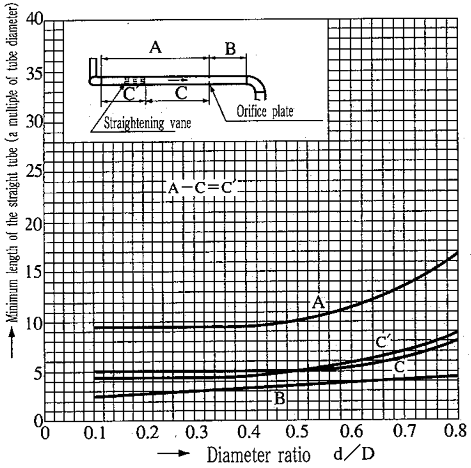
(a) Two bends on the upstream of the orifice plate (in the same plane)



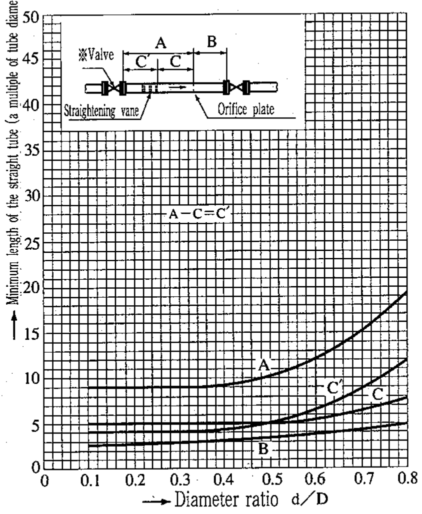
(c) Variation in pipe diameter



(b) Two bends on the upstream of the orifice plate (in different planes)

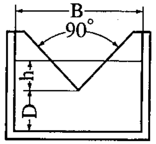
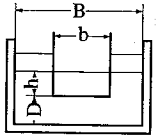
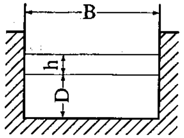


(d) Valve or regulating valve on the upstream of the orifice plate



Note※: As examples, gate valve, globe valve and Bragg valve are used as partially closed condition to adjust the gas flow rate.

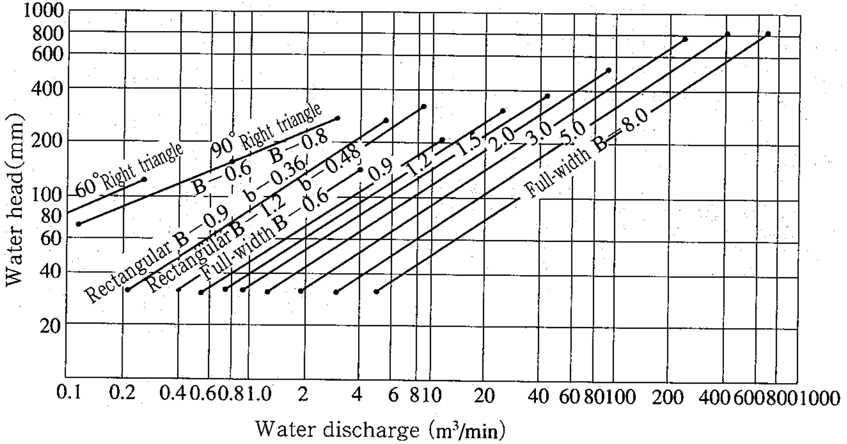
5-5 Measurement of Water Discharge by means of Weirs (JIS B 8302-1990)

Types	Right-angle triangular weir	Rectangular weir	Full-width weir
Shape			
Range of dimension	$B = 0.5 \sim 1.2\,m$ $D = 0.1 \sim 0.75\,m$ $h \leqq B/3$	$B = 0.5 \sim 6.3\,m$ $b = 0.15 \sim 5.0\,m$ $D = 0.15 \sim 3.5\,m$ $bD/B^2 \geqq 0.06$	$B \geqq 0.5\,m$ $D = 0.3 \sim 2.5\,m$
Range of water head	$h = 0.07 \sim 0.26\,m$	$h = 0.03 \sim 0.45\sqrt{b}\,m$	$h = 0.03 \sim D\,m$ (h shall be not longer than 0.8m and not longer than B/4.)

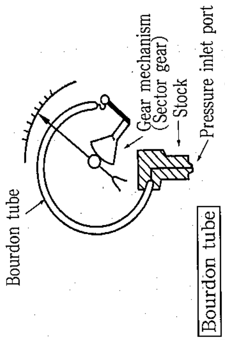
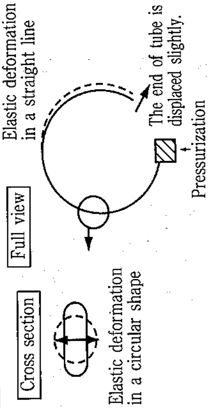
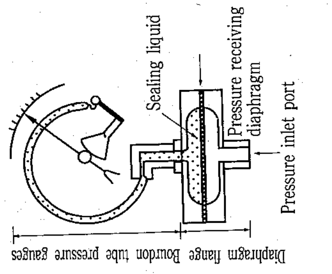
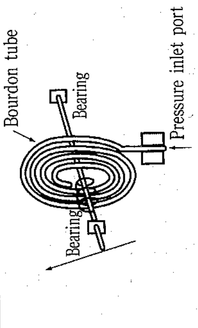
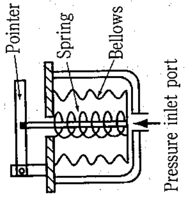
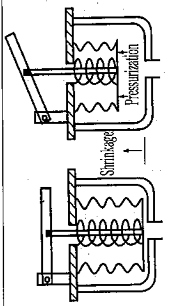
The discharge formulas for the above three types of weirs are shown as follows:

Right-angle triangular weir	Full-width weir
$Q = Kh^{5/2}(m^3/min)$ $K = 81.2 + \frac{0.24}{h} + \left(8.4 + \frac{12}{\sqrt{D}}\right)\left(\frac{h}{B} - 0.09\right)^2$ h : Head of weir (m)	$Q = KBh^{3/2}(m^3/min)$ $K = 107.1 + \left(\frac{0.177}{h} + 14.2 + \frac{h}{D}\right)(1+\varepsilon)$ ε : correction term When D is 1m or less: $\varepsilon = 0$ When D is 1m or more: $\varepsilon = 0.55(D-1)$ h : Head of weir (m)
Rectangular weir	
$Q = Kbh^{3/2}(m^3/min)$ $K = 107.1 + \frac{0.177}{h} + 14.2\frac{h}{D} - 25.7\sqrt{\frac{(B-b)h}{DB}} + 2.04\sqrt{\frac{B}{D}}$ h : Head of weir (m)	

In addition to the use of the flow rate formulas, approximate head of weir shall be calculated by using the approximate water discharge curves, and the range of head of weir shall be confirmed.



5-6 Structures and Principles of Pressure Gauges

	Structure	Principles of operation	Features	Main applications	Types of pressure gauges
1 Bourdon tube pressure gauge	 **Bourdon tube** • It is the metal tube shaped C character with the cross section of ellipse. • The structure is that one end of the Bourdon tube is closed, and the pressure is added at the pressure inlet port of the stock side.	 • By pressurization on the pressure inlet port, the cross section of Bourdon tube deforms in a circular shape and the tube itself is going to deform in a straight line. • By this pressurization, the nose of tube displaces slightly according to the pressure. This slight displacement is amplified by gear mechanism and changed to rotation movement, and indicates the pressure by pointer.	• Compared to Bellows type, its sensitivity is not high, because of using the slight displacement of the Bourdon tube. • Because the Bourdon tube is simple in its structure and easy to change the wall thickness, high pressure measurement is possible.	• General systems	Types | Element materials Class A | Diaphragm pressure gauge | Better than SUS equivalent (Inconel) Class B | General pressure gauge | Better than SUS equivalent (Inconel) Class C | | Brass • Diaphragm pressure gauge 
2 Gearless pressure gauge	 • The nose of Bourdon tube and the shaft of pointer are linked directly, and there is no gear mechanism as Bourdon tube pressure gauge.	• The Bourdon tube, which length is about ten times of that of the Bourdon tube pressure gauge, rotate-drives the pointer directly not using gear mechanism and indicate the pressure.	• It does not use the gear mechanism and uses less wear parts, so it is strong to pulsation. • The gauge for the measurement of fine low pressure (0-2K) is not manufactured because the length of Bourdon tube becomes long to keep the rotation of the pointer.	• BFP outlet pressure • Condensate pump outlet pressure (pump outlet pressure gauge)	
3 Micro pressure gauge	 **Bellows** • Bellows shaped element with about ten ruffles	 • By Pressurization on the pressure inlet port, bellows receive the compressive force from outside and shrink to the position which balance the elastic force of spring and bellows and the pressurization force. • By this displacement, indication mechanism attached to the bellows is driven.	• Because bellows have large pressure receiving area and large output is obtained to the same input, the gauge is used as measurement of fine low pressure with high sensitivity.	• Furnace pressure gauge • Differential pressure gauge	

5-7 Selection of Pressure Gauges

It is necessary to select the proper pressure gauge depending on the pressure of the fluid to be measured, chemical properties and installation place. For measurement, the nominal pressure limit of the pressure gauge shall be 1.5 to 2 times the working pressure.

The following table shows guidelines for the ordinary measuring ranges of various types of pressure gauges.

	Type	Measuring range (kPa〔abs〕)	
Pressure gauges	Plumb bob pressure gauge	290～ (1,300,000)	
	Bourdon tube pressure gauges	29～ (550,000)	
	Bellows pressure gauge	0.78 ～ 21,000	Measuring of absolute pressure is possible.
	Diaphragm pressure gauge	0.0098～290	ditto
	Manometer	0.78 ～390	ditto

	Type	Measuring differential pressure	Maximum working pressure (kPa〔abs〕)
Differential pressure gauges	Bell-jar differential pressure gauge	0～25mmAq	980
	Diaphragm differential pressure gauge	0～21mAq	41,000
	Bellows differential pressure gauge	0～1400mAq	27,000
	Manometer	0～10mAq	34,000

5-8 Classification of Bourdon Tube Pressure Gauges (JIS B 7505-1994)

(1) Classification According to Accuracy Class and Application

Symbol and tolerance for accuracy class

Accuracy class	Symbol	Tolerance (%) (1)	
		Range of scale A (2)	Range of scale B (3)
Class 0.6	(0.6) or CL 0.6	±0.6	±0.9
Class 1.0	(1.0) or CL 1.0	±1.0	±1.5
Class 1.6	(1.6) or CL 1.6	±1.6	±2.4
Class 2.5	(2.5) or CL 2.5	±2.5	±3.8
Class 4.0	(4.0) or CL 4.0	±4.0	±6.0

Note: (1) The value of tolerance shall be expressed by percentage to the pressure span.

(2) The range of scale A is made by subtracting 10% of each end of pressure span and 5% each of upper and lower parts of zero point of compound pressure gauge.

(3) The range of scale B is made of 10% of each end of pressure span and 5% each of upper and lower parts of zero point of compound pressure gauge.

Classification according to application

Classification	Symbol	Working conditions
Ordinary type	—	−5 to 45℃ (JIS C 1803, Environmental Division C, Class CJ3)
Ordinary type for steam	M	Ambient temperature 10 to 50℃, capable of withstanding the instantaneous high temperature
Heatproof type	H	Ambient temperature −5 to 80℃
Vibration-proof type	V	−5 to 45℃ (JIS C 1803, Environmental Division C, Class CJ3)
Vibration-proof type for steam	MV	Ambient temperature 10 to 50℃, capable of withstanding the instantaneous high temperature
Heatproof/Vibration-proof type	HV	Ambient temperature −5 to 80℃

(2) Shape of Bourdon Tube Pressure Gauge

Division	Symbol for shape	Position of rim	Position of stock
Rimless type	A	No	Lower
Circular rim type	B	Rear	Lower
Front rim type	B2	Front	Lower
Embeded type	D	Front	Back
	D2	No	Back
Screwed type	D3	Front	Center
	D4	No	Center

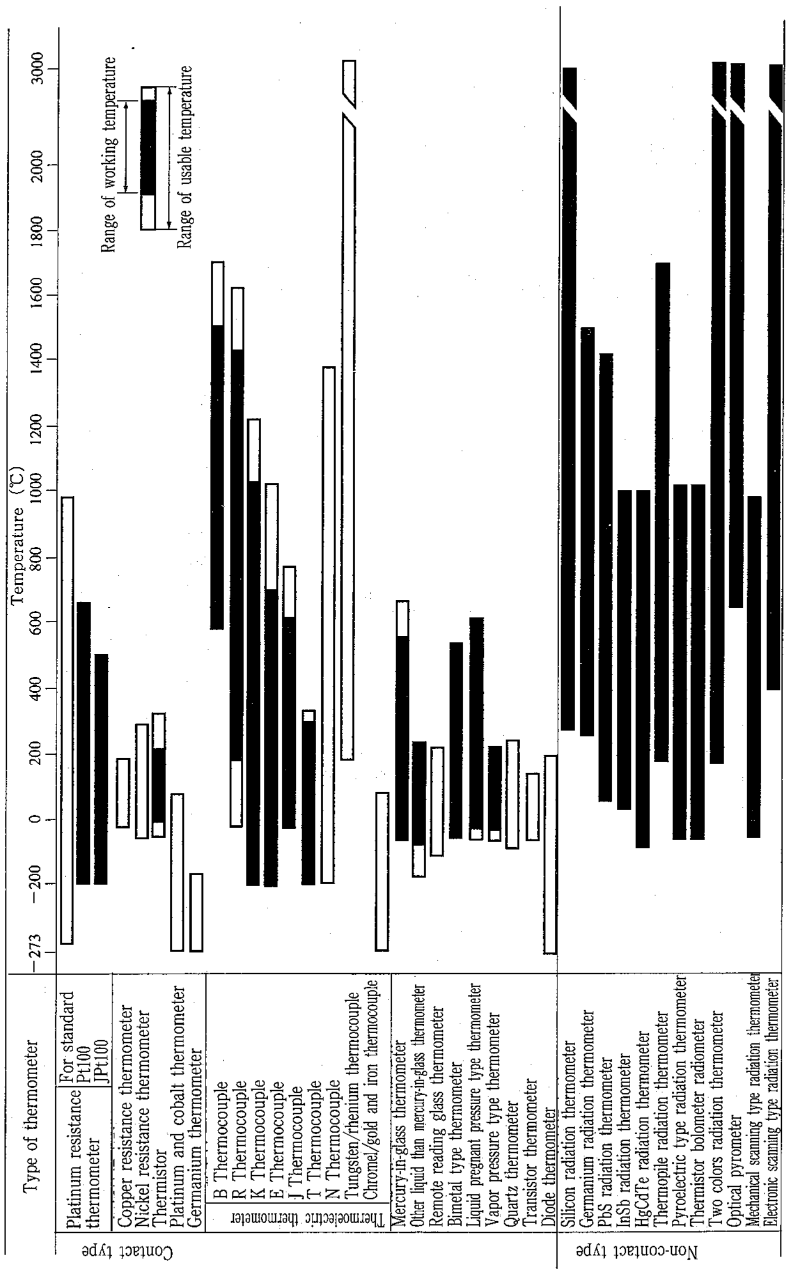
(3) Size of Bourdon Tube

The size of Bourdon tube pressure gauges shown by the outer diameter (mm) of dial scale plate shall be 50, 60, 75, 100, 150, 200.

5-9 Various Types of Thermometers

Style	Type	Characteristics	Error factor
Contact style	Resistance thermometer	(1) Measured value becomes the average value of the temperature of a degree of several cm^3 (size of detecting element). (2) Suitable for measurement of temperature with high precision at about−273℃ to +500℃ (3) Unsuitable for the object with strong vibration.	Changing speed of temperature Aged deterioration of detector Change due to heat history Self-heating Outflow and inflow of heat from measurement conductor
	Thermistor thermometer	(1) The measured value becomes the average value of the temperature of a degree of several mm^3 (size of detecting element). (2) The resistance of detector is larger compared with resistance of conductor. (3) The range of working temperature by one detector is narrow. (4) Weak against impact.	Aged deterioration of detector Self-heating Outflow and inflow of heat from measurement conductor
	Thermoelectric thermometer	(1) Theoretically, it is possible to measure the temperature at the space approximately equal to the size of junction. (2) Response is good. (3) Strong against vibration and impact (4) Measurement of difference of temperature is possible. (5) Measurement of high temperature is possible. (6) Reference junction is needed.	Stability of reference junction Influence of compensating conductor Parasitic thermoelectric power Aged deterioration of detector Change due to heat history Outflow and inflow of heat from thermocouple line and the like
	Glass thermometer Mercury-in glass thermometer Other liquid than mercury-in glass thermometer Remote reading glass thermometer	(1) Handy in use and high in reliability (2) Weak against impact (3) Measurement of temperature with high precision is possible.	Being out of liquid Influence of exposed part Aged deterioration
	Pregnant type thermometer Liquid pregnant pressure type thermometer Vapor pressure type thermometer	(1) Strong against vibration and impact (2) Possible to use easily	Outflow and inflow of heat from conductor pipe Change due to heat history Influence of exposed part of conductive pipe part Aged deterioration
Non-contact style	Radiation thermometer	(1) Suitable for measurement of temperature at a range of high temperature (2) Remote measurement is possible (3) It is possible to measure the temperature of moving or rotating object. (4) It is unlikely to put the temperature of measured object out of order. (5) Theoretically, measurement of less time-lag is possible.	Incorrectness of emissivity Change of emissivity Absorption and scatter in optical path Stray light (extraneous light and reflected light) Aged deterioration

5-10 Outline of Range of Working Temperature in Various Types of Thermometers (JIS Z 8710-1993)



Reference : JPt100 was abolished.

5-11 Various Types of Thermocouples (JIS C 1602-1995)

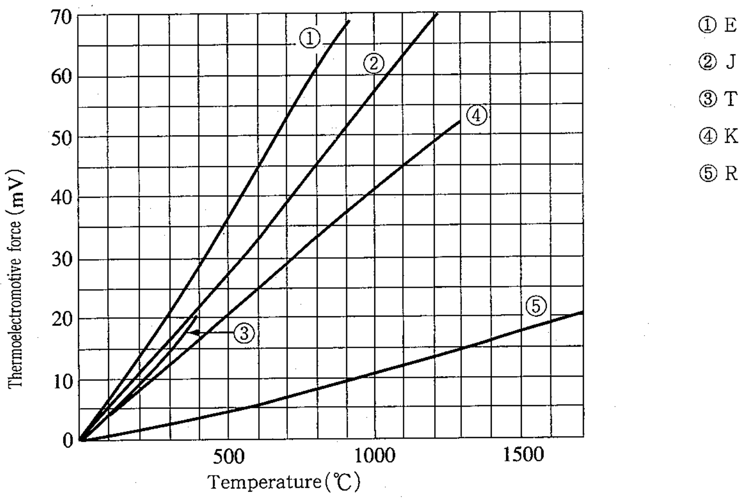
Type of thermocouple combined for service	Composing materials		Diameter of element wire (mm)	Normal operating temperature limit (℃)	Elevated operating temperature limit (℃)
	+ leg	− leg			
B	Platinum rhodium alloy containing 30% rhodium	Platinum rhodium alloy containing 6% rhodium	0.50	1500	1700
R	Platinum rhodium alloy containing 13% rhodium	Platinum	0.50	1400	1600
S	Platinum rhodium alloy containing 10% rhodium	Platinum			
N	Alloy main components of which are nickel, chromium and silicon.	Alloy main components of which are nickel and silicon.	0.65	850	900
			1.00	950	1000
			1.60	1050	1100
			2.30	1100	1150
			3.20	1200	1250
K	Alloy main components of which are nickel and chromium.	Alloy main component of which is nickel.	0.65	650	850
			1.00	750	950
			1.60	850	1050
			2.30	900	1100
			3.20	1000	1200
E	Alloy main components of which are nickel and chromium.	Alloy main components of which are copper and nickel.	0.65	450	500
			1.00	500	550
			1.60	550	600
			2.30	600	750
			3.20	700	800
J	Iron	Alloy main components of which are copper and nickel.	0.65	400	500
			1.00	450	550
			1.60	500	650
			2.30	550	750
			3.20	600	750
T	Copper	Alloy main components of which are copper and nickel.	0.32	200	250
			0.65	200	250
			1.00	250	300
			1.60	300	350

Remark: 1 The +leg means a leg to be connected to +terminal of an Instrument to measure thermoelectromotive force, and −leg means opposite side one.

2 Normal operating temperature limit means the limit of temperature within which thermocouples can be continuously used in the air.

3 Elevated operating temperature limit means the limit of temperature at which thermocouples can be used for a short time in the case of unavoidable needs.

5-12 Thermoelectromotive Force Characteristics of Thermocouples (JIS C 1602-1995)



5-13 Tolerances of Extension and Compensating Cables for Thermocouples (JIS C 1610-1995)

Type of thermocouple combined for service	Materials composing cores		Classification of extension and compensating cables		Compensating junction temperature (℃)	Tolerance		Electrical resistance of cores of 1 m go and return (Ω)	Color coding of outer sheath	
	+ side core	− side core	Symbol	Old symbol (informative)		(℃)	(μV)		Present standard	Old standard (informative)
B	Copper	Copper	BC-G	BX-G	0～+100	−	−	≦0.05	Gray	Gray
R	Copper	Alloy mainly composed of copper and nickel	RCA-2-G	RX-G,H	0～+100	±4.0	±30	≦0.1	Yellowish red (Orange)	Black
	Copper	Alloy mainly composed of copper and nickel	RCB-2-H,S		0～+200	±7.0	±60			
S	Copper	Alloy mainly composed of copper and nickel	SCA-2-G	SX-G,H	0～+100	±4.0	±30	≦0.1	Yellowish red (Orange)	Black
	Copper	Alloy mainly composed of copper and nickel	SCB-2-H,S		0～+200	±7.0	±60			
N	Alloy mainly composed of nickel and chromium	Alloy mainly composed of nickel and silicon	NX-1-G,H,S	−	−25～+200	±1.5	±60	≦2.0	Light red (Pink)	−
	Alloy mainly composed of nickel and chromium	Alloy mainly composed of nickel and silicon	NX-2-G,H,S	−		±2.5	±100			
	Alloy mainly composed of copper and nickel	Alloy mainly composed of copper and nickel	NC-2-G,H	−	0～+150	±2.5	±100	≦0.5		
K	Alloy mainly composed of nickel and chromium	Alloy mainly composed of nickel	KX-1-G,H,S	KX-GS,HS	−25～+200	±1.5	±60	≦1.5	Green	Blue
	Alloy mainly composed of nickel and chromium	Alloy mainly composed of nickel	KX-2-G,H,S	KX-G,H		±2.5	±100			
	————	————	KCA-2-G,H	−	0～+150	±2.5	±100	≦1.5		
	Iron	Alloy mainly composed of copper and nickel	KCB-2-G,H	WX-G,H	0～+150	±2.5	±100	≦0.8		
	Copper	Alloy mainly composed of copper and nickel	KCC-2-G	VX-G	0～+100	±2.5	±100	≦0.8		
E	Alloy mainly composed of nickel and chromium	Alloy mainly composed of copper and nickel	EX-1-G,H,S	EX-G,H	−25～+200	±1.5	±120	≦1.5	Blue purple (Violet)	Purple
	Alloy mainly composed of nickel and chromium	Alloy mainly composed of copper and nickel	EX-2-G,H,S			±2.5	±200			
J	Iron	Alloy mainly composed of copper and nickel	JX-1-G,H,S	JX-G,H	−25～+200	±1.5	±85	≦0.8	Black	Yellow
	Iron	Alloy mainly composed of copper and nickel	JX-2-G,H,S			±2.5	±140			
T	Copper	Alloy mainly composed of copper and nickel	TX-1-G	−	−25～+100	±0.5	±30	≦0.8	Dark yellow red (Brown)	Brown
	Copper	Alloy mainly composed of copper and nickel	TX-2-G	TX-GS,HS		±1.0	±60			

Remark: 1 The symbol for classification of extension and compensating cables is denoted by [The type and the materials composing cores of thermocouples] − [Class of tolerance (1 or 2)] − [Service category (G,H,S)]

2 Service categories for extension and compensating cables are as follows. The insulation resistance shall be applied for cables with sectional area not less than 1.25㎟

Symbol	Service category	Material of insulation	Operating temperature range (℃)	Insulation resistance value (MΩ･km)
G	General	P.V.C. system	−20～+90	50
H	Heat resistant service	Glass system	0～+150	0.05
S	Super heat resistant service	Tetrafluoroethylene system	−25～+200	1,000

3 The tolerance means the maximum allowable value of the remainder of the thermoelectromotive force of extension or compensating cable minus the reference thermoelectromotive force of the thermocouple used in combination.

4 The electrical resistance shall be applied for cables with sectional area not less than 1.25㎟

5 Color coding of outer sheath shows the color of outer sheath of + side. The color of outer sheath of − side is white in every case.

5-14 Resistance-Temperature Characteristics and Tolerances of Resistance Thermometer Sensors (JIS C 1604-1997)

(1) Reference Resistance Value of the Platinum Resistance Thermometer Sensor Pt100 (R_{100}=100.00Ω, R_{100}/R_0=1.3851)

Temperature (℃)	Reference resistance value (Ω)	Temperature (℃)	Reference resistance value (Ω)	Temperature (℃)	Reference resistance value (Ω)	Temperature (℃)	Reference resistance value (Ω)	Temperature (℃)	Reference resistance value (Ω)
−200	18.52	20	107.79	240	190.47	460	267.56	680	339.06
−190	22.83	30	111.67	250	194.10	470	270.93	690	342.18
−180	27.10	40	115.54	260	197.71	480	274.29	700	345.28
−170	31.34	50	119.40	270	201.31	490	277.64	710	348.38
−160	35.54	60	123.24	280	204.90	500	280.98	720	351.46
−150	39.72	70	127.08	290	208.48	510	284.30	730	354.53
−140	43.88	80	130.90	300	212.05	520	287.62	740	357.59
−130	48.00	90	134.71	310	215.61	530	290.92	750	360.64
−120	52.11	100	138.51	320	219.15	540	294.21	760	363.67
−110	56.19	110	142.29	330	222.68	550	297.49	770	366.70
−100	60.26	120	146.07	340	226.21	560	300.75	780	369.71
−90	64.30	130	149.83	350	229.72	570	304.01	790	372.71
−80	68.33	140	153.58	360	233.21	580	307.25	800	375.70
−70	72.33	150	157.33	370	236.70	590	310.49	810	378.68
−60	76.33	160	161.05	380	240.18	600	313.71	820	381.65
−50	80.31	170	164.77	390	243.64	610	316.92	830	384.60
−40	84.27	180	168.48	400	247.09	620	320.12	840	387.55
−30	88.22	190	172.17	410	250.53	630	323.30	850	390.48
−20	92.16	200	175.86	420	253.96	640	326.48		
−10	96.09	210	179.53	430	257.38	650	329.64		
0	100.00	220	183.19	440	260.78	660	332.79		
10	103.90	230	186.84	450	264.18	670	335.93		

JPt100 was stipulated in the old JIS,

(2) Classification by Service Temperature Range

Unit ℃

Symbol	Classification	Service temperature range
L	For low temperature	−200～+100
M	For medium temperature	0～350
H	For high temperature	0～650(1)
S (2)	For extra-high temperature	0～850

Note: (1) This shall be 500℃ for sheathed resistance thermometer sensor.
(2) Not applicable for sheathed resistance thermometer sensor.

(3) Tolerance

Unit ℃

Class	Tolerance
A	±(0.15+0.002 | *t* |)
B	±(0.3+0.005 | *t* |)

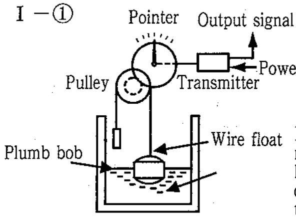
Remark:

1. The tolerance means the maximum limit of error allowed on such a value that the measurement temperature by reference apparatus "t" is subtracted from the value of temperature converted by means of the reference resistance value table from the resistance value shown by the sensing resistor.
2. | t | means the measurement temperature expressed by a temperature(℃) unrelated to signs of + or −.
3. The tolerance of class A Is not applicable to thermometers of 2 connecting-wire system and a measurement temperature exceeding 650℃.

5-15 Level Gauges

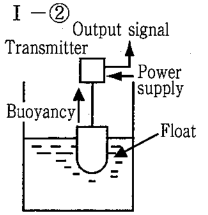
I Float type level gauge

I-①



[Float type]
Float type level gauge measures the liquid level by detecting directly the position of the float on the liquid surface.

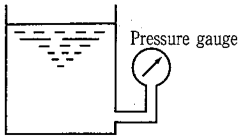
I-②



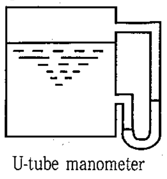
[Displacer type]
Liquid level measuring method by utilizing the theory that the buoyancy and the liquid level have linear relation where the cross section of float is constant, because the buoyancy of a cylindrical displacer (float) is equal to the weight of the excluded liquid.

II Pressure type level gauge

II-①

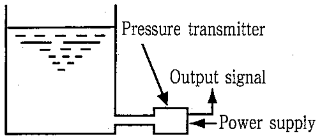


II-②

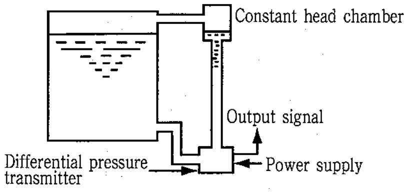


[Differential pressure type]
Liquid level measuring method by measuring static pressure utilizing that the static pressure at any point is proportional to a product of the distance from the point to the liquid surface and the density.

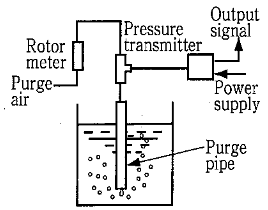
II-③



II-④ Same as II-②

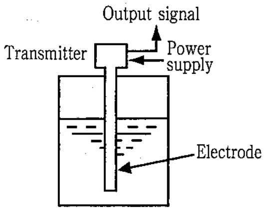


II-⑤



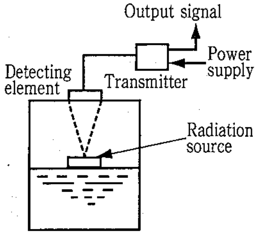
[Purge type]
Insert the pipe into the liquid, and run the constant flow of purge air through the pipe. Liquid level measuring method by utilizing that the air pressure in the pipe (back pressure) is equal to the hydraulic pressure while the bubble from the end of pipe is running.

III Electrical capacitance type level gauge



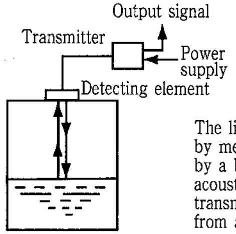
Liquid level measuring method by utilizing that the electrical capacitance of two facing electrodes changes according to the dielectric constant of material located between the electrodes.

IV Radiation level gauge



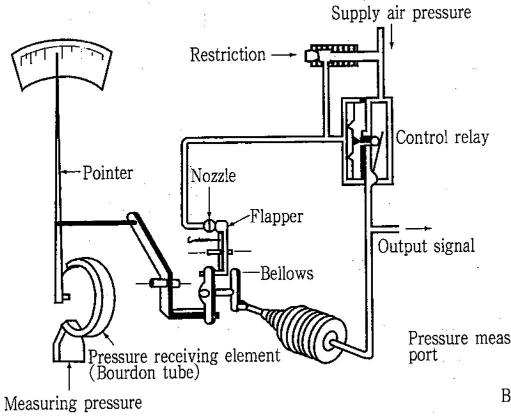
This is a effective method when the transmitter is difficult to install inside the closed tank or the tank containing corrosive liquid. It measures the displacement of liquid by measuring the radiation transmission dose from the radiation source.

V Ultrasonic level gauge

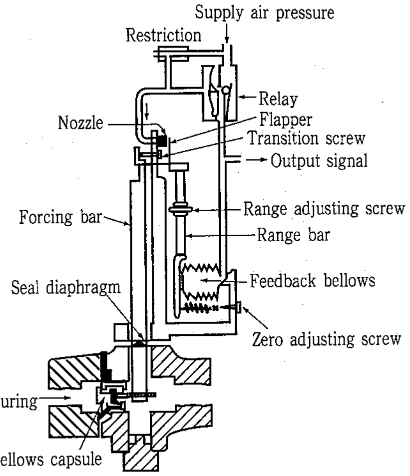


The liquid level is measured by measuring the time taken by a beam of ultrasonic acoustic energy to be transmitted to and reflected from a surface of liquid.

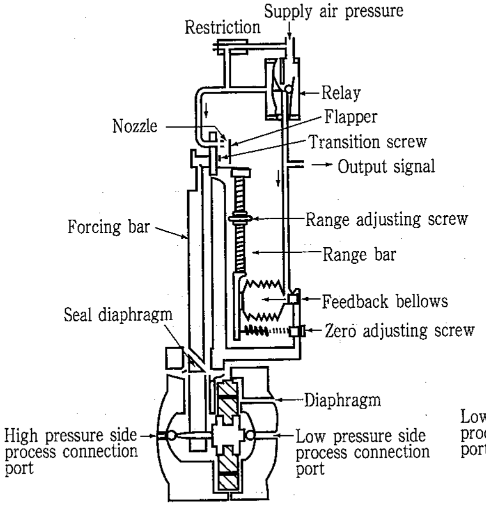
5-16 Various Types of Pressure Transmitters



Deviation balancing type (pneumatic type)

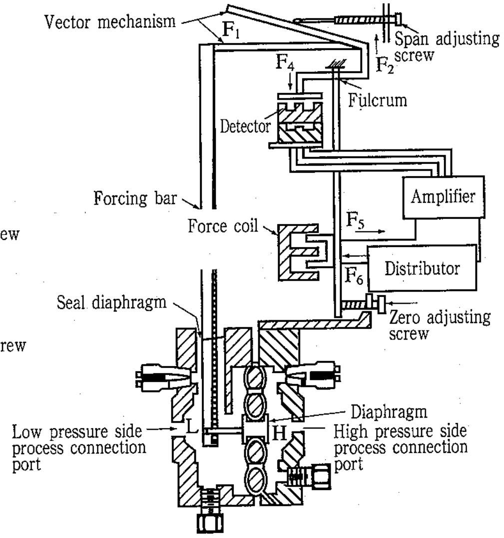


Force balancing type (pneumatic type)



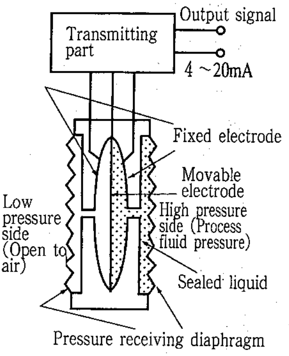
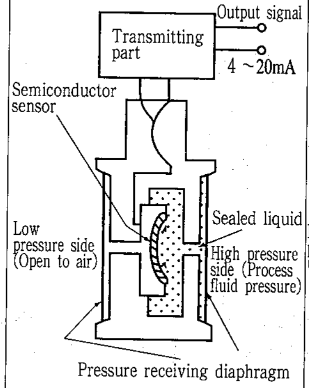
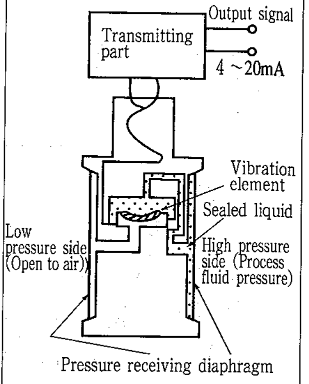
Force balancing type (pneumatic type)

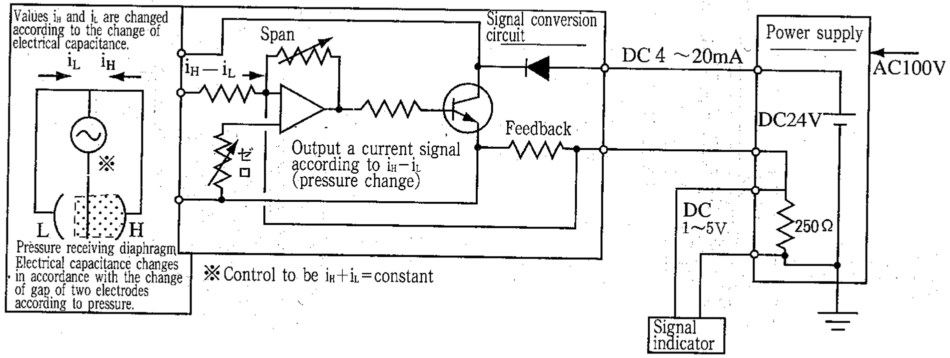
Deviation balancing type: A pressure is taken out as a mechanical deviation through a Bourdon tube, etc. and the mechanical deviation is converted to a pneumatic pressure signal through a nozzle and flapper.



Force balancing type (electric type)

Force balancing type: A pressure is transmitted to a forcing bar through a diaphragm, etc. and the pressure is detected by giving a force balancing the force produced by the forcing bar by a feedback device.

	Electrical capacitance pressure transmitter	Semiconductor pressure transmitter	Vibrator type pressure transmitter
Structure of detecting element			
Principle	It outputs the signal according to the change of electrical capacitance in accordance with the change of gap between fixed and movable electrodes which receive the pressure change of pressure receiving diaphragm via sealed liquid.	It outputs the signal according to the change of electrical resistance of piezoelectric element in semiconductor composite sensor which receives the pressure change of pressure receiving diaphragm via sealed liquid.	It outputs the signal according to the change of natural frequency of vibration element which receives the pressure change of pressure receiving diaphragm via sealed liquid.



6-1 Viscosity and Kinematic Viscosity

ρ = density〔kg/m^3 = 10^{-3}g/cm^3 = N·s^2/m^4〕

μ = viscosity〔Pa·s = $\frac{\mathrm{N \cdot s}}{\mathrm{m}^2}$, mPa·s = $10^{-3}\frac{\mathrm{N \cdot s}}{\mathrm{m}^2}$, μPa·s = $10^{-6}\frac{\mathrm{N \cdot s}}{\mathrm{m}^2}$〕

$\nu = \frac{\mu}{\rho}$ = kinematic viscosity〔m^2/s = 10^{-6}mm^2/s〕

Table 1 ρ (kg/m^3), μ (mPa·s), ν (mm^2/s) of water at 1 atm.

Temperature, ℃	0	10	20	30	40	50
ρ	999.840	999.700	998.204	995.648	992.215	988.033
μ	1.791 9	1.306 9	1.002 0	0.797 3	0.652 9	0.547 0
ν	1.792 1	1.307 2	1.003 8	0.800 8	0.658 0	0.553 6
Temperature, ℃	60	70	80	90	100	
ρ	983.193	977.761	971.788	965.311	958.357	
μ	0.466 7	0.404 4	0.355 0	0.315 0	0.282 2	
ν	0.474 7	0.413 6	0.365 3	0.326 3	0.294 5	

〔Source: Mechanical Engineers' Handbook, Part A5, edited by The Japan Society of Mechanical Engineers, 1987.〕

Table 2 dry air ρ(kg/m^3), μ (μPa·s), ν(mm^2/s)

t ℃	ρ				μ				ν			
	720*	740	760	780	720	740	760	780	720	740	760	780
−10	1.270 9	1.306 2	1.341 6	1.376 9	16.74	16.74	16.74	16.74	13.17	12.82	12.48	12.16
0	1.224 2	1.258 3	1.292 3	1.326 3	17.24	17.24	17.24	17.24	14.08	13.70	13.34	13.00
10	1.180 9	1.213 7	1.246 5	1.279 3	17.74	17.74	17.74	17.74	15.02	14.62	14.23	13.87
20	1.140 5	1.172 2	1.203 9	1.235 5	18.24	18.24	18.24	18.24	15.99	15.56	15.15	14.76
30	1.102 8	1.133 4	1.164 0	1.194 7	18.72	18.72	18.72	18.72	16.97	16.52	16.08	15.67
40	1.067 5	1.097 1	1.126 8	1.156 4	19.20	19.20	19.20	19.20	17.99	17.50	17.04	16.60

Note: The value in line marked by * indicates an air pressure in mmHg.

〔Source: Mechanical Engineers' Handbook, Part A5, edited by The Japan Society of Mechanical Engineers, 1987.〕

6-2 Settling Velocity of Spherical Particles

The settling velocity of a spherical particle in a suspension is given by

$$V = \frac{1}{18}\frac{g \cdot d^2}{\nu_0}\left(\frac{\rho}{\rho_0}-1\right) \cdots\cdots\cdots\cdots \text{Stokes' formula}$$

V=settling velocity (cm/s) d=diameter of spherical particle (cm) ρ =density of particle (g/cm^3)

ρ_0=density of liquid (g/cm^3) g =acceleration of gravity (cm/s^2) ν_0=kinematic viscosity of liquid (cm^2/s)

This formula is for the case of single particle settling in a static liquid or a laminar flow with the Reynolds number of not higher than 0.4. The settling velocity of a particle in a cluster state is greatly lower than the value calculated with this formula.

As example, the settling velocities of the particle are shown below.

Settling velocity of particle (10℃, in distilled water)

Diameter of particle (mm)		1.0	0.5	0.1	0.05	0.01	0.005	0.001
Settling velocity (mm/s)	Specific gravity 1) 2.65	100.0	53.0	7.4	1.7	0.069	0.017	0.00069
	Specific gravity 2) 1.25	12.0	6.2	0.8	0.26	0.0084	0.0021	0.000084

Note: 1) Correspond to a inorganic matter composed chiefly of sand in water.
2) Correspond to an organic matter existing in drainage.

6-3 Channel with Constant Cross-section and Velocity

Denoting v =mean velocity (m/s), m=mean depth of fluid=A/S (m), A =cross-sectional area of flow (m^2), S =length of wetted perimeter (m), i=gradient of fluid surface, the mean velocity v is expressed by Chezy's formula as:

$$v = \mathrm{C}\sqrt{\mathrm{m}\cdot i}$$

where, C is a velocity coefficient. According to Ganguillet-Kutta

$$C = \frac{23+(1/n)+(0.00155/i)}{1+\{23+(0.00155/i)\}(n/\sqrt{m})}$$

here, n is a coefficient depending on the wall surface roughness shown in the following table.

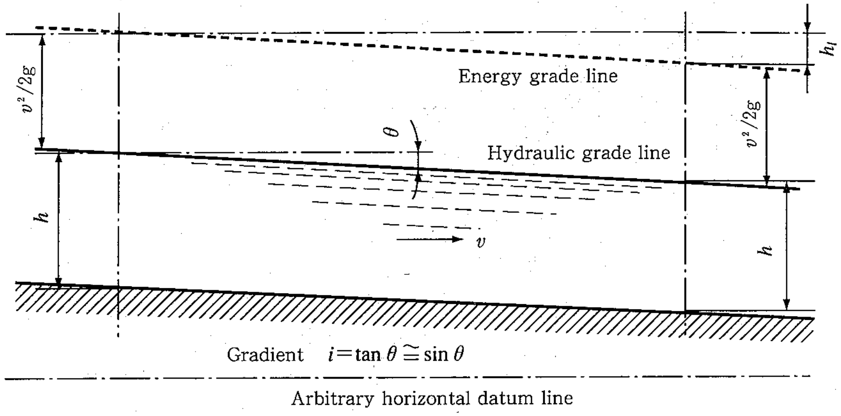
Also, according to Manning,

$$v = (1/n)m^{2/3}\ i^{1/2}$$

where the coefficient n is practically equal to that of Ganguillet-Kutta's equation.

Roughness coefficient, n

Kind of channel	Value of n
Closed pipe line	
Brass pipe	0.009～0.013
Cast iron pipe	0.011～0.015
Pure cement smoothed plane	0.010～0.013
Concrete pipe	0.012～0.016



〔Source: Mechanical Engineers' Handbook, Part A5, edited by The Japan Society of Mechanical Engineers, 1987.〕

6-4 Friction Loss of Pipes and Ducts

(1) Friction loss

$$\Delta \mathrm{P} = \lambda\frac{l}{d}\ \frac{\rho v^2}{2}\,Pa, \quad \Delta \mathrm{P} = \lambda\frac{l}{d}\ \frac{\rho v^2}{2g}\,\mathrm{mm}Aq$$

where ΔP = friction loss
l =length of pipe or duct (m)
d =diameter of pipe or duct (m)
ρ =density of fluid (kg/m^3)
v =mean velocity of fluid (m/s)
g =acceleration of gravity = 9.8 (m/s^2)
λ =friction factor

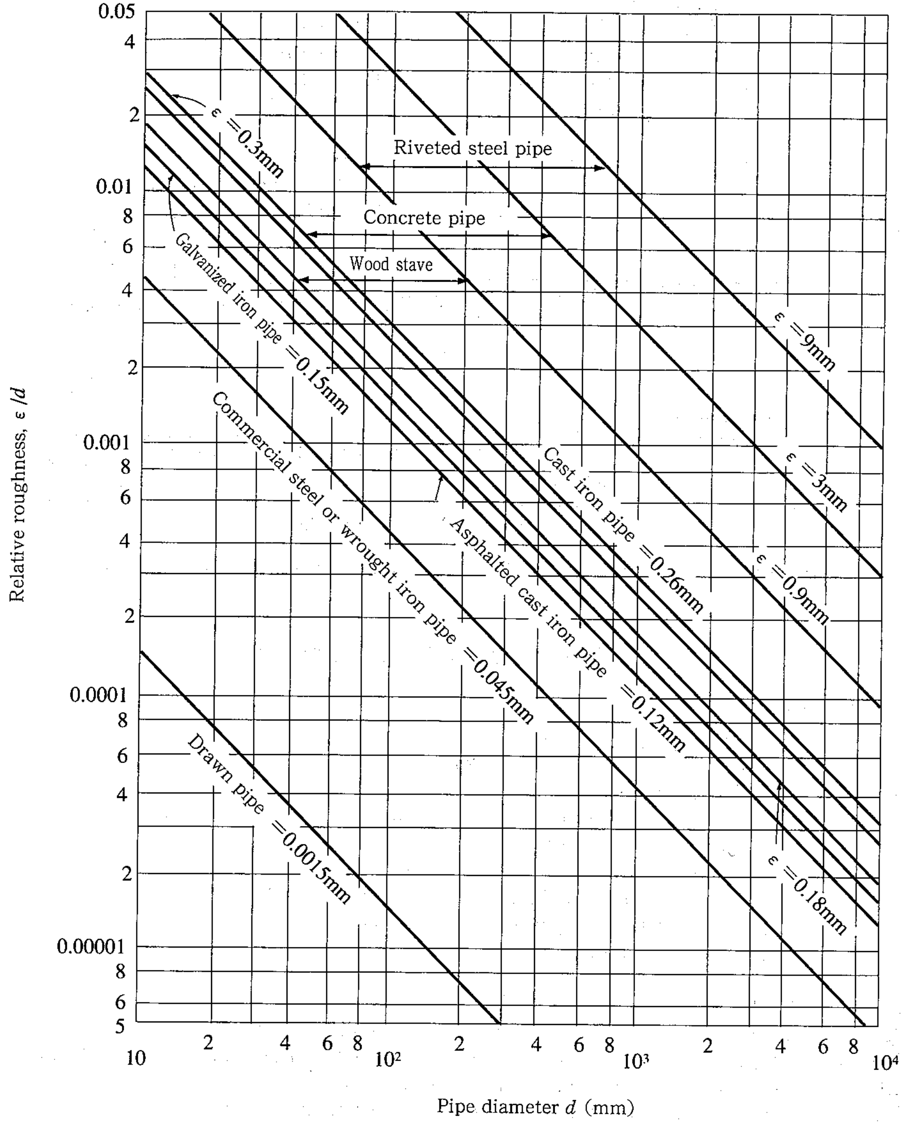
(2) Friction factor

To obtain friction factor λ, the following method shall be used.

When the average roughness of inner wall is set to ε, Fig. 1 shows a relative roughness ε/d with respect to a diameter d and material of pipe or duct.

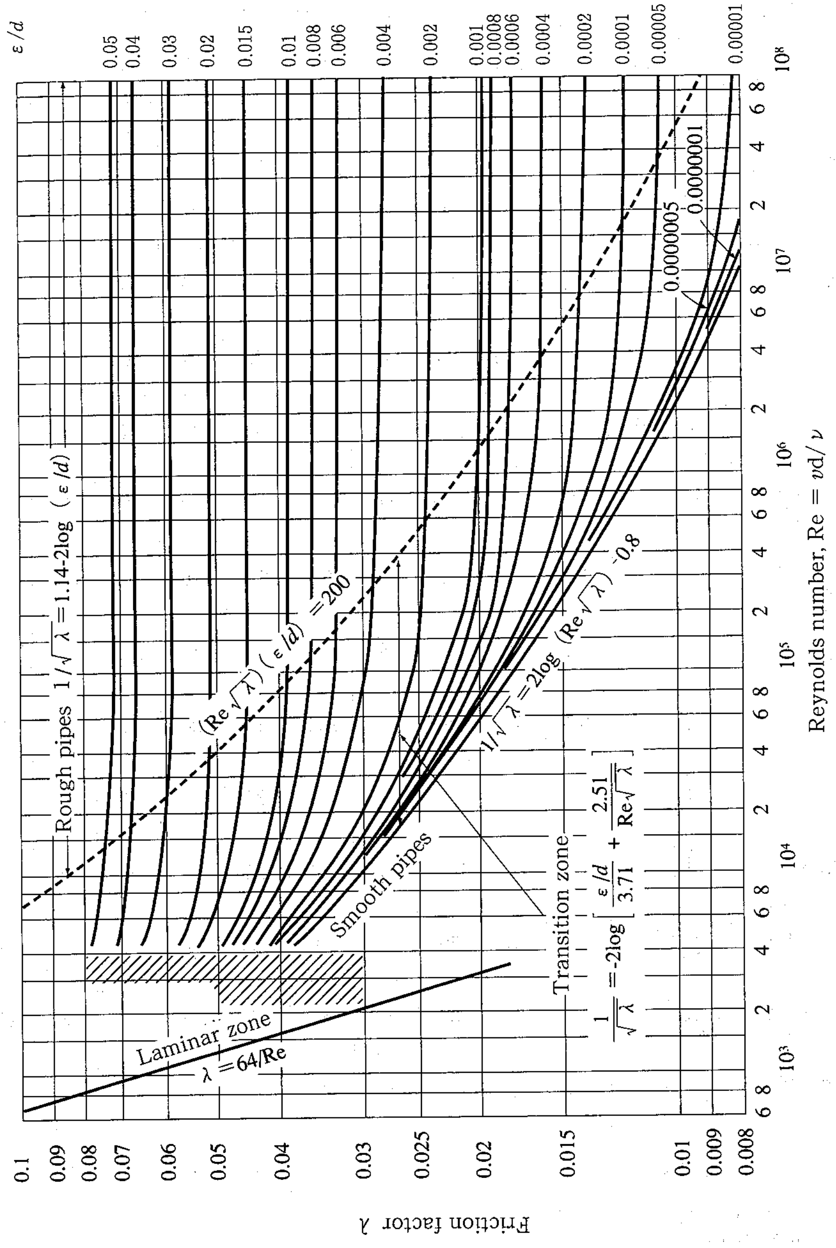
Then, λ shall be obtain in terms of Reynolds number Re and ε/d in Fig. 2.

Fig. 1 Relative roughness of pipes for practical use.



〔Source: Mechanical Engineers' Handbook, Part A5, edited by The Japan Society of Mechanical Engineers, 1987.〕

Fig. 2 Moody diagram



〔Source: Mechanical Engineers' Handbook, Part A5, edited by The Japan Society of Mechanical Engineers, 1987.〕

6-5 Equivalent Straight Pipe Length of Bends, Valves (at full open) and Fittings

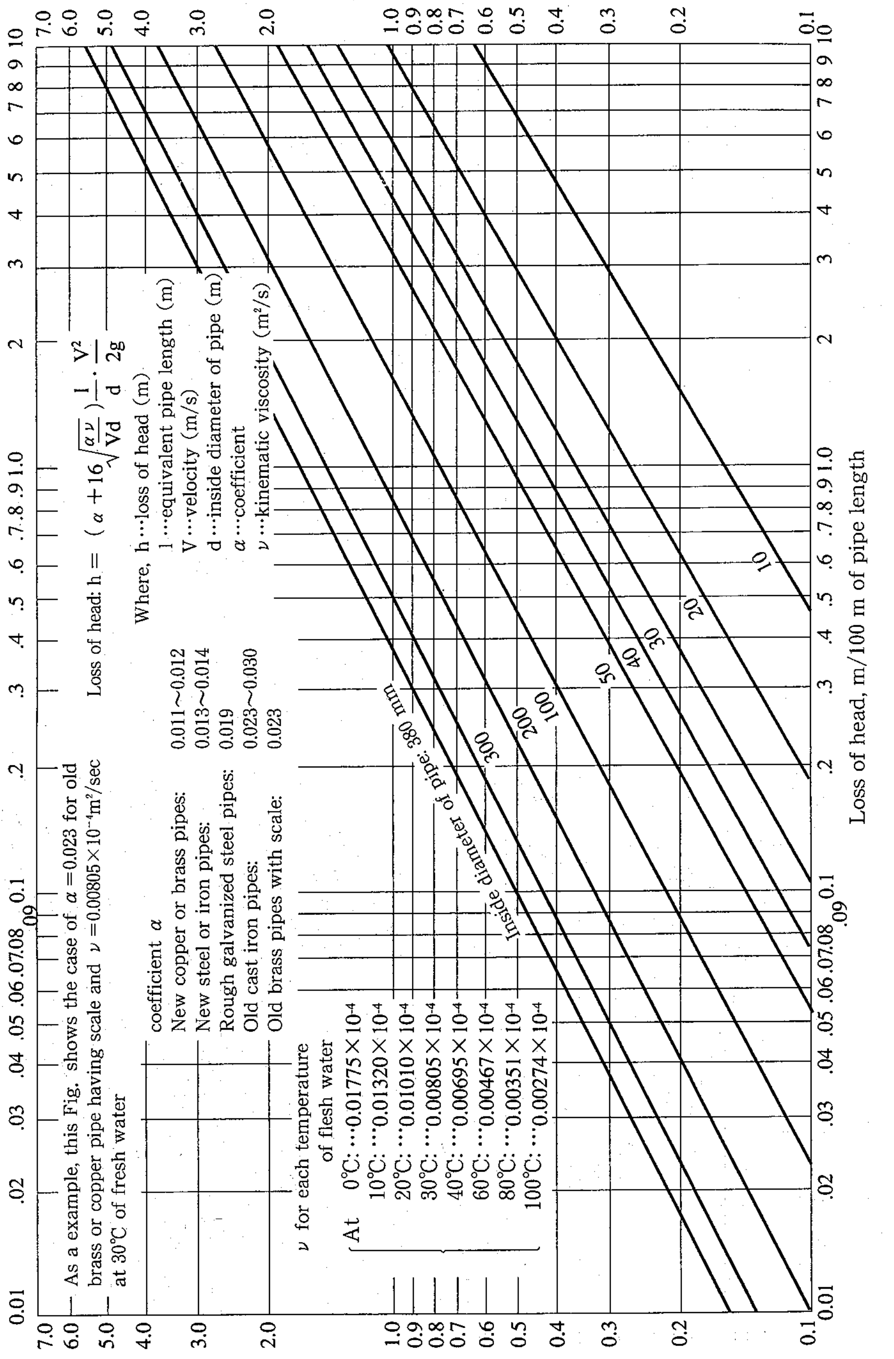
$$\Delta P = \phi \frac{\rho v^2}{2} = \lambda \frac{le}{dx} \frac{\rho v^2}{2}$$

ϕ =Loss factor λ =Friction factor
le =Equivalent straight pipe length (Unit: m)

Type / Length / Inside diameter of pipe (mm)	50	100	150	200	250	300	350	400	450	500
90°bend R= 4 d	1	1.7	2.5	3.2	4	5	6	7	8	9
90°bend R= 3 d	1.5	2.5	4	5	6	7.5	9	11	12.5	14
Elbow Casting	3.2	7.5	12.5	18	24	30	38	44	50	55
Elbow Steel plate	7.5	17.5	29	42	56	70	87	102	115	137
Expansion joint B A A • B=12d	4	9.5	14.5	20	27	33	41	48	54	64
Expansion joint with wrinkle1)	5	12	18.5	26	34	42	52	61	69	82
Bend with wrinkle1) R= 4 d	1.7	2.8	4.2	5.5	6.5	8.5	10	12	13.5	15
Bend with wrinkle1) R= 3 d	2.4	4	6.5	8	9.5	12	14.5	17.5	20	23
Tee joint	3.6	5.5	8	6.3	15.5	21	26	32	36	43
Tee joint	4.5	7	9.5	14	19	25	31	38	43	51
Tee joint	4.5	9	14.5	20	26	34	41	47	54	63
Globe valve 2)	13	31	50	73	100	130	160	200	230	270
Angle valve 2)	10	20	32	45	61	77	95	115	130	150
Swing check2) valve	3.2	7.5	12.5	18	24	30	38	44	50	59
Parallel slide2) valve	0.6	1.5	2	3	4	5	6.5	7.5	8.5	10

Note: 1) For a wave shape, it shall be doubled.
2) As a reference.
〔Source: Mechanical Engineers' Handbook, Part B6, edited by The Japan Society of Mechanical Engineers, 1987, partially retouched〕

6-6 Pressure Loss of Water in Straight Pipes



As a example, this Fig. shows the case of α =0.023 for old brass or copper pipe having scale and ν =0.00805×10^{-4}m²/sec at 30℃ of fresh water

Loss of head: $h = \left(\alpha + 16\sqrt{\frac{\alpha\nu}{Vd}}\right) \cdot \frac{l}{d} \cdot \frac{V^2}{2g}$

Where, h…loss of head (m)
l…equivalent pipe length (m)
V…velocity (m/s)
d…inside diameter of pipe (m)
α…coefficient
ν…kinematic viscosity (m²/s)

coefficient α	
New copper or brass pipes:	0.011～0.012
New steel or iron pipes:	0.013～0.014
Rough galvanized steel pipes:	0.019
Old cast iron pipes:	0.023～0.030
Old brass pipes with scale:	0.023

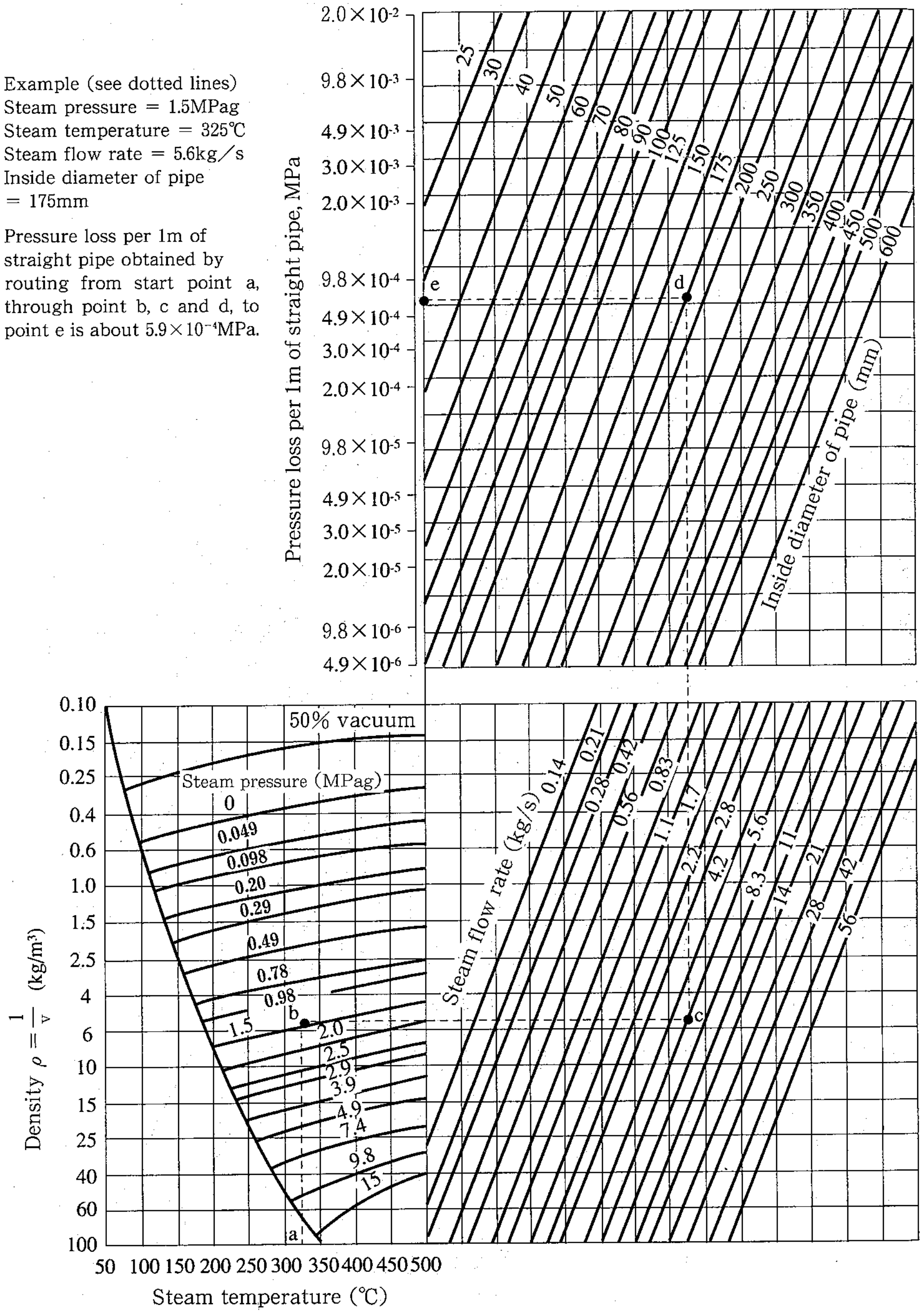
ν for each temperature of flesh water

At 0℃:	…0.01775×10^{-4}
10℃:	…0.01320×10^{-4}
20℃:	…0.01010×10^{-4}
30℃:	…0.00805×10^{-4}
40℃:	…0.00695×10^{-4}
60℃:	…0.00467×10^{-4}
80℃:	…0.00351×10^{-4}
100℃:	…0.00274×10^{-4}

6-7 Pressure Loss of Steam Pipes

Example (see dotted lines)
Steam pressure = 1.5MPag
Steam temperature = 325℃
Steam flow rate = 5.6kg/s
Inside diameter of pipe
= 175mm

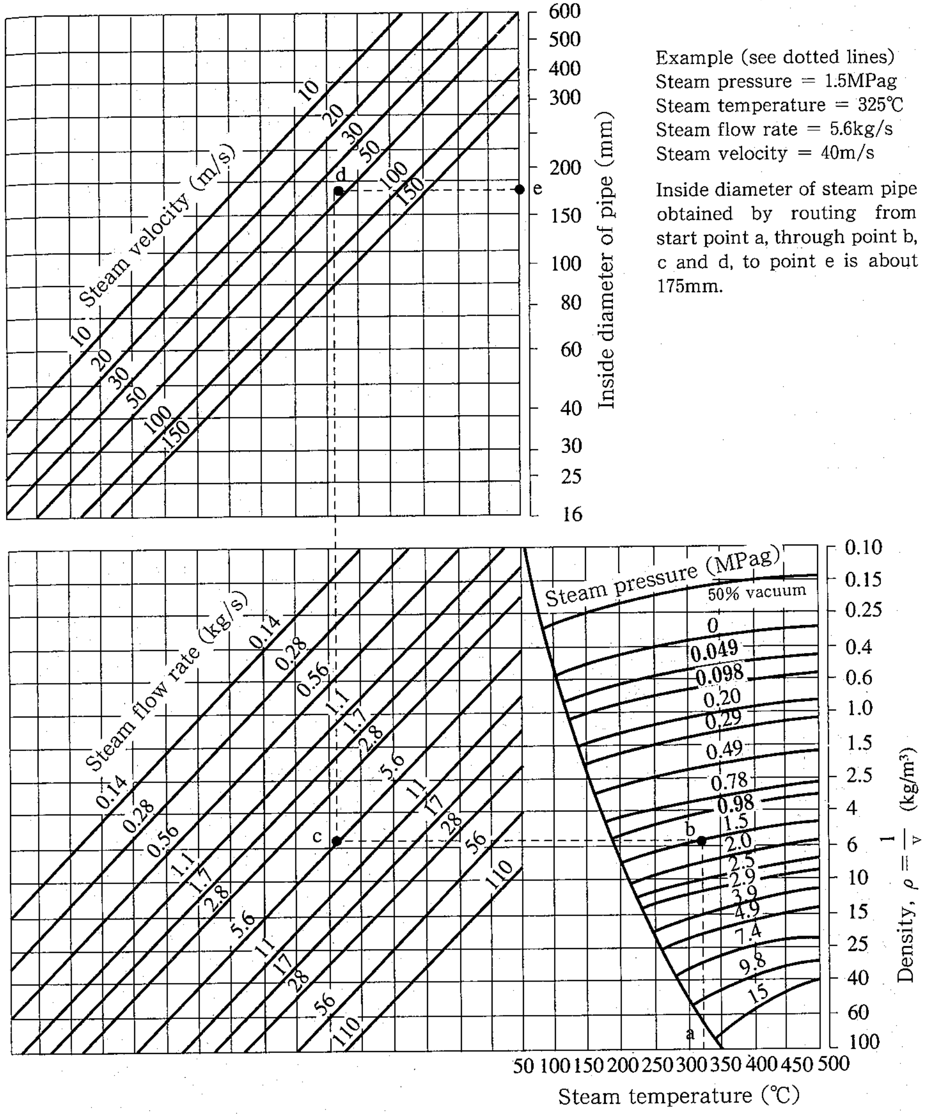
Pressure loss per 1m of straight pipe obtained by routing from start point a, through point b, c and d, to point e is about 5.9×10⁻⁴MPa.



6-8 A Method for Obtaining Inside Diameter of Steam Pipes

Example (see dotted lines)
Steam pressure = 1.5MPag
Steam temperature = 325℃
Steam flow rate = 5.6kg/s
Steam velocity = 40m/s

Inside diameter of steam pipe obtained by routing from start point a, through point b, c and d, to point e is about 175mm.



6-9 Pressure Loss of Air and Gas Pipes

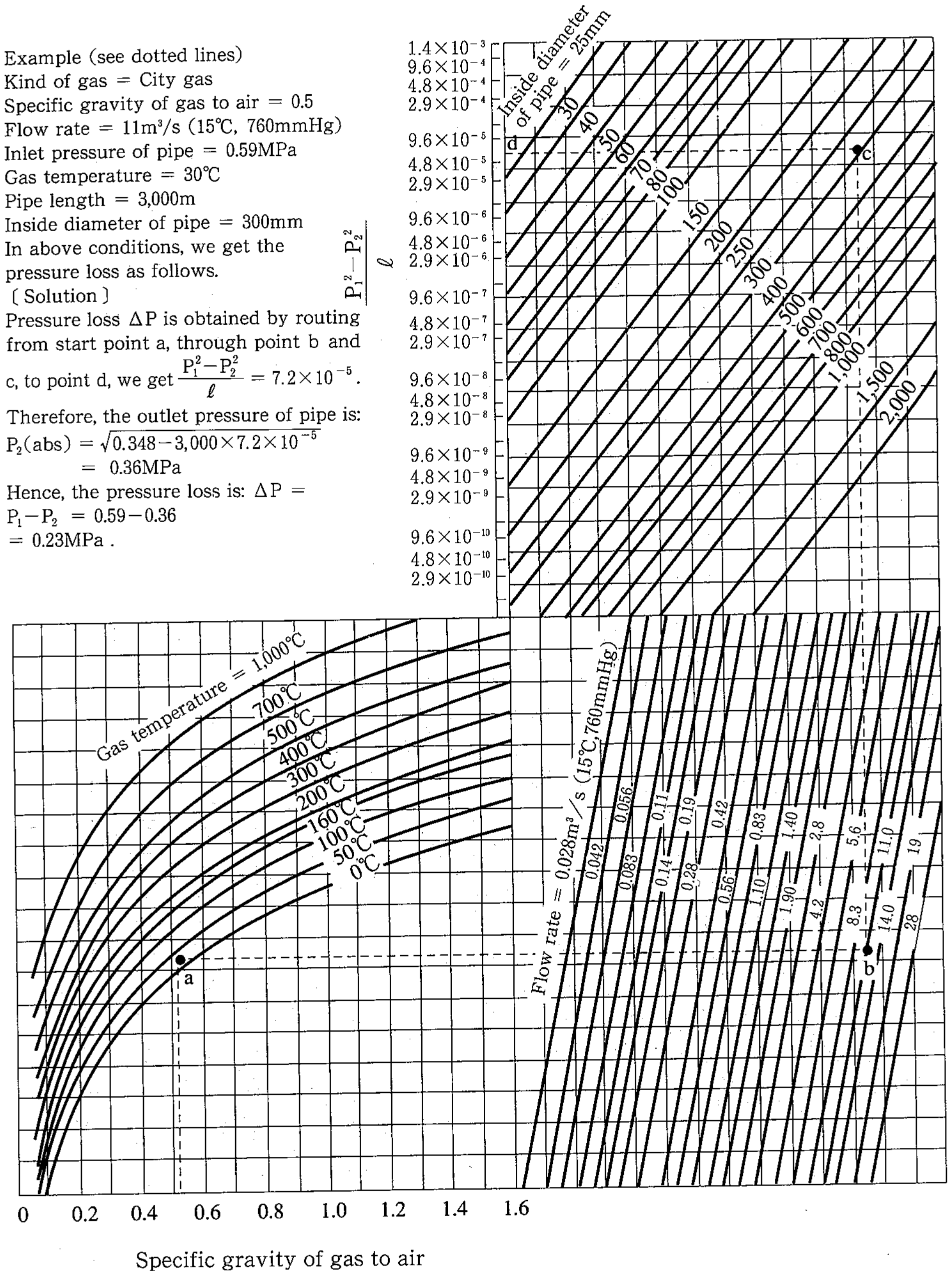
Example (see dotted lines)
Kind of gas = City gas
Specific gravity of gas to air = 0.5
Flow rate = 11m³/s (15℃, 760mmHg)
Inlet pressure of pipe = 0.59MPa
Gas temperature = 30℃
Pipe length = 3,000m
Inside diameter of pipe = 300mm
In above conditions, we get the pressure loss as follows.

〔Solution〕

Pressure loss ΔP is obtained by routing from start point a, through point b and c, to point d, we get $\frac{P_1^2-P_2^2}{\ell} = 7.2\times10^{-5}$.

Therefore, the outlet pressure of pipe is:
$P_2(\text{abs}) = \sqrt{0.348-3,000\times7.2\times10^{-5}}$
$= 0.36\text{MPa}$

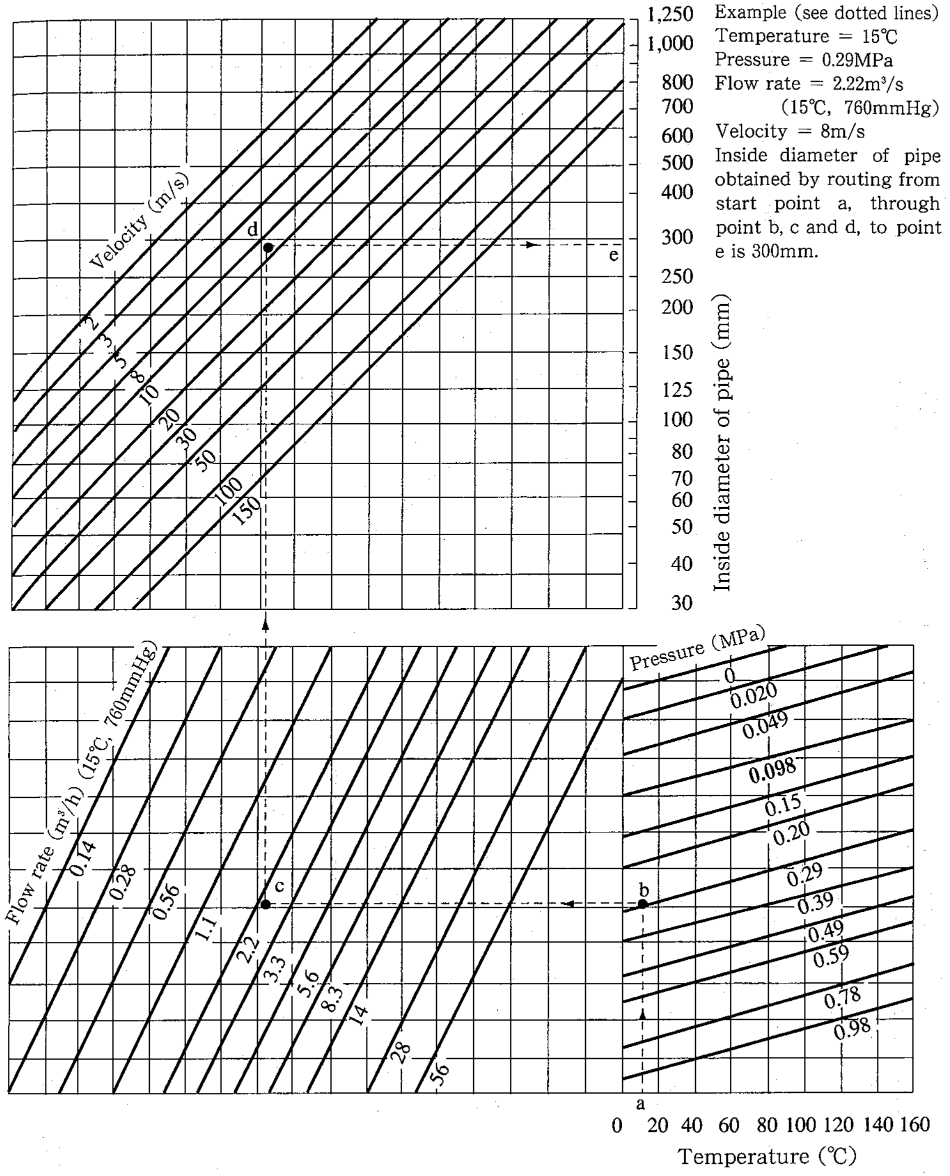
Hence, the pressure loss is: $\Delta P = P_1-P_2 = 0.59-0.36$
$= 0.23\text{MPa}$.



6-10 A Method for Obtaining Inside Diameter of Air and Gas Pipes

Example (see dotted lines)
Temperature = 15℃
Pressure = 0.29MPa
Flow rate = 2.22m³/s
(15℃, 760mmHg)
Velocity = 8m/s

Inside diameter of pipe obtained by routing from start point a, through point b, c and d, to point e is 300mm.

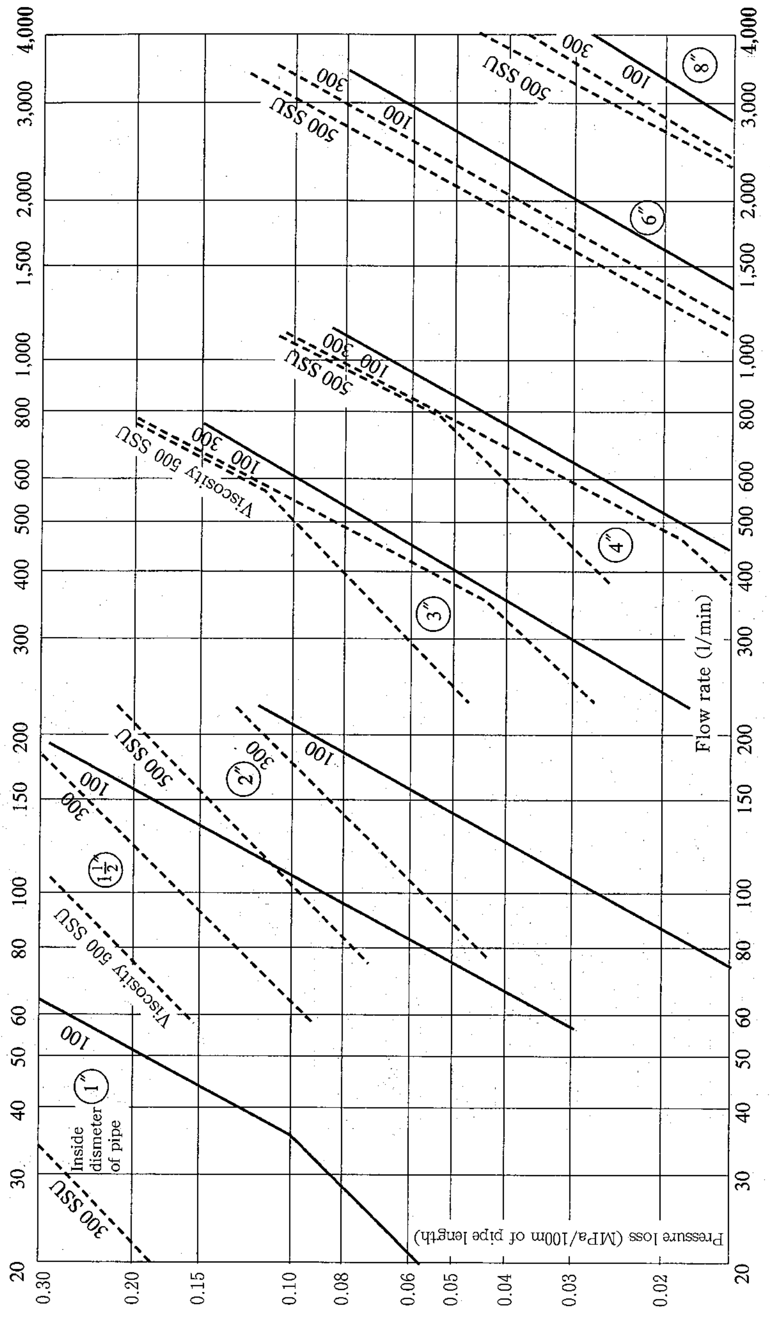


6-11 Pressure Loss of Viscous Fluid in Straight Pipes

This graph is for the fluid of specific gravity 1.0. For other fluids, obtained value shall be multiplied by its specific gravity.

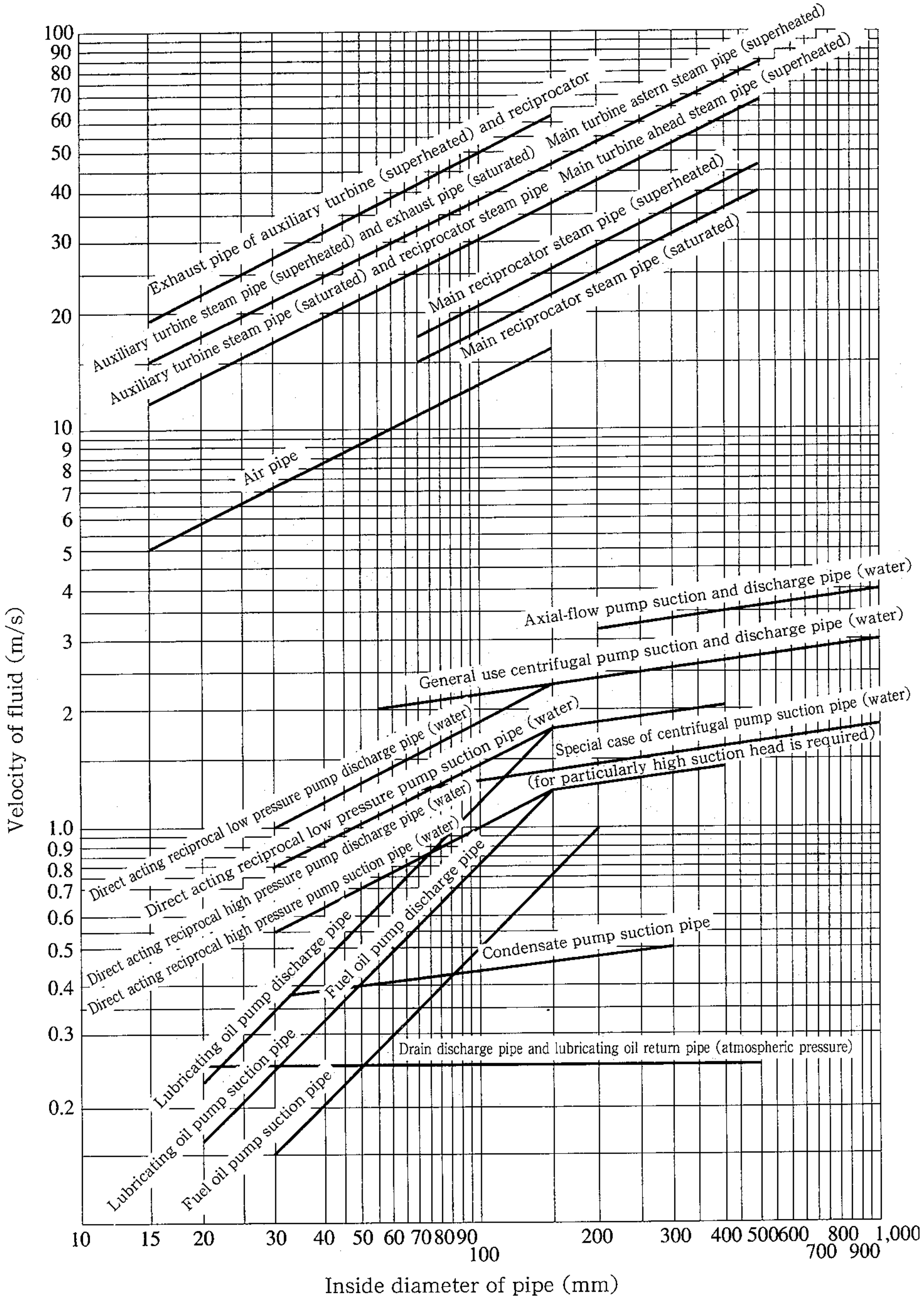
For conversion of viscosity SSU, see clause 10-11.

Using for an actual equipment, it shall have a margin of 15%.

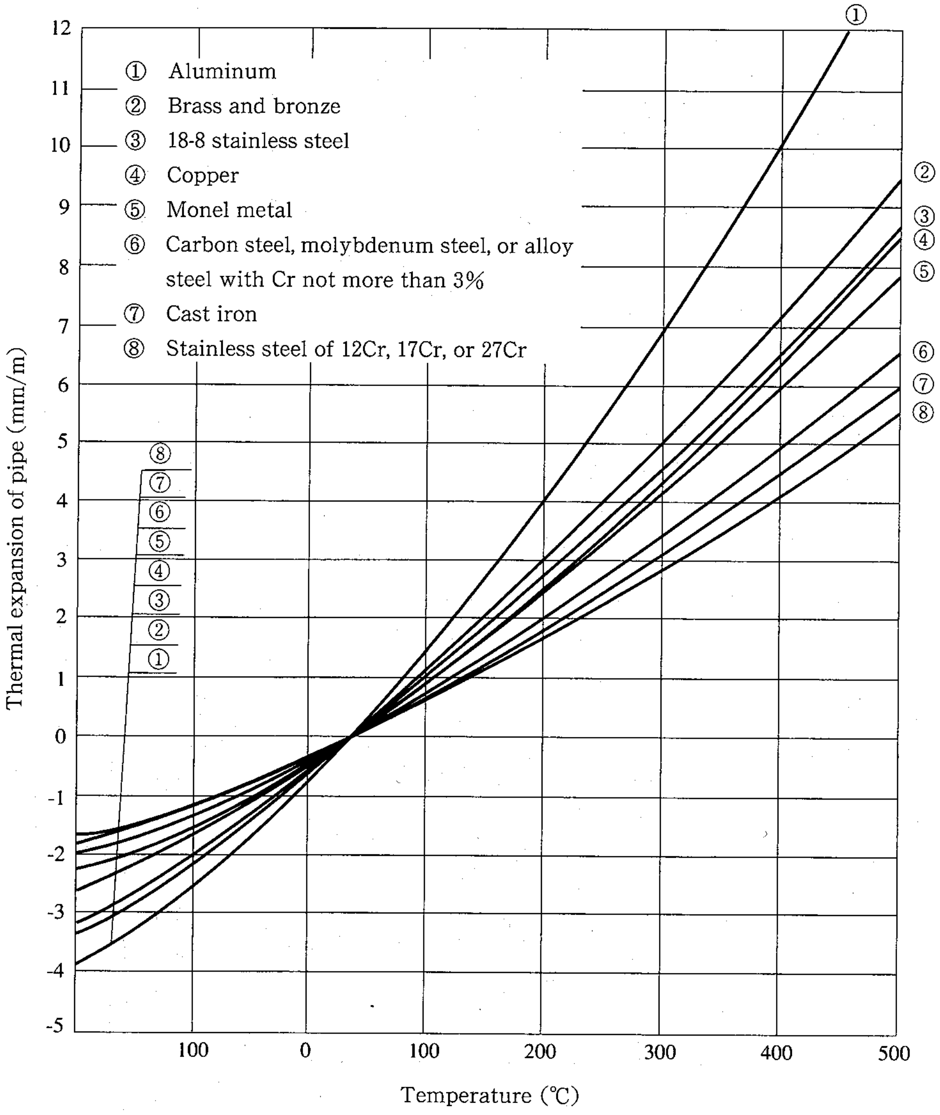


6-12 Standard Velocities of Steam, Water and Oil in Pipes

[Source: JIS F 7101 (1975)]



6-13 Thermal Expansion of Pipe Materials



6-14 Identification Marking for Piping Systems

[Source: JIS Z 9102 (1987)]

Identification marking for piping systems aims at safety and proper operation of piping system, by protecting miss handling of valves.

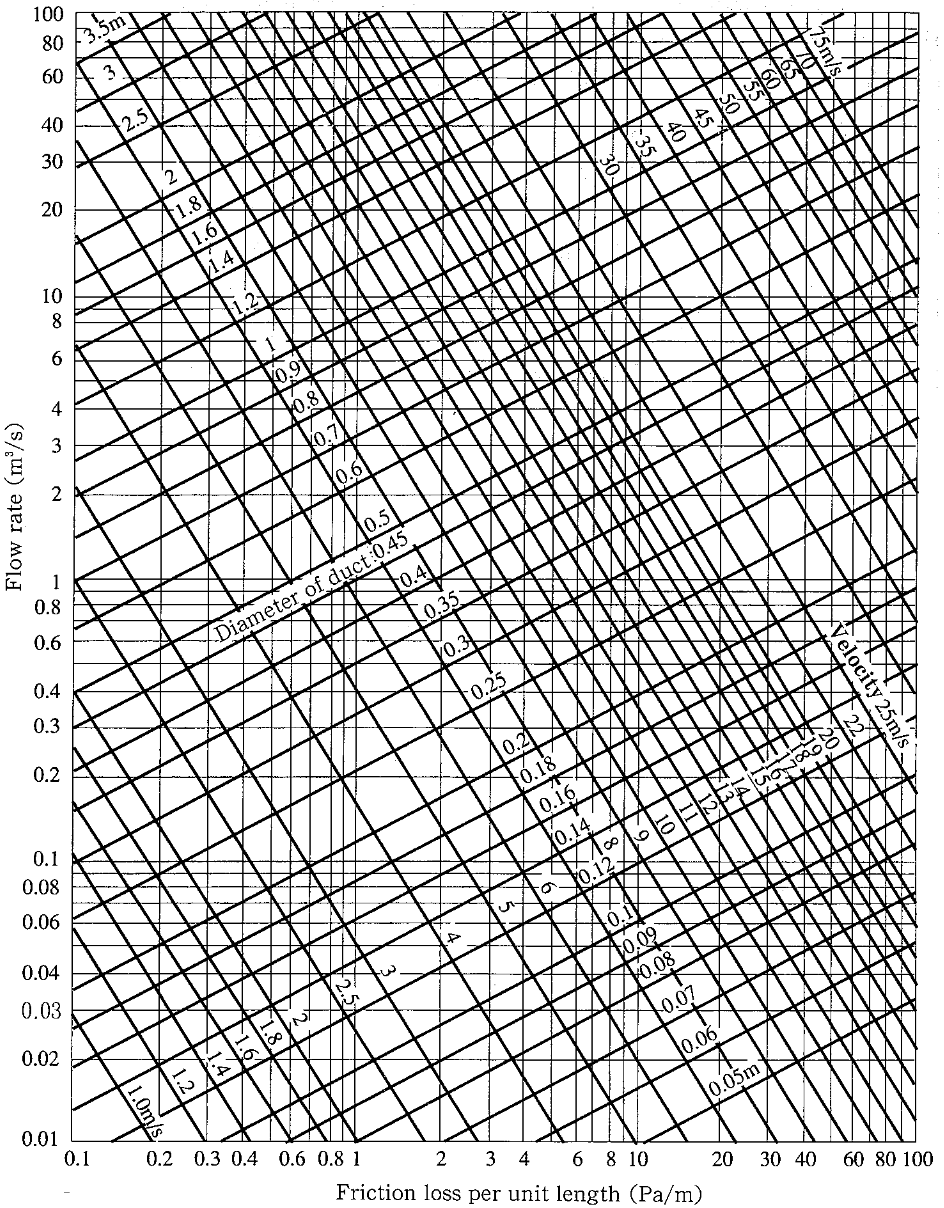
Identification marking of the kind of substance in a pipe is indicated using seven colors shown in the following table.

Kind of material	Identification color	Reference of color
Water	Blue	2.5PB5/8
Steam	Dark red	7.5R3/6
Air	White	N9.5
Gas	Pale yellow	2.5Y8/6
Acid and alkali	Grayish purple	2.5P5/5
Oil	Brown	7.5YR5/6
Electricity	Pale yellowish red	2.5YR7/6

6-15 Friction Loss of Ducts (for example)

As an example, Fig. 1 shows the friction loss of duct in case of following conditions. Fluid = standard atmospheric pressure air, relative humidity = 60%, duct = circular duct with galvanized steel (roughness, ε = 0.18mm).

Fig.1 Friction loss of duct



〔Source: Mechanical Engineers' Handbook, Part B8, edited by The Japan Society of Mechanical Engineers, 1987.〕

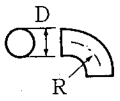
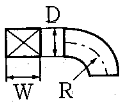
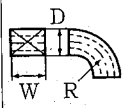
6-16 Circular Duct Equivalent to Rectangular Duct

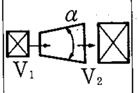
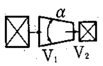
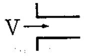
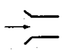
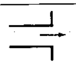
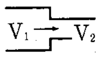
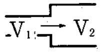
The diameter *De* of circular duct (it is called "Circular equivalent of rectangular duct") which gives the same friction loss of rectangular duct sized a×b is obtained by:

$$De = 1.3\left[\frac{(ab)^5}{(a+b)^2}\right]^{0.125}$$

〔Source: Mechanical Engineers' Handbook, Part B8, edited by The Japan Society of Mechanical Engineers, 1987.〕

6-17 Equivalent Length of Circular Ducts to Various Shapes Ducts

Shape of duct		Form	Condition		Equivalent circular duct length
Circular bend			R/D	0.5	43D
				0.75	23D
				1.0	15D
				1.5	10D
				2.0	9 D
Bend of rectangular cross section	Without guide vane		W/D	R/D	
			0.5	0.5	79D
				0.75	29D
				1.0	17D
				1.5	11D
			1 ~ 3	0.5	57D
				0.75	20D
				1.0	12D
				1.5	8 D
	With guide vane		1	0.5	42D
				0.75	10D
				1.0	8 D
				1.5	7 D
			2	0.5	27D
				0.75	7 D
				1.0	6 D
				1.5	5 D

Shape of duct	Form	Condition		Equivalent circular duct length
Diffusion duct	 Loss for V_1-V_2	α	5°	10D
			10°	17D
			20°	27D
			30°	36D
			40°	43D
Tapering duct	 Loss for V_2	α	30°	1 D
			40°	2 D
			60°	4 D
Abruptly reducing inlet				30D
Inlet with bell-mouth				2 D
Abrupt outlet				60D
Outlet with bell-mouth				60D
Abrupt reduction	 Loss for V_2	V_1/V_2	0	30D
			0.25	27D
			0.5	19D
			0.75	11D
Abrupt expansion	 Loss for V_1	V_2/V_1	0	60D
			0.2	39D
			0.4	22D
			0.6	9 D
			0.8	2 D

6-18 Working Pressure-Temperature Ratings of Valves

Working pressure temperature ratings for first and second class valve (for thermal electric power generation station valve) of the Standard for Electric Power E-101, and for flanged valve and welding end valve (for nuclear electric power generation class 1 and class 3 valve) of appendix table of MITI notification No.501 (1994), are showed in table 6-18-1 and 6-18-2 respectively, about typical valve body materials SCPH2 (WCB), SCPH21 (WC6) and SCPH32 (WC9).

The pressure temperature ratings of valve with other materials, based on E-101 of the above and the notification No. 501, shall be referred these standards respectively.

[Notes about table 6-18-1]

(Note 1) First class valve shall be applied for flanged valve and welding end valve, and second class valve shall be applied for welding end valve. Second class valve can be used in the higher pressure temperature class compared with first class valve, by carrying out a non-destructive test (radiographic test or ultrasonic test as volume test, and magnetic test or liquid penetrant test as surface test) on body and bonnet in addition to the inspection of first class valve, and raising the quality of a product.

(Note 2) When flanges other than flange of ANSI B16.5 are used for the flanged valve, if the allowable pressure of the flange (in the case of JIS flange, it shall be based on JIS B 2201-1984 "Pressure Rating for Ferrous Material Pipe Flanges") is higher than the allowable pressure of this table, the value of this table shall be use, and if the allowable pressure of the flange is lower than this table, the allowable pressure of the flange shall be used.

(Note 3) As the unit of the Standard for Electric Power E-101 (1987) is in metric, values of pressure temperature ratings table are converted from MKS system to SI system of units. Conversion method is same of the MITI notification No. 501 (1984), the calculated pressure of $kg/cm^2 \times 0.098$ 0665= MPa is rounded to the nearest whole number at third decimal point.

Table 6-18-1(1) Working Pressure – Temperature Ratings by Standard for Electric Power E-101 (SCPH2)
Unit : MPa

Temperature (℃)	Working pressures by classes (LB)													
	150	300	600	900	1500	2000	2500	3500	4500	1500 II	2000 II	2500 II	3500 II	4500 II
-30~38	1.96	5.10	10.20	15.30	25.50	34.03	42.56	59.53	78.59	25.89	34.52	43.05	60.31	77.57
93	1.81	4.66	9.32	13.93	23.24	30.99	38.74	54.33	69.82	25.89	34.52	43.05	60.31	77.57
149	1.57	4.51	9.07	13.63	22.65	30.20	37.76	52.76	67.86	25.89	34.52	43.05	60.31	77.57
204	1.37	4.36	8.78	13.14	21.87	29.13	36.38	50.99	65.51	25.89	34.52	43.05	60.31	77.57
260	1.18	4.12	8.29	12.36	20.69	27.56	34.42	48.15	61.88	25.89	34.52	43.05	60.31	77.57
316	0.98	3.78	7.55	11.28	18.83	25.11	31.48	44.03	56.58	24.61	32.75	40.99	57.37	73.75
343	0.88	3.68	7.40	11.08	18.53	24.71	30.89	43.15	55.51	24.12	32.17	40.21	56.19	72.28
371	0.74	3.68	7.35	10.98	18.34	24.52	30.60	42.88	55.11	23.93	31.87	39.81	55.80	71.78
399	0.64	3.48	6.96	10.40	11.47	23.14	28.93	40.50	52.17	21.67	28.93	36.19	50.70	65.12
427	0.54	2.84	5.69	8.53	14.22	18.93	23.63	33.05	42.56	17.75	23.63	29.52	41.38	53.15
454	0.44	1.86	3.68	5.59	9.22	12.36	15.40	21.48	27.65	11.47	15.40	19.22	26.87	34.62

Table 6-18-1(2) Working Pressure – Temperature Ratings by Standard for Electric Power E-101 (SCPH21)
Unit : MPa

Temperature (℃)	Working pressures by classes (LB)													
	150	300	600	900	1500	2000	2500	3500	4500	1500 II	2000 II	2500 II	3500 II	4500 II
-30~38	2.01	5.15	10.35	15.49	25.89	34.52	43.05	60.31	77.57	25.89	34.52	43.05	60.31	77.57
93	1.81	4.90	9.81	14.71	24.52	32.75	40.89	57.27	73.65	25.89	34.52	43.05	60.31	77.57
149	1.57	4.66	9.27	13.93	23.24	30.89	38.64	54.13	69.53	25.89	34.52	43.05	60.31	77.57
204	1.37	4.56	9.07	13.63	22.65	30.20	37.85	52.96	68.06	25.89	34.52	43.05	60.31	77.57
260	1.18	4.41	8.88	13.24	22.16	29.52	36.87	51.68	66.39	25.89	34.52	43.05	60.31	77.57
316	0.98	4.17	8.34	12.55	20.89	27.85	34.72	48.64	62.08	25.89	34.52	43.05	60.31	77.57
343	0.88	4.07	8.09	12.16	20.30	27.07	33.83	47.37	60.80	24.81	33.05	41.38	57.96	74.43
371	0.74	3.92	7.85	11.77	19.61	26.09	32.66	45.70	58.74	23.83	31.68	39.62	55.51	71.39
399	0.64	3.68	7.35	10.98	18.34	24.42	30.50	42.76	54.92	22.85	30.50	38.15	53.45	68.74
427	0.54	3.53	7.01	10.49	17.55	23.34	29.13	40.80	52.47	21.87	29.13	36.48	50.99	65.61
454	0.44	3.33	6.72	10.10	16.77	22.36	27.95	39.23	50.41	20.99	27.95	34.91	48.94	62.96
482	0.34	3.09	6.23	9.32	15.49	20.69	25.79	36.19	46.48	19.42	25.79	32.26	45.21	58.06
510	0.25	2.60	5.20	7.75	13.04	17.36	21.67	30.40	39.03	16.28	21.67	27.07	37.95	48.74
538	0.15	1.57	3.09	4.61	7.65	10.30	12.85	17.95	23.05	9.61	12.85	15.98	22.46	28.83
566	0.15	0.98	1.91	2.84	4.71	6.28	7.94	11.08	14.22	5.88	7.94	9.90	13.83	17.75
593	0.15	0.64	1.32	1.96	3.33	4.41	5.49	7.75	9.90	4.12	5.49	6.86	9.61	12.45

Table 6-18-1(3) Working Pressure – Temperature Ratings by Standard for Electric Power E-101 (SCPH32)
Unit : MPa

Temperature (℃)	Working pressures by classes (LB)													
	150	300	600	900	1500	2000	2500	3500	4500	1500 II	2000 II	2500 II	3500 II	4500 II
-30~38	2.01	5.15	10.35	15.49	25.89	34.52	43.05	60.31	77.57	25.89	34.52	43.05	60.31	77.57
93	1.81	4.95	9.86	14.81	24.71	32.95	41.09	57.57	74.04	25.89	34.52	43.05	60.31	77.57
149	1.57	4.66	9.37	14.02	23.34	31.09	38.83	54.43	70.02	25.89	34.52	43.05	60.31	77.57
204	1.37	4.46	8.92	13.44	22.36	29.81	37.27	52.17	66.98	25.89	34.52	43.05	60.31	77.57
260	1.18	4.41	8.83	13.24	22.06	29.42	36.77	51.48	66.19	25.40	33.93	42.36	59.33	76.30
316	0.98	4.17	8.34	12.55	20.89	27.85	34.72	48.64	62.57	25.40	33.93	42.36	59.33	76.30
343	0.88	4.07	8.09	12.16	20.30	27.07	33.83	47.37	60.80	25.40	33.93	42.36	59.33	76.30
371	0.74	3.92	7.85	11.77	19.61	26.09	32.66	45.70	58.74	25.30	33.73	42.17	58.94	75.81
399	0.64	3.68	7.35	10.98	18.34	24.42	30.50	42.76	54.92	25.11	33.54	41.87	58.64	75.32
427	0.54	3.53	7.01	10.49	17.55	23.34	29.13	40.80	52.47	24.81	33.05	41.38	57.96	74.43
454	0.44	3.33	6.72	10.10	16.77	22.36	27.95	39.23	50.41	23.34	31.09	38.93	54.52	70.02
482	0.34	3.09	6.23	9.32	15.49	20.69	25.79	36.19	46.48	20.69	27.56	34.52	48.25	62.08
510	0.25	2.60	5.20	7.75	13.04	17.36	21.67	30.40	39.03	16.28	21.67	27.07	37.95	48.74
538	0.15	1.86	3.68	5.59	9.22	12.36	15.40	21.48	27.65	11.47	15.40	19.22	26.87	34.62
566	0.15	1.37	2.75	4.12	6.86	9.12	11.47	15.98	20.59	8.63	11.47	14.32	20.01	25.69
593	0.15	0.78	1.57	2.35	3.92	5.20	6.47	9.12	11.77	4.90	6.47	8.14	11.38	14.61

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Table 6-18-2 Allowable Pressure for Valves or Flanges (MPa)

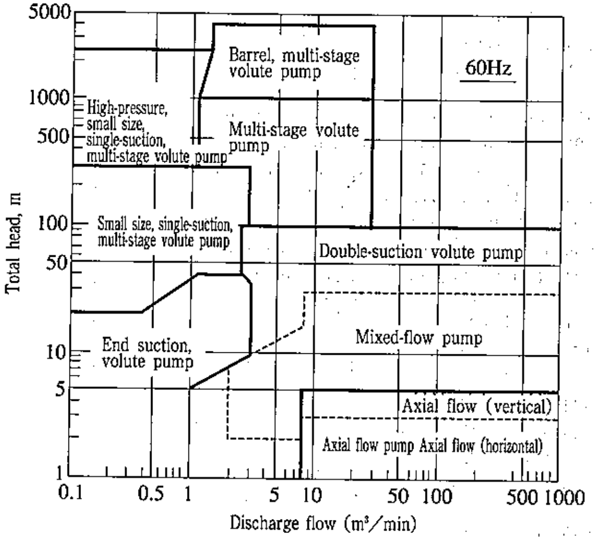
Kind of material	Sort	Nominal pressure MPa	Temperature (℃)																									
			−30 −40	100	150	200	260	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
SB46 and SB49 of JIS G 3103 (1987) "Carbon steel and molybdenum alloy steel plate for boilers and other pressure vessels", SGV49 of JIS G 3118 (1987) "Carbon steel plates for pressure vessels for intermediate and moderate temperature service", S25C and S28C of JIS G 4051 (1979) "Carbon steels for machine structural use", SF45A and SF50A of JIS G 3201 (1988) "Carbon steel forgings for general use", SFVC of JIS G 3202 (1988) "Carbon steel forgings for pressure vessels", SFVQ1 of JIS G 3204 (1988) "Quenched tempered alloy steel forgings", second class of standard for nuclear power generation "Carbon steel forgings for low temperature and alloy steel forgings for low temperature", SC49 of JIS G 5101 (1991) "Carbon Steel Castings", SCPH2 of JIS G 5151 (1991) "Steel castings for high temperature and high pressure service", second class of Standard for Nuclear Power Generation "Carbon steel castings", or carbon steels which have the mechanical strength equivalent to or more than of these.	Flange or flanged valve	1.03	1.96	1.78	1.58	1.39	1.18	1.02	0.93	0.83	0.75	0.65	0.56															
		2.08	5.10	5.08	4.51	4.39	4.14	3.89	3.76	3.69	3.69	3.47	2.86															
		2.78	6.83	6.81	6.03	5.85	5.51	5.17	5.00	4.92	4.89	4.61	3.84															
		4.14	10.21	10.17	9.06	8.80	8.28	7.76	7.50	7.39	7.34	6.95	5.77															
		6.24	15.31	15.25	13.57	13.16	12.38	11.61	11.24	11.08	11.02	10.39	8.63															
		10.40	25.55	25.46	22.60	21.96	20.65	19.36	18.74	18.48	18.36	17.34	14.40															
		17.34	42.54	42.39	37.70	36.57	34.40	32.27	31.24	30.79	30.58	28.89	23.97															
	Welding end valve	1.03	2.00	2.00	2.00	2.00	2.00	1.92	1.88	1.85	1.82	1.65	1.39															
		2.08	5.17	5.17	5.17	5.17	5.17	5.00	4.89	4.82	4.79	4.32	3.60															
		2.78	6.89	6.89	6.89	6.89	6.89	6.65	6.51	6.43	6.36	5.77	4.79															
		4.14	10.35	10.35	10.35	10.35	10.35	9.97	9.77	9.64	9.57	8.65	7.20															
		6.24	15.51	15.51	15.51	15.51	15.51	14.96	14.66	14.45	14.32	12.97	10.80															
		10.40	25.86	25.86	25.86	25.86	25.86	24.94	24.42	24.06	23.90	21.63	17.96															
		17.34	43.09	43.09	43.09	43.09	43.09	41.55	40.69	40.09	39.81	36.05	29.94															
SCMV3 of JIS G 4109 (1987) "Chromium-molybdenum alloy steel plates for boilers and pressure vessels" , SFVA of JIS G 3203 (1988) "Alloy steel forgings for pressure vessels for high-temperature service", SCPH21 of JIS G 5151 (1991) "Steel castings for high temperature and high pressure service", or alloy steels which have the mechanical strength equivalent to or more than of these.	Flange or flanged valve	1.03	2.00	1.77	1.58	1.39	1.18	1.02	0.93	0.83	0.75	0.65	0.56	0.46	0.37	0.28	0.19	0.09										
		2.08	5.17	4.86	4.65	4.56	4.41	4.24	4.14	4.04	3.91	3.65	3.53	3.37	3.17	2.78	2.03	1.28										
		2.78	6.89	6.51	6.17	6.08	5.89	5.65	5.50	5.38	5.18	4.88	4.67	4.51	4.22	3.71	2.70	1.70										
		4.14	10.35	9.77	9.27	9.08	8.86	8.48	8.26	8.04	7.79	7.33	7.02	6.77	6.33	5.56	4.05	2.55										
		6.24	15.51	14.62	13.93	13.64	13.27	12.73	12.40	12.08	11.01	10.97	10.54	10.14	9.50	8.34	6.08	3.83										
		10.40	25.86	24.39	23.19	22.73	22.13	21.21	20.65	20.13	19.49	18.31	17.56	16.91	15.83	13.90	10.13	6.38										
		17.34	43.09	40.62	38.63	37.89	36.88	35.34	34.43	33.60	32.44	30.49	29.24	28.18	26.38	23.16	16.89	10.64										
	Welding end valve	1.03	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.88	1.81	1.76	1.70															
		2.08	5.17	5.17	5.17	5.17	5.17	5.17	5.17	4.91	4.74	4.58	4.39															
		2.78	6.89	6.89	6.89	6.89	6.89	6.89	6.89	6.55	6.31	6.09	5.84															
		4.14	10.35	10.35	10.35	10.35	10.35	10.35	10.35	9.83	9.46	9.16	8.78															
		6.24	15.51	15.51	15.51	15.51	15.51	15.51	15.51	14.74	14.20	13.74	13.17															
		10.40	25.86	25.86	25.86	25.86	25.86	25.86	25.86	24.58	23.66	22.86	21.92															
		17.34	43.09	43.09	43.09	43.09	43.09	43.09	43.09	40.95	39.43	38.10	36.54															
SFVA of JIS G 3203 (1988) "Alloy steel forgings for pressure vessels for high-temperature service", SCPH32 of JIS G 5151 (1991) "Steel castings for high temperature and high pressure service", or alloy steels which have the mechanical strength equivalent to or more than of these.	Flange or flanged valve	1.03	2.00	1.77	1.58	1.39	1.18	1.02	0.93	0.83	0.75	0.65	0.56															
		2.08	5.17	4.90	4.65	4.49	4.41	4.24	4.14	4.04	3.72	3.65	3.52															
		2.78	6.89	6.55	6.24	5.98	5.89	5.65	5.50	5.38	5.18	4.88	4.67															
		4.14	10.35	9.80	9.34	8.96	8.83	8.47	8.26	8.04	7.79	7.33	7.02															
		6.24	15.51	14.74	13.98	13.45	13.24	12.72	12.40	12.08	11.70	10.97	10.54															
		10.40	25.86	24.55	23.32	22.42	22.06	21.19	20.65	20.13	19.49	18.31	17.56															
		17.34	43.09	40.89	38.85	37.36	36.75	35.31	34.43	33.60	32.44	30.49	29.24															
	Welding end valve	1.03	2.00	2.00	2.00	2.00	2.00	1.96	1.96	1.96	1.93	1.93	1.90															
		2.08	5.17	5.17	5.17	5.17	5.17	5.10	5.10	5.10	5.06	5.03	4.97															
		2.78	6.89	6.89	6.89	6.89	6.89	6.80	6.80	6.80	6.76	6.69	6.62															
		4.14	10.35	10.35	10.35	10.35	10.35	10.17	10.17	10.17	10.10	10.06	9.93															
		6.24	15.51	15.51	15.51	15.51	15.51	15.24	15.24	15.24	15.15	15.06	14.91															
		10.40	25.86	25.86	25.86	25.86	25.86	25.41	25.41	25.41	25.25	25.12	24.84															
		17.34	43.09	43.09	43.09	43.09	43.09	42.36	42.36	42.36	42.09	41.84	41.39															

7-1 Classification and Applicable Ranges of Pumps

(1) Classification of pumps

- Pumps
  - Turbo-pumps
    - Centrifugal pumps……volute pump and diffuser pump
    - Mixed-flow pumps……volute type mixed flow pump and mixed-flow pump
    - Axial-flow pump
  - Non-conventionally structured turbo-pump……submersible motor pump, tubular type pump, self-priming pump, canned motor pump, in-line pump, non-clogging pump, etc.
  - Positive-displacement pumps
    - Reciprocating pumps……piston pump, plunger pump, diaphragm pump, etc.
    - Rotary pumps……gear pump, screw pump, cam pump, vane pump, etc.
  - Special pumps…… peripheral pump, shear force pump, air lift pump, jet pump, electromagnetic pump, etc.

(2) Applicable ranges of turbo-pumps



[Source: Mechanical Engineers' Handbook, edited by the Japan Society of Mechanical Engineers, 6th edition(1976)]

NOTE: The boundary line of the pump types in the above figure are not strict. The figure shows the applicable range for 60Hz, but the head of single-stage pumps directly coupled with the motor are made slightly narrow for 50Hz. For final decision of selection, refer to the manufacturer's catalog.

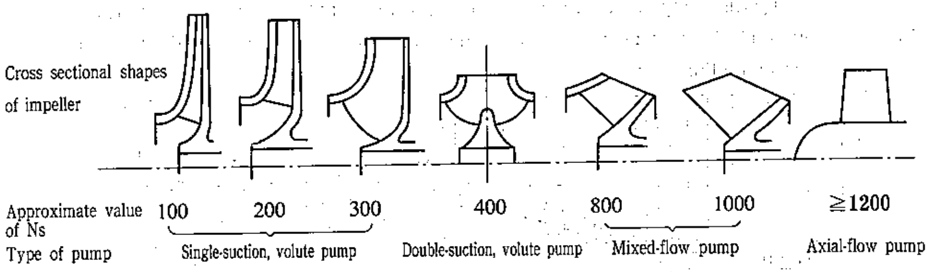
(3) Specific speed and turbo-pump types

Specific speed $Ns = n \cdot Q^{1/2}/H^{3/4}$

n: rotating speed (rpm), Q: discharge flow (to be halved for double-suction impeller) (m³/min.)

H: total head (head per one stage for multi-stage pump) (m)

The specific speed is a value derived from a hydraulic similarity law of pumps, which is constant irrespective of impeller size and rotating speed for geometric similar impellers and is always calculated at the best efficiency point. It is used for classifying the pump types in view of practical use. The following figure shows cross sectional shapes of impellers arranged in order of the value of the specific speed *Ns* and types of T corresponding to them.



7-2 Pump Bore and Total Head

(1) Pump bore and total head

Pump size is represented by suction and discharge bore for horizontal pumps or by discharge bore for vertical pumps. Even for the vertical pumps, pit barrel type is represented by both suction bore and discharge bore. The following figure shows a relation between bore of discharge pipe and flow rate.

(2) Total head

$$H = \frac{1}{\rho g}(P_2 - P_1) + h_s + h_f + \frac{V_d^2}{2g}$$

H: total head (m),

P_2: pressure acting on a discharge liquid surface (Pa)

P_1: pressure acting on a suction liquid surface (Pa)

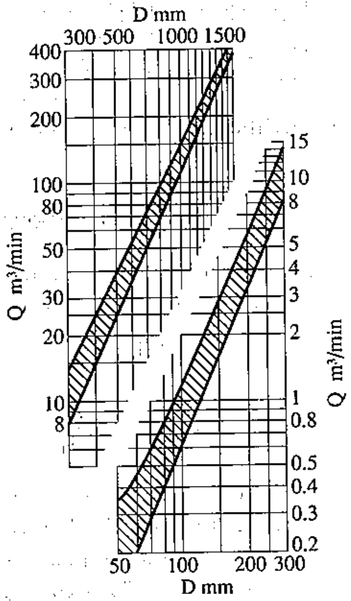
h_s: actual height (m)

h_f: loss of head in the pipe (m),

V_d: flow velocity (m/s) at the end of pipe line,

g: acceleration of gravity of 9.81 (m/s²),

ρ: density of liquid (kg/m³)



Relation between a discharge bore and flow rate

[Source: Mechanical Engineers' Handbook, Part B5, edited by The Japan Society of Mechanical Engineers, (1987)]

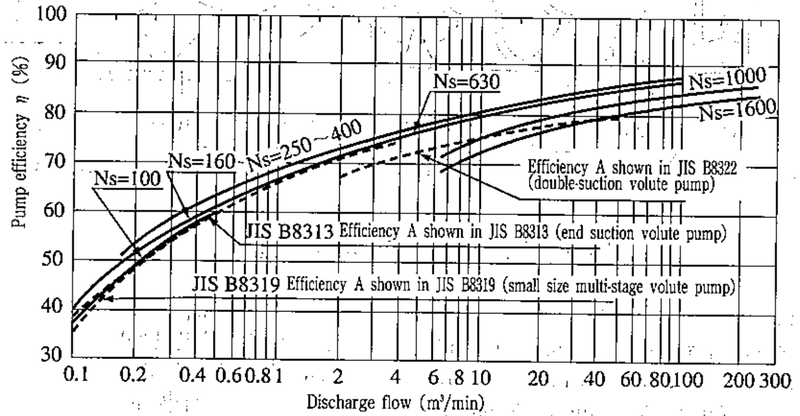
7-3 Pump Efficiency and Required Power

If a pump efficiency is estimated, a shaft power of pump can be obtained by

$$P = \frac{16.3\rho \cdot Q \cdot H}{\eta}$$

where, P: shaft power of pump (kW) ρ: density of fluid (kg/l)
Q: discharge flow (m^3/min) H: total head (m) η: pump efficiency (%)

The following graph shows standard pump efficiencies prepared by researches of the JIS standard and the Federation of Pump Engineers.



NOTE: Efficiency A shows a lower limit of a maximum efficiency for volute pump.

7-4 Temperature Rise in Pumps

A temperature rise Δt in ℃ inside a pump at the given discharge flow can be obtained by

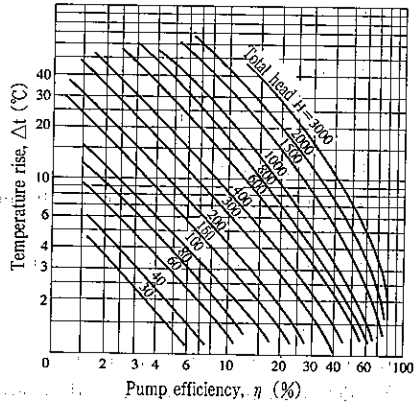
$$\Delta t = \frac{100-\eta}{427 \cdot \eta} H$$

where,

η: pump efficiency (%) for the given discharge flow

H: total head (m) for given discharge flow.

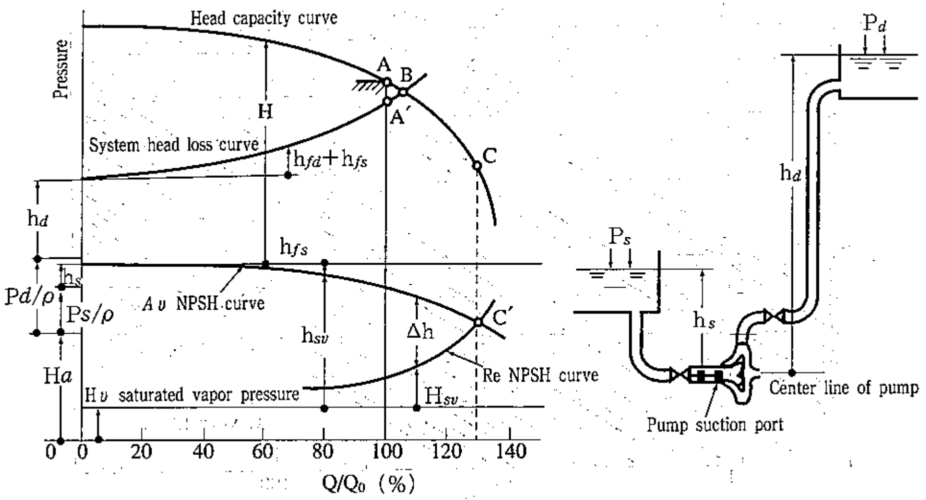
A temperature rise is usually limited 10 ℃to 20 ℃ degree. A minimum flow of pump is defined in view of the discharge flow corresponding to temperature rise, the discharge flow required for inceptive cavitations and stability of pump rotor.



Curves for obtaining pump efficiency with respect to temperature rise and total head. (Explanation in JIS B 8307-1976)

7-5 Net Positive Suction Head (NPSH) of Pumps

(1) Illustration for the NPSH



Available NPSH (Av NPSH)

$$hsv = (Ha + Ps/\rho + h_s - h_{fs}) - Hv$$

This value is determined in terms of the piping route arrangement in the plant and is changed by Q.

Required NPSH (Re NPSH) Hsv

This value is determined by the pump design and is changed by Q.

NPSH margin $\Delta h = h_{sv} - H_{sv}$

A: pump design specification point
A′: required head
B: pump operating point.
C, C′: cavitation limits.
H: pump total head.
Ha: atmospheric pressure.
Ps/ρ: static pressure acting on suction liquid surface (Head)
Pd/ρ: static pressure acting on output liquid surface (Head)

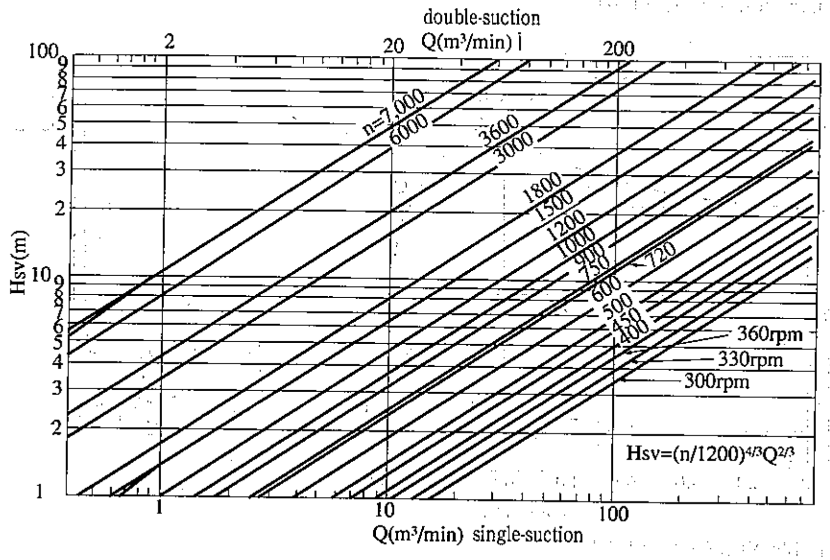
<Explanation of terms>

Cavitation: A flow velocity and pressure inside pump remarkably change. If the pressure at a certain area inside pump descends below steam saturated pressure of pumping liquid at the liquid temperature, liquid will be vaporized and vapor cavity is generated and collapsed. This phenomenon is called Cavitation and as the pressure is decreased further more, pump efficiency and generated head will be fallen, the noise level and vibration level will be increased due to collapse of vapor cavity and finally causes erosion damage of the impellers and casing.

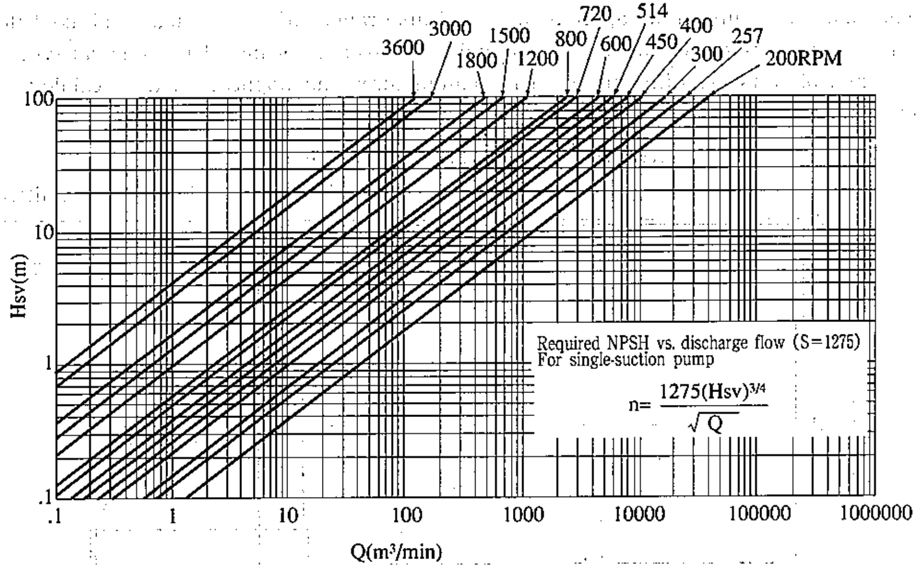
NPSH: The difference between the total pressure of the liquid in a pump impeller entrance and steam saturated pressure means the margin against generating a pump cavitation. Then, the pressure difference expressed with the head is called Net Positive Suction Head (NPSH), and NPSH decided from an actual pump operating condition is called available NPSH. On the other hand, if rotation speed and flow are constant about a certain pump and available NPSH is descended, a cavitations will occur at the certain NPSH. This NPSH at this time is called required NPSH of the pump.

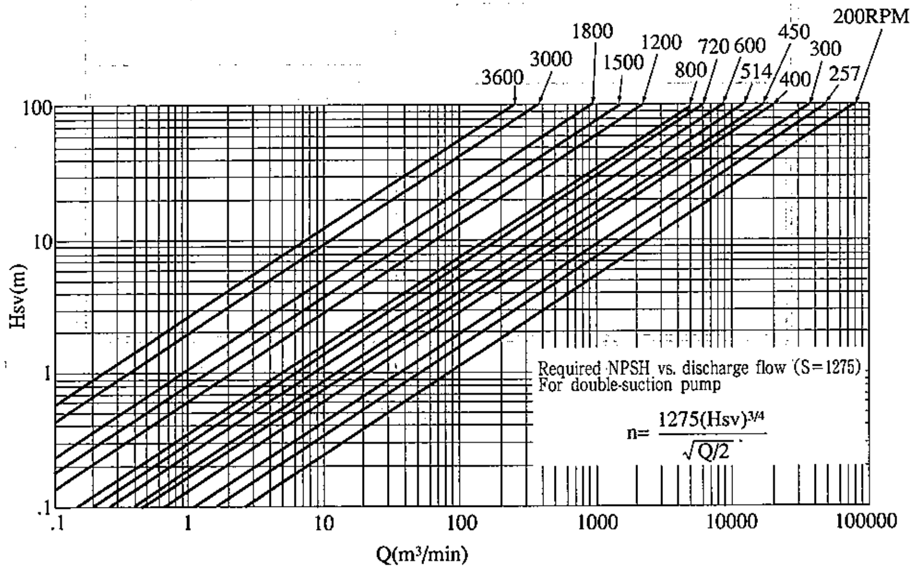
(2) Required NPSH

In the case of suction specific speed: $S = nQ^{1/2}/Hsv^{3/4} = 1{,}200$



(3) NPSH of centrifugal pump



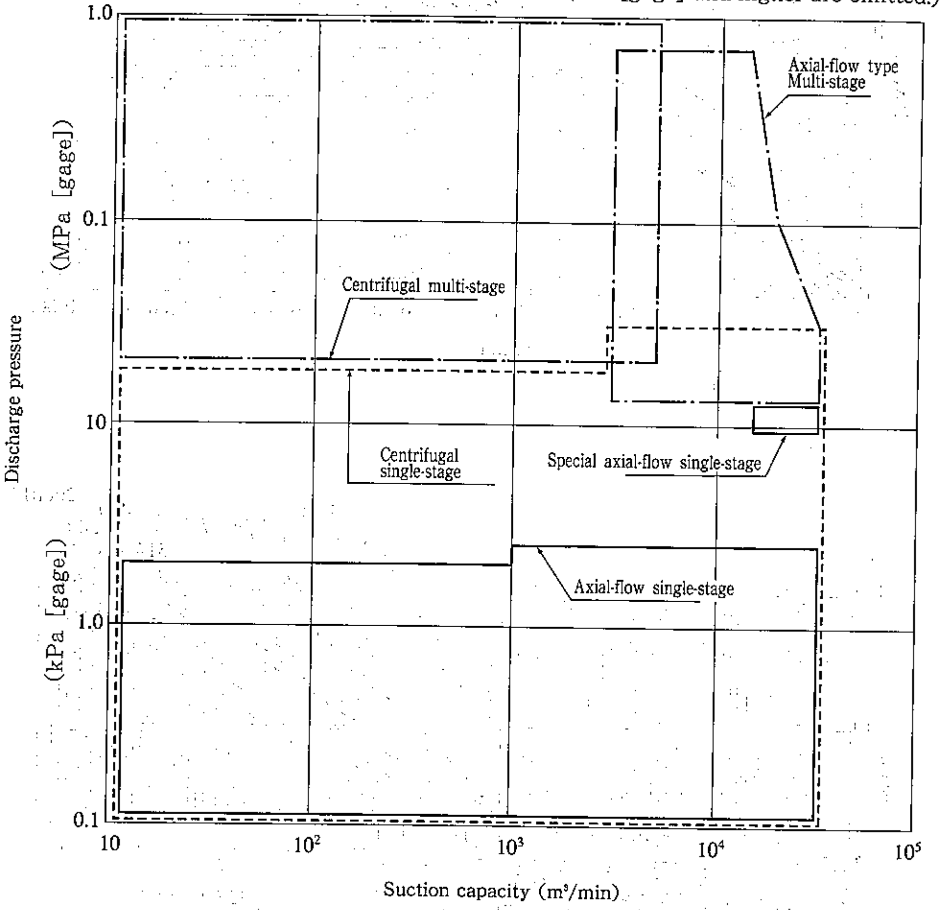


8-1 Types and Applicable Ranges of Fans and Blowers

The following figure shows approximate applicable ranges of a centrifugal and axial flow fans and blowers for both a single stage and a multi-stages of impeller. As actual types of fans and blowers are different to their manufacturer and application, their catalog and pamphlet may be referred.

Applicable ranges of fans and blowers

(Discharge pressure 1 MPa [gage] and higher are omitted.)



8-2 Required Power of Fans and Blowers

The required power for a fan, a turbo-blower and a compressor shall be calculated by the following equations.

(1) For a pressure ratio higher than 1.03 and lower than 1.1 (JIS B 8330, 1981)

$$L_T = \frac{\kappa}{\kappa-1} \cdot \frac{P_{T1}Q_1}{60\times10^3}\left[\left(\frac{P_{T2}}{P_{T1}}\right)^{\frac{\kappa-1}{\kappa}} -1\right](\mathrm{kW}) \quad \cdots\cdots(1)$$

where L_T =total pressure air power (kW)
Q_1 =suction capacity (m³/min)
P_{T1} =suction total pressure $(=P_{S1}+P_{d1})$ (Pa)
P_{T2} =discharge total pressure $(=P_{S2}+P_{d2})$ (Pa)
P_{S1} =suction static pressure (Pa)
P_{S2} =discharge static pressure (Pa)
P_{d1} =suction dynamic pressure (Pa)
P_{d2} =discharge dynamic pressure (Pa)
κ =specific heat ratio $(=C_P/C_V)$, which is 1.4 for air

(2) For a pressure ratio 1.03 or lower (JIS B 8330, 1981)

$$L_T = \frac{Q_1}{60\times10^3}[(P_{s2}-P_{s1})+(P_{d2}-P_{d1})](\mathrm{kW}) \quad \cdots\cdots(2)$$

(3) For pressure ratio 1.1 or higher (JIS B8340, 1995)

If the intercooler is not provided, theoretical adiabatic air power L_{ad} is to be calculated on the basis of the adiabatic compression. If the power which the intercooler is provided is calculated in terms of the full pressure ratio, a theoretical isothermal air power L_{is} is to be calculated on the basis of the isothermal compression. The air powers are calculated respectively as follows.

$$L_{ad} = \frac{\kappa}{\kappa-1} \cdot \frac{P_1Q_1}{60\times10^3}\left[\left(\frac{P_2}{P_1}\right)^{\frac{\kappa-1}{\kappa}} -1\right](\mathrm{kW}) \quad \cdots\cdots(3)$$

$$L_{is} = \frac{P_1Q_1}{60\times10^3}\log_e\left(\frac{P_2}{P_1}\right) = \frac{P_1Q_1}{26.06\times10^3}\log_{10}\left(\frac{P_2}{P_1}\right)(\mathrm{kW}) \quad \cdots\cdots(4)$$

where P_1 =absolute suction air pressure (Pa)
Q_1 =air flow converted to suction condition (m³/min)
κ =adiabatic exponent (isentropic exponent) of air, and
P_2 =absolute discharge air pressure (Pa)

(4) Shaft power of fans and blowers

$$S = \frac{L_T}{\eta},\ S = \frac{L_{ad}}{\eta},\ S = \frac{L_{is}}{\eta}$$

where S=shaft power, η =efficiency of fans and blowers.

The efficiency of fans and blowers η differs a little depending on the fans and blowers type and capacity, but an approximate value is

η = 65 to 80%

[Example] Obtain air power of the fans and blowers in the following case;

Q_1 =1,000 m³/min, P_1 =atmospheric pressure and, P_2 =9,000mmAq (=9.8 Pa), without a intercooler.

First, with the atmospheric pressure =10,330mmAq, the pressure ratio is

$$\text{Pressure ratio} = \frac{P_2}{P_1} = \frac{10{,}330+9{,}000}{10{,}330} \fallingdotseq \frac{19{,}330}{10{,}330} = 1.871$$

Therefore, Eq. (3) is used.

$$L_{ad} = \frac{1.4}{1.4-1}\times\frac{10{,}330\times9.8\times1{,}000}{60\times10^3}\times\{1.871^{\frac{1.4-1}{1.4}}-1\} = 3.5\times1.687\times\{1.871^{0.286}-1\}$$
$$\fallingdotseq 1{,}160\mathrm{kW}$$

8-3 Flow Control of Fans and Blowers

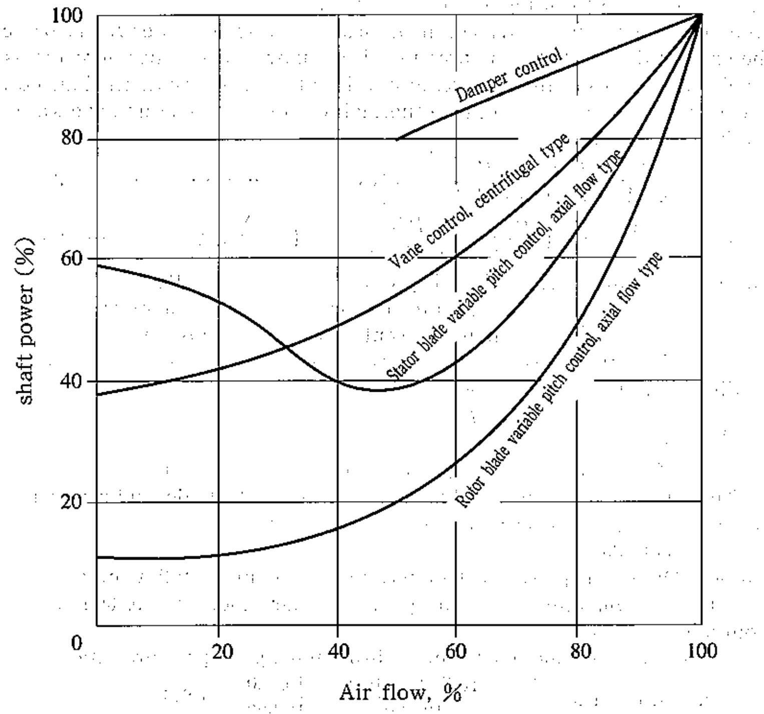
(1) Flow control method of fans and blowers

Flow control methods of fans and blowers include:

Control methods……
- Damper control
- Vane control (centrifugal type)
- Rotor blade variable pitch control (axial flow type)
- Stator blade variable pitch control (axial flow type)
- Speed controls……
  - by motor
  - by steam turbine
  - by hydraulic transmission
  - by gear transmission
  - by other methods

(2) Comparison of shaft power by control methods of fans and blowers

(On square resistance curves)



8-4 Compressors

(1) Shaft power of compressor

Shaft power of displacement type compressor (a pressure ratio about 2 or higher) is to be calculated with the equation below (JIS B 8341, 1995)

$$L_s = \frac{L_{ad}}{\eta_{ad}} \times 100$$

where, L_s =shaft power of compressor (kW)

η_{ad} : total adiabatic efficiency (%), (Refer to the table below for example)

L_{ad} : theoretical adiabatic air power (kW)

$$L_{ad} = \frac{(i+1)\kappa}{\kappa-1} \cdot \frac{\mathrm{P_s Q_s}}{60 \times 10^3} \left\{ \left(\frac{\mathrm{P_d}}{\mathrm{P_s}} \right)^{\frac{\kappa-1}{(i+1)\kappa}} - 1 \right\} (\mathrm{kW})$$

P_s : absolute suction air pressure (Pa)

Q_s : air flow converted to suction condition (m³/min)

κ : adiabatic exponent (isentropic exponent) of air

P_d : absolute suction air pressure (Pa)

i : number of intercoolers

Name	Discharge pressure MPa[gage]	Type	Total adiabatic efficiency, %	Volumetric efficiency, %
Air compressor for service air	0.69	Reciprocating, single-stage compression, oil lubricating type	70～78	56～72
		Reciprocating, two-stage compression, oil lubricating type	72～77	81～87
		Screw, two-stage compression, oilless type	64～66	83～88
Oilless compressor for control air	0.69	Reciprocating, single-stage compression, oilless type	67～75	53～72
		Reciprocating, two-stage compression, oilless type	68～73	81～84
		Screw, two-stage compression, oilless type	62～65	81～84
Compressor for soot blower	3.43	Reciprocating, two-stage compression, oil lubricating type	approx. 75	approx. 65
		Reciprocating, three-stage compression, oil lubricating type	78～79	78～84

Note: 1. Care should be taken in the efficiency as that is greatly different depending on compressor capacity and manufacture's model.

2. The volumetric efficiency (%) is represented by percentages of output air flow versus stroke capacity for the reciprocating type and by percentages of output air flow versus suction air flow for the screw type.

(2) Compressor capacity

Reciprocating compressor for service air		
Discharge pressure (MPa[gage)]	Stroke capacity (m³/min)	Motor (kW)
0.69	1.08	5.5
0.69	1.45	7.5
0.69	2.18	11
0.69	3.08	15
0.69	4.62	22
0.69	7.92	37
0.69	11.89	55
0.69	15.84	75
0.69	34.6	150
0.69	43.1	190
0.69	52.5	220
0.69	62.9	300
0.69	86.2	370
0.69	105	440

Reciprocating oilless compressor for control air		
Discharge pressure (MPa[gage)]	Stroke capacity (m³/min)	Motor (kW)
0.69	4.06	18.5
0.69	6.5	30
0.69	10.0	45
0.69	16.9	75

Reciprocating compressor for soot blower		
Discharge pressure (MPa[gage)]	Stroke capacity (m³/min)	Motor (kW)
3.43	25	265
3.43	28	310
3.43	31.5	330
3.43	35	365
3.43	40	415
3.43	45	465
3.43	50	520

Screw oilless compressor					
Discharge pressure (MPa[gage)]	Air flow in the suction condition (m³/min)	Motor (kW)	Discharge pressure (MPa[gage)]	Air flow in the suction condition (m³/min)	Motor (kW)
0.69	2.0	15	0.69	17.2	110
0.69	3.5	22	0.69	20.7	132
0.69	4.5	30	0.69	25.1	160
0.69	5.9	50	0.69	30.0	190
0.69	11.5	75	0.69	36.8	230
0.69	14.0	90	0.69	46.0	280

9-1 Properties of Major Gases

Kinds of Gases		He	H_2	Air	CH_4	N_2	O_2	CO	H_2O	CO_2	SO_2	NH_3
Molecular weight M		4.003	2.016	28.964	16.04	28.013	31.999	28.01	18.015	44.01	64.06	17.03
Density(1) ρ kg/m³$_N$		0.1785	0.08989	1.2930	0.7168	1.2505	1.4290	1.2505	—	1.9770	2.926	0.7713
Specific gravity to air		0.1380	0.0695	1.0000	0.5544	0.9671	1.105	0.9671	0.6220	1.529	2.263	0.5965
Specific heat(2)	c_p kJ/(kg•K)	5.24	14.25	1.005	2.16	1.039	0.914	1.041	1.859	0.819	0.608	2.06
	c_v kJ/(kg•K)	3.16	10.12	0.718	1.63	0.743	0.654	0.743	1.398	0.630	0.479	1.57
	C_p kJ/(kmol•K)	21.0	28.7	29.1	34.7	29.1	29.2	29.2	33.5	36.0	38.9	35.1
	C_v kJ/(kmol•K)	12.6	20.4	20.8	26.1	20.8	20.9	20.8	25.2	27.7	30.7	26.7
$k = c_p / c_v = C_p / C_v$		1.66	1.41	1.40	1.32	1.40	1.40	1.40	1.33	1.30	1.27	1.31
R kJ/(kg•K)		2.077	4.125	0.2870	0.5183	0.2968	0.2598	0.2968	0.4615	0.1889	0.1298	0.4882

(1) Density ρ is a value at the standard state (0℃, 760 mmHg). [Source: JSME Mechanical Engineers' Handbook, A 6 (1987)]

(2) Specific heat at constant pressure Cp, Specific heat at constant volume Cv, and gas constant R are values at 0℃ and low pressure state.

(a) Most gases can be handled approximately as the perfect gas that complies with the following formulation. Denoting P=pressure kPa and T=absolute temperature K, $PV=R_0T$ for 1 kmol of general gas, where R_0=universal gas constant=8.3145 k J/(kmol•K). $Pv=RT$ for 1 kg of specific gas, where R=specific gas constant (value shown in the Table above) $\fallingdotseq R_0/M$ k J/(kg•K). In addition, the following equations are satisfied. $c_p - c_v = R = 8.3145/M$ kJ/(kg•K), $C_p - C_v = R_0 = 8.3145$kJ/(kmol•K)

(b) Mixed gases

	Molecular Weight	Gas Constant	Volume Ratio	Mass Ratio	Specific Heat at Constant Pressure	Specific Heat at Constant Volume	Molar Heat Capacity at Constant Pressure	Molar Heat Capacity at Constant Volume
Gas 1	M_1	R_1	r_1	s_1	c_{p1}	c_{v1}	C_{p1}	C_{v1}
Gas 2	M_2	R_2	r_2	s_2	c_{p2}	c_{v2}	C_{p2}	C_{v2}
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Gas i	M_i	R_i	r_i	s_i	c_{pi}	c_{vi}	C_{pi}	C_{vi}
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Mixed gas	M	R	$\Sigma r_i = 1$	$\Sigma s_i = 1$	c_p	c_v	C_p	C_v

When some molecular weight M_i perfect gases are mixed at a volume ratio of r_i (= partial pressure ratio) or mass ratio of s_i, the molecular weight M and gas constant R of the mixed gas can be calculated with the following equations.

Molecular weight $M = \Sigma r_i M_i$ or $M = 1/\Sigma(s_i/M_i)$, Gas constant $R = 1/\Sigma(r_i/R_i)$or $R = \Sigma s_i R_i$

Specific heat at constant pressure $c_p = \Sigma s_i c_{pi}$, Specific heat at constant volume $c_v = \Sigma s_i c_{vi}$

Molar heat capacity $C_p = \Sigma r_i C_{pi}$, $C_v = \Sigma r_i C_{vi}$

Internal energy $u = \Sigma s_i u_i$, Enthalpy $h = \Sigma s_i h_i$

In equations above, $r_i = (s_i/M_i)M$, and $s_i = r_i M_i/M$

(c) Dry air composition, etc. (standard atmospheric pressure)

Volume (%)		Mass (%)		Molecular Weight	Gas Constant (kJ/(kg•K))	Specific Volume (m^3_N/kg)	Boiling Point at Liquid State (℃)		
O_2	N_2	O_2	N_2				O_2	N_2	Air
21.0	79.0	23.2	76.8	28.964	0.2870	0.7735	−183.2	−195.8	−194.4

Density ρ kg/m³ = 3.484P/(273.15+t), 〔P : kPa〕.

ρ kg/m³ = {353.0/(273.15+t)}{P/760}, 〔P : mmHg〕.

(d) Properties of moist air

	Molecular Weight	Gas Constant (kJ/(kg•K))	Mass (kg)	Pressure (kPa)	Mol Number	Volume Ratio	Mass Ratio
Dry air	28.96	0.2870	1 (kg′)	P−e (partial pressure)	1/28.96	(P−e)/P	1/(x+1)
Vapor	18.02	0.4615	x (kg)	e (partial pressure)	x/18.02	e/P	x/(x+1)
Moist air	$28.96 \times \left(1-\frac{0.378e}{P}\right)$	$\frac{0.2870}{1-\frac{0.378e}{P}}$	1+x(kg)	P (total pressure)	1/28.96 +x/18.02	1	1

x〔kg/kg′〕=Absolute humidity, that is, the vapor mass contained in 1 kg of dry air (represented by 1 kg′). e〔kPa〕=Vapor partial pressure in moist air (Refer to 9-2).

The relationship between e and x is $x=0.622\,e/(P-e)$ or $e=xP/(x+0.622)$.

If the unit of P and e is changed from kPa to mmHg, 1 mmHg=0.13332kPa is assumed. Thus, R shown in Table above will take the following value. $R=3.462\,(x+0.622)/(x+1)$ or $R=2.153/(1-0.378e/P)$.

As the result, the moist air density ρ kg/m³ can be calculated with the equation shown below

$$\rho = \frac{219.6(x+1)}{(x+0.622)(273.15+t)}\cdot\frac{P}{760} \text{ or } \rho = \frac{353.0(P/760-0.000498e)}{273.15+t}, \quad 〔P,e : mmHg〕$$

Specific heat at constant pressure $c_p \fallingdotseq 1.005+1.859x$〔kJ/(kg′•K)〕(per 1 kg of dry air, that is, per (1+x)kg of moist air).

Enthalpy $h \fallingdotseq 1.005t+(2501+1.859t)x$〔kJ/kg′〕(same as above).

Applying $e=e_s$ (saturated water vapor pressure at temperature t℃) to the equations above, the saturated moist air properties can be obtained. (Refer to 9-4).

9-2 Partial Pressure of Water Vapor by Dry and Wet Bulb Hygrometer (Normal state)

(Unit: mmHg)

Wet bulb temperature t′ ℃	Temperature Difference between Dry and Wet Bulb t−t′ (℃)										
	0°	0.5°	1.0°	1.5°	2.0°	2.5°	3.0°	3.5°	4.0°	4.5°	5.0°
0°	4.6	4.3	4.0	3.7	3.4	3.1	2.8	2.5	2.1	1.8	1.5
5°	6.5	6.2	5.9	5.6	5.3	5.0	4.7	4.4	4.1	3.8	3.5
10°	9.2	8.9	8.6	8.3	8.0	7.7	7.4	7.1	6.8	6.5	6.2
15°	12.8	12.5	12.2	11.9	11.6	11.3	11.0	10.7	10.4	10.1	9.7
20°	17.5	17.2	16.9	16.6	16.3	16.0	15.7	15.4	15.1	14.8	14.5
25°	23.7	23.4	23.1	22.8	22.5	22.2	21.9	21.6	21.3	21.0	20.7
30°	31.8	31.5	31.2	30.9	30.6	30.3	30.0	29.7	29.4	29.1	28.8

Remark: The table above indicates the values calculated with the following equation for the values of a general dry and wet bulb hygrometer.

$$e = e'_s - 0.00080P\,(t-t')$$

Where, t=dry bulb scale ℃, e_s =saturated vapor pressure at t℃, mmHg. (Refer to 9-9).

t′=wet bulb scale ℃, e'_s =saturated vapor pressure at t′℃, mmHg.

e=vapor partial pressure mmHg, P=atmospheric pressure mmHg (P=760 is assumed to calculate the values in the table).

When the wind hits wet bulb at a speed of 2.5 m/s or more, the following equation is used;

$$e = e'_s - 0.00065P\,(t-t')\,(1+t'/610)$$

In addition, the relative humidity is expressed as $\varphi = e/e_s$ and the percentage humidity $\psi = x/x_s$. (Usually, these values are multiplied by 100 to be represented in %).

9-3 Relative Humidity by Dry and Wet Bulb Hygrometer (JIS Z8806-1981)

(Over the Ice Point of Wet Bulb Temperature)

Wet bulb temp.(℃)	Temperature Difference between Dry and Wet Bulb (℃)																	
	0	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6	7	8	9	10	11	12	13	14	15
0	100	91	83	75	68	61	54	42	32	22	14	—	—	—	—	—	—	—	—
1	100	92	84	77	69	63	56	45	34	25	17	10	—	—	—	—	—	—	—
2	100	92	84	77	70	64	58	47	37	28	21	14	—	—	—	—	—	—	—
3	100	93	85	78	71	66	60	49	39	31	23	17	11	—	—	—	—	—	—
4	100	93	86	79	73	67	61	51	42	33	26	20	14	—	—	—	—	—	—
5	100	93	86	80	74	68	63	53	44	36	29	22	17	12	—	—	—	—	—
6	100	93	87	81	75	69	64	54	46	38	31	25	19	15	10	—	—	—	—
7	100	94	87	81	76	70	65	56	48	40	33	27	22	17	13	—	—	—	—
8	100	94	88	82	76	71	66	57	49	42	35	29	24	19	15	11	—	—	—
9	100	94	88	83	77	72	67	59	51	44	37	32	26	22	18	14	10	—	—
10	100	94	88	83	78	73	69	60	52	45	39	33	28	24	20	16	13	10	—
11	100	94	89	84	79	74	70	61	54	47	41	35	30	26	22	18	15	12	—
12	100	95	89	84	79	75	70	62	55	48	42	37	32	28	24	20	17	14	11
13	100	95	89	85	80	76	71	63	56	50	44	39	34	29	25	22	19	16	13
14	100	95	90	85	81	76	72	64	57	51	45	40	35	31	27	24	20	17	15
15	100	95	90	86	81	77	73	65	59	52	47	42	37	33	29	25	22	19	16
16	100	95	90	86	82	78	74	66	60	54	48	43	38	34	30	27	24	21	18
17	100	95	91	86	82	78	74	67	61	55	49	44	40	36	32	28	25	22	20
18	100	95	91	87	83	79	75	68	62	56	50	45	41	37	33	30	27	24	21
19	100	96	91	87	83	80	75	69	62	57	51	47	42	38	34	31	28	25	22
20	100	96	91	87	83	80	76	69	63	58	52	48	43	39	36	32	29	26	24
21	100	96	92	88	84	81	77	70	64	58	53	49	44	40	37	33	30	28	25
22	100	96	92	88	84	81	77	71	65	59	54	50	45	41	38	35	31	29	26
23	100	96	92	88	84	81	78	71	65	60	55	51	46	42	39	36	33	30	27
24	100	96	92	89	85	82	78	72	66	61	56	51	47	43	40	37	34	31	28
25	100	96	92	89	85	82	78	72	67	62	57	52	48	44	41	38	35	32	29
26	100	96	92	89	85	82	79	73	67	62	57	53	49	45	42	39	36	33	30
28	100	97	93	90	86	83	80	74	68	63	59	55	51	47	43	40	37	35	32
30	100	97	93	90	86	84	80	75	69	65	60	56	52	48	45	42	39	36	34
32	100	97	93	90	87	84	81	76	70	66	61	57	53	50	46	43	41	38	35
34	100	97	93	91	87	85	82	76	71	67	62	58	55	51	48	45	42	39	37

9-4 Properties of Dry Air(a) and Saturated Moist Air(s) (Refer to 9-1)

x_s indicates (Moisture (kg)/dry air (kg′)) in saturated wet air. (760mmHg)

Temperature	Saturated Pressure	Saturated Humidity	Enthalpy	Specific Volume	Enthalpy	Specific Volume	Temperature
t (℃)	e_s (kPa)	x_s (kg/kg′)	h_s (kJ/kg′)	v_s (m³/kg′)	h_a (kJ/kg)	v_a (m³/kg)	t (℃)
−20	0.125	0.00077	−18.21	0.718	−20.10	0.717	−20
−15	0.191	0.00118	−12.18	0.733	−15.07	0.731	−15
−10	0.287	0.00176	−5.69	0.748	−10.05	0.746	−10
− 5	0.421	0.00260	1.47	0.763	−5.02	0.760	− 5
0	0.611	0.00377	9.42	0.779	0.00	0.774	0
2	0.705	0.00436	12.94	0.785	2.01	0.780	2
4	0.813	0.00503	16.62	0.792	4.02	0.785	4
6	0.935	0.00579	20.56	0.798	6.03	0.791	6
8	1.072	0.00665	24.74	0.805	8.04	0.797	8
10	1.227	0.00763	29.27	0.812	10.05	0.802	10
11	1.312	0.00816	31.61	0.816	11.05	0.805	11
12	1.402	0.00872	34.08	0.819	12.06	0.808	12
13	1.497	0.00933	36.59	0.823	13.06	0.811	13
14	1.597	0.00996	39.27	0.827	14.07	0.814	14
15	1.704	0.01064	41.99	0.830	15.07	0.816	15
16	1.814	0.01136	44.80	0.834	16.08	0.819	16
17	1.937	0.01212	47.77	0.838	17.08	0.822	17
18	2.062	0.01293	50.83	0.842	18.09	0.825	18
19	2.196	0.01378	54.05	0.846	19.09	0.828	19
20	2.337	0.01469	57.36	0.850	20.10	0.831	20
21	2.486	0.01564	60.83	0.854	21.10	0.833	21
22	2.642	0.01666	64.43	0.859	22.11	0.836	22
23	2.809	0.01773	68.20	0.863	23.11	0.839	23
24	2.850	0.01887	72.14	0.867	24.12	0.842	24
25	3.166	0.02007	76.24	0.872	25.12	0.845	25
26	3.361	0.02134	80.51	0.877	26.13	0.848	26
27	3.565	0.02268	84.99	0.881	27.13	0.850	27
28	3.780	0.02410	89.64	0.886	28.14	0.853	28
29	4.005	0.02560	94.54	0.891	29.14	0.856	29
30	4.244	0.02718	99.65	0.896	30.14	0.859	30
32	4.756	0.0306	110.6	0.907	32.15	0.865	32
34	5.319	0.0345	122.5	0.918	34.16	0.870	34
36	5.942	0.0387	135.7	0.930	36.17	0.876	36
38	6.626	0.0435	150.1	0.943	38.18	0.882	38
40	7.378	0.0488	166.0	0.957	40.19	0.887	40
45	9.586	0.0645	213.1	0.996	45.22	0.901	45
50	12.34	0.0862	273.9	1.042	50.24	0.916	50
55	15.75	0.1144	353.1	1.101	55.27	0.930	55
60	19.93	0.1523	457.9	1.175	60.29	0.944	60
65	25.01	0.2039	599.5	1.272	65.31	0.958	65
70	31.17	0.2763	797.2	1.404	70.34	0.972	70
75	38.56	0.3820	1083.5	1.592	75.36	0.986	75
80	47.37	0.5460	1526.5	1.879	80.39	1.000	80

〔Source: Converted into SI unit from JSME Data Book: Heat Transfer, 3rd Edition (1975)〕

9-5 Specific Heat at Constant Pressure of Gases (C_p kJ/(kmol·K))

(760mmHg)

t (℃)	H_2	N_2	O_2	CO	H_2O	CO_2	SO_2	Air
0	28.72	29.14	29.27	29.14	33.41	36.05	38.98	29.06
100	29.14	29.22	29.85	29.31	33.91	40.57	42.58	29.27
200	29.27	29.52	30.86	29.68	34.83	43.84	45.80	29.73
300	29.35	29.98	31.88	30.27	35.84	47.02	48.27	30.31
400	29.43	30.61	32.82	30.98	37.01	49.36	50.37	30.98
500	29.56	31.28	33.58	31.69	38.18	51.29	51.83	31.69
600	29.81	31.95	34.25	32.45	39.40	52.88	52.96	32.32
700	30.14	32.57	34.79	33.08	40.70	54.18	53.84	32.95
800	30.48	33.12	35.21	33.62	41.95	55.27	54.51	33.45
900	30.90	33.62	35.59	34.12	43.12	56.14	55.06	33.91
1 000	31.36	34.08	36.01	34.50	44.30	56.94	55.48	34.37
1 100	31.78	34.50	36.26	34.88	45.22	57.53	55.85	34.71
1 200	32.20	34.83	36.55	35.21	46.39	58.07	56.14	35.04
1 300	32.66	35.09	36.80	35.46	47.35	58.53	56.35	35.29
1 400	33.03	35.34	37.05	35.71	48.23	58.91	56.56	35.55
1 500	33.41	35.55	37.26	35.88	49.03	59.24	56.77	35.76
1 600	33.83	35.76	37.51	36.09	49.74	59.54	56.90	35.96
1 700	34.16	35.96	37.72	36.26	50.41	59.79	57.02	36.17
1 800	34.50	36.13	38.02	36.38	51.04	60.00	57.15	36.34
1 900	34.83	36.26	38.27	36.51	51.62	60.21	57.23	36.51
2 000	35.09	36.43	38.48	36.63	52.13	60.37	57.32	36.72
2 100	35.38	36.55	38.69	36.76	52.63	60.54	57.36	36.84
2 200	35.63	36.68	38.90	36.89	53.09	60.67	57.44	36.97
2 300	35.88	36.76	39.10	36.97	53.51	60.79	57.48	37.10
2 400	36.09	36.84	39.31	37.05	53.88	60.88	57.53	37.22
2 500	36.34	36.97	39.48	37.14	54.22	61.00	57.61	37.35
2 600	36.55	37.01	39.65	37.22	54.51	61.09	57.65	37.43
2 700	36.76	37.10	39.82	37.26	54.76	61.17	57.65	37.51
2 800	36.97	37.18	39.98	37.30	55.01	61.25	57.69	37.60
2 900	37.18	37.22	40.15	37.35	55.18	61.29	57.74	37.68
3 000	37.39	37.26	40.28	37.39	55.27	61.38	57.74	37.76
M=	2.016	28.013	31.999	28.01	18.015	44.01	64.06	28.964

The specific heat at the constant pressure of gases kJ/(kg·K) for 1 kg of gas is calculated by dividing this value by molecular weight M.
The specific heat at constant pressure of gases kJ/(m_N^3·K) for 1 m_N^3 of gas is calculated by dividing this value by 22.4 m_N^3 of 1 kmol gas volume.

9-6 Enthalpy of Gases ($h_t - h_o$)(kJ/kmol)

(760mmHg)

t (℃)	H_2	N_2	O_2	CO	H_2O	CO_2	SO_2	Air
0	0	0	0	0	0	0	0	0
100	2 897	2 918	2 952	2 918	3 362	3 839	4 078	2 914
200	5 820	5 862	5 983	5 862	6 799	8 081	8 499	5 866
300	8 767	8 847	9 115	8 868	10 325	12 636	13 214	8 859
400	11 690	11 878	12 359	11 920	13 967	17 417	18 154	11 924
500	14 637	14 972	15 684	15 056	17 731	22 504	23 258	15 039
600	17 614	18 112	19 071	18 267	21 604	27 708	28 512	18 259
700	20 620	21 328	22 525	21 529	25 615	33 063	33 850	21 487
800	23 634	24 618	26 034	24 865	29 777	38 502	39 255	24 836
900	26 695	27 968	29 580	28 253	34 064	44 087	44 757	28 211
1 000	29 793	31 368	33 159	31 694	38 351	49 697	50 283	31 623
1 100	32 975	34 801	36 760	35 173	42 915	55 475	55 852	35 085
1 200	36 145	38 267	40 394	38 694	47 478	61 253	61 462	38 577
1 300	39 385	41 768	44 045	42 245	52 142	67 073	67 114	42 077
1 400	42 663	45 301	47 730	45 762	56 982	72 934	72 725	45 636
1 500	45 971	48 818	51 456	49 321	61 797	78 879	78 377	
1 750	54 387	57 778	60 876	58 322	74 358	93 742	94 831	
2 000	63 053	66 821	70 422	67 449	87 169	100 441	106 931	
2 250	71 971	75 990	80 093	76 660	100 420	123 929	121 250	
2 500	80 973	85 201	89 912	85 955	113 776	139 169	139 002	
2 750	90 184	94 454	99 855	95 250	127 446	154 409	150 013	
3 000	99 520	103 749	109 904	104 503	141 053	169 775	164 541	

The specific heat at constant pressure kJ/(kmol•K) for 1 kmol gas can be calculated with ($h_{t2} - h_{t1}$)/($t_2 - t_1$).
The enthalpy kJ/kg or average specific heat at constant pressure kJ/(kg•K) for 1 kg of gas can be calculated by dividing this value by the molecular weight.
The enthalpy kJ/ m^3_N or average specific heat at constant pressure kJ/ (m^3_N • K) for 1 m^3_N of gas can be calculated by dividing this value by 22.4 m^3_N of 1 kmol of gas volume.

9-7 Specific Heat at Constant Pressure of Compressed Water and Superheated Steam(c_p kJ/(kg•K))

Pressure (MPa)	Temperature (℃)										
	100°	150°	200°	250°	300°	350°	400°	450°	500°	550°	600°
0.01	1.906	1.920	1.944	1.971	2.001	2.032	2.064	2.097	2.131	2.166	2.201
0.1	2.074	1.986	1.976	1.989	2.012	2.040	2.070	2.101	2.135	2.169	2.203
0.5	4.216	4.310	2.145	2.078	2.066	2.075	2.095	2.121	2.149	2.180	2.213
1	4.215	4.309	2.429	2.212	2.141	2.123	2.128	2.145	2.168	2.195	2.224
2	4.212	4.305	4.491	2.560	2.320	2.230	2.200	2.196	2.207	2.225	2.249
3	4.210	4.302	4.486	3.077	2.543	2.354	2.278	2.251	2.247	2.256	2.273
4	4.208	4.299	4.480	4.865	2.820	2.497	2.364	2.309	2.289	2.288	2.298
5	4.206	4.296	4.474	4.851	3.171	2.661	2.459	2.371	2.333	2.321	2.324
6	4.203	4.293	4.469	4.838	3.638	2.850	2.563	2.436	2.379	2.355	2.350
7	4.201	4.290	4.463	4.825	4.292	3.070	2.678	2.507	2.426	2.390	2.377
8	4.199	4.287	4.458	4.812	5.287	3.329	2.804	2.582	2.476	2.426	2.404
9	4.197	4.284	4.452	4.800	5.730	3.637	2.943	2.662	2.529	2.463	2.432
10	4.194	4.281	4.447	4.788	5.682	4.012	3.096	2.747	2.583	2.501	2.460
11	4.192	4.278	4.442	4.777	5.636	4.478	3.266	2.838	2.640	2.541	2.489
12	4.190	4.275	4.437	4.765	5.592	5.075	3.455	2.935	2.700	2.581	2.519
13	4.188	4.272	4.432	4.754	5.551	5.873	3.667	3.039	2.763	2.623	2.549
14	4.186	4.269	4.427	4.743	5.513	7.006	3.906	3.150	2.828	2.667	2.580
15	4.184	4.266	4.422	4.732	5.476	8.789	4.178	3.269	2.896	2.711	2.612
16	4.182	4.263	4.417	4.722	5.441	12.41	4.488	3.396	2.967	2.757	2.644
17	4.180	4.260	4.412	4.712	5.408	9.687	4.846	3.532	3.041	2.805	2.678
18	4.177	4.257	4.408	4.702	5.376	8.999	5.265	3.679	3.119	2.853	2.711
19	4.175	4.255	4.403	4.692	5.346	8.494	5.760	3.837	3.200	2.904	2.746
20	4.173	4.252	4.398	4.682	5.317	8.106	6.360	4.007	3.284	2.955	2.781
21	4.171	4.249	4.394	4.673	5.289	7.797	7.101	4.191	3.373	3.008	2.817
22	4.169	4.246	4.389	4.664	5.262	7.543	8.033	4.389	3.465	3.063	2.854
23	4.167	4.244	4.385	4.655	5.237	7.328	9.229	4.604	3.561	3.119	2.891
24	4.165	4.241	4.380	4.646	5.212	7.142	10.80	4.835	3.661	3.176	2.929
25	4.163	4.238	4.376	4.637	5.188	6.980	13.00	5.086	3.766	3.235	2.968
26	4.161	4.236	4.372	4.629	5.165	6.837	16.24	5.357	3.875	3.296	3.007
27	4.159	4.233	4.367	4.620	5.143	6.708	21.14	5.651	3.989	3.358	3.047
28	4.157	4.230	4.363	4.612	5.122	6.593	27.31	5.970	4.108	3.421	3.088
29	4.155	4.288	4.359	4.604	5.101	6.489	29.85	6.316	4.231	3.486	3.129
30	4.153	4.225	4.355	4.596	5.081	6.393	25.80	6.691	4.360	3.553	3.171
32	4.150	4.220	4.347	4.580	5.043	6.225	16.93	7.533	4.631	3.690	3.257
34	4.146	4.215	4.339	4.565	5.008	6.081	12.84	8.482	4.920	3.834	3.345
36	4.142	4.210	4.331	4.551	4.974	5.954	10.76	9.464	5.226	3.982	3.435
38	4.138	4.205	4.323	4.537	4.942	5.842	9.526	10.36	5.546	4.136	3.526
40	4.135	4.200	4.316	4.523	4.912	5.742	8.701	10.95	5.875	4.294	3.619

〔Source: JSME Steam Tables (1999)〕

9-8 Specific Heat, etc. of Saturated Water$^{(\prime)}$ and Saturated Steam$^{(\prime\prime)}$

Temperature ℃	Isobaric specific heat capacity(kJ/(kg•K))		Dynamic viscosity (μPa•s)		Kinematic viscosity (mm²/s)		Thermal conductivity (mW/(m•K))		Prandtl number	
	c_p'	c_p''	μ'	μ''	ν'	ν''	λ'	λ''	P_r'	P_r''
0.01	4.220	1.888	1791	9.216	1.792	1899	562.0	16.49	13.45	1.055
10	4.196	1.896	1306	9.461	1.306	1006	581.9	17.21	9.417	1.042
20	4.185	1.906	1002	9.727	1.003	561.9	599.5	17.95	6.993	1.033
30	4.180	1.918	797.4	10.01	0.8009	329.2	615.0	18.71	5.420	1.026
40	4.179	1.932	653.0	10.31	0.6581	201.2	628.6	19.48	4.341	1.022
50	4.180	1.948	546.8	10.62	0.5535	127.7	640.5	20.28	3.569	1.020
60	4.183	1.966	466.4	10.93	0.4744	83.84	650.8	21.10	2.998	1.019
70	4.188	1.987	403.9	11.26	0.4131	56.75	659.6	21.96	2.565	1.019
80	4.196	2.012	354.3	11.59	0.3646	39.48	667.0	22.86	2.229	1.020
90	4.205	2.042	314.4	11.93	0.3257	28.14	673.0	23.80	1.964	1.023
100	4.217	2.077	281.7	12.27	0.2940	20.51	677.8	24.79	1.753	1.028
110	4.230	2.121	254.7	12.61	0.2678	15.25	681.3	25.85	1.582	1.035
120	4.246	2.174	232.1	12.96	0.2461	11.55	683.6	26.96	1.441	1.045
130	4.265	2.237	212.9	13.30	0.2277	8.886	684.8	28.15	1.326	1.057
140	4.286	2.311	196.5	13.65	0.2122	6.940	684.9	29.42	1.230	1.072
150	4.310	2.396	182.5	13.99	0.1990	5.492	683.9	30.77	1.150	1.089
160	4.338	2.492	170.2	14.34	0.1876	4.399	681.8	32.22	1.083	1.109
170	4.369	2.599	159.6	14.68	0.1778	3.562	678.7	33.77	1.027	1.130
180	4.406	2.716	150.1	15.03	0.1693	2.913	674.6	35.42	0.9805	1.152
190	4.447	2.846	141.8	15.37	0.1618	2.403	669.5	37.19	0.9417	1.176
200	4.494	2.990	134.3	15.71	0.1553	1.999	663.4	39.10	0.9099	1.202
210	4.548	3.150	127.6	16.06	0.1496	1.675	656.3	41.14	0.8843	1.230
220	4.611	3.328	121.5	16.41	0.1446	1.413	648.2	43.34	0.8644	1.260
230	4.683	3.528	116.0	16.76	0.1402	1.199	639.1	45.72	0.8497	1.294
240	4.767	3.755	110.9	17.13	0.1363	1.023	629.0	48.32	0.8401	1.331
250	4.865	4.012	106.1	17.49	0.1328	0.8762	617.8	51.16	0.8356	1.372
260	4.981	4.308	101.7	17.88	0.1298	0.7540	605.6	54.30	0.8363	1.418
270	5.119	4.655	97.50	18.28	0.1270	0.6511	592.2	57.81	0.8427	1.471
280	5.286	5.070	93.51	18.70	0.1246	0.5639	577.7	61.79	0.8555	1.534
290	5.492	5.581	89.66	19.15	0.1225	0.4895	562.0	66.37	0.8761	1.611
300	5.752	6.223	85.90	19.65	0.1206	0.4257	545.0	71.75	0.9066	1.704
310	6.088	7.051	82.17	20.21	0.1190	0.3706	526.5	78.24	0.9502	1.821
320	6.541	8.157	78.41	20.85	0.1175	0.3226	506.5	86.35	1.013	1.969
330	7.189	9.738	74.54	21.61	0.1163	0.2805	484.8	96.96	1.105	2.170
340	8.217	12.24	70.43	22.55	0.1153	0.2432	461.4	111.7	1.254	2.471
350	10.10	16.64	65.87	23.82	0.1146	0.2096	436.5	134.5	1.525	2.946
360	14.87	27.57	60.36	25.73	0.1144	0.1787	411.9	176.6	2.179	4.016
370	47.10	93.40	51.92	29.70	0.1154	0.1469	418.1	309.5	5.848	8.964
371	64.10	125.1	50.54	30.50	0.1157	0.1431	432.6	347.0	7.489	10.99
372	101.2	190.3	48.83	31.57	0.1163	0.1388	462.0	403.7	10.69	14.88
373	231.9	401.1	46.42	33.22	0.1173	0.1336	535.0	507.0	20.13	26.28

〔Source: JSME Steam Tables (1999)〕

9-9 Saturation State Steam Table (Temperature Base)

Temperature	Saturation pressure		Specific volume(m³/kg)		Specific enthalpy(kJ/kg)			Specific entropy(kJ/(kg•K))	
(℃)	(MPa)	(mmHg)	v'	v''	h'	h''	$r = h'' - h'$	s'	s''
0.01	0.00061166	4.6	0.00100021	205.997	0.00	2500.91	2500.91	0.00000	9.15549
5	0.00087257	6.5	0.00100008	147.017	21.02	2510.07	2489.05	0.07625	9.02486
10	0.0012282	9.2	0.00100035	106.309	42.02	2519.23	2477.21	0.15109	8.89985
15	0.0017057	12.8	0.00100095	77.8807	62.98	2528.36	2465.38	0.22447	8.78037
20	0.0023392	17.5	0.00100184	57.7615	83.92	2537.47	2453.55	0.29650	8.66612
25	0.0031697	23.8	0.00100301	43.3414	104.84	2546.54	2441.71	0.36726	8.55680
30	0.0042467	31.9	0.00100441	32.8816	125.75	2555.58	2429.84	0.43679	8.45211
35	0.0056286	42.2	0.00100604	25.2078	146.64	2564.58	2417.94	0.50517	8.35182
40	0.0073844	55.4	0.00100788	19.5170	167.54	2573.54	2406.00	0.57243	8.25567
45	0.0095944	72.0	0.00100991	15.2534	188.44	2582.45	2394.02	0.63862	8.16344
50	0.012351	92.6	0.00101214	12.0279	209.34	2591.31	2381.97	0.70379	8.07491
55	0.015761	118.2	0.00101454	9.56492	230.24	2600.11	2369.87	0.76798	7.98989
60	0.019946	149.6	0.00101711	7.66766	251.15	2608.85	2357.69	0.83122	7.90817
65	0.025041	187.8	0.00101985	6.19383	272.08	2617.51	2345.43	0.89354	7.82960
70	0.031201	234.0	0.00102276	5.03973	293.02	2626.10	2333.08	0.95499	7.75399
75	0.038595	289.5	0.00102582	4.12908	313.97	2634.60	2320.63	1.01560	7.68118
80	0.047415	355.6	0.00102904	3.40527	334.95	2643.01	2308.07	1.07539	7.61102
85	0.057867	434.0	0.00103242	2.82593	355.95	2651.33	2295.38	1.13440	7.54336
90	0.070182	526.4	0.00103594	2.35915	376.97	2659.53	2282.56	1.19266	7.47807
95	0.084609	634.6	0.00103962	1.98065	398.02	2667.61	2269.60	1.25019	7.41502
100	0.10142	760.7	0.00104346	1.67186	419.10	2675.57	2256.47	1.30701	7.35408
110	0.14338	1075.4	0.00105158	1.20939	461.36	2691.07	2229.70	1.41867	7.23805
120	0.19867	1490.1	0.00106033	0.891304	503.78	2705.93	2202.15	1.52782	7.12909
130	0.27026	2027.1	0.00106971	0.668084	546.39	2720.09	2173.70	1.63463	7.02641
140	0.36150	2711.5	0.00107976	0.508519	589.20	2733.44	2144.24	1.73929	6.92927
150	0.47610		0.00109050	0.392502	632.25	2745.92	2113.67	1.84195	6.83703
160	0.61814		0.00110199	0.306818	675.57	2757.43	2081.86	1.94278	6.74910
170	0.79205		0.00111426	0.242616	719.21	2767.89	2048.69	2.04192	6.66495
180	1.0026		0.00112739	0.193862	763.19	2777.22	2014.03	2.13954	6.58407
190	1.2550		0.00114144	0.156377	807.57	2785.31	1977.74	2.23578	6.50600
200	1.5547		0.00115651	0.127222	852.39	2792.06	1939.67	2.33080	6.43030
220	2.3193		0.00119016	0.0861007	943.64	2801.05	1857.41	2.51782	6.28425
240	3.3467		0.00122946	0.0597101	1037.52	2803.06	1765.54	2.70194	6.14253
260	4.6921		0.00127613	0.0421755	1134.83	2796.64	1661.82	2.88472	6.00169
280	6.4165		0.00133285	0.0301540	1236.67	2779.82	1543.15	3.06807	5.85783
300	8.5877		0.00140422	0.0216631	1344.77	2749.57	1404.80	3.25474	5.70576
320	11.284		0.00149906	0.0154759	1462.05	2700.67	1238.62	3.44912	5.53732
340	14.600		0.00163751	0.0107838	1594.45	2622.07	1027.62	3.65995	5.33591
360	18.666		0.00189451	0.00694494	1761.49	2480.99	719.50	3.91636	5.05273
373.946	22.064		0.00310559	0.00310559	2087.55	2087.55	0	4.41202	4.41202

The steam h-s diagram (SI unit) is inserted in the back cover. 〔Source: JSME Steam Tables(1999)〕

9-10 Saturation State Steam Table (Pressure Base)

Pressure		Saturation temperature	Specific volume(m^3/kg)		Specific enthalpy(kJ/kg)			Specific entropy(kJ/(kg·K))	
(MPa)	(mmHg)	(℃)	v′	v″	h′	h″	r = h″ − h′	s′	s″
0.0010	7.5	6.970	0.00100014	129.183	29.30	2513.68	2484.38	0.10591	8.97493
0.0030	22.5	24.080	0.00100277	45.6550	100.99	2544.88	2443.89	0.35433	8.57656
0.0050	37.5	32.875	0.00100532	28.1863	137.77	2560.77	2423.00	0.47625	8.39391
0.0070	52.5	39.001	0.00100749	20.5252	163.37	2571.76	2408.39	0.55908	8.27456
0.010	75.0	45.808	0.00101026	14.6706	191.81	2583.89	2392.07	0.64922	8.14889
0.020	150.0	60.059	0.00101714	7.64815	251.40	2608.95	2357.55	0.83195	7.90723
0.030	225.0	69.095	0.00102222	5.22856	289.23	2624.55	2335.32	0.94394	7.76754
0.050	375.0	81.317	0.00102991	3.24015	340.48	2645.21	2304.74	1.09101	7.59296
0.070	525.0	89.932	0.00103589	2.36490	376.68	2659.42	2282.74	1.19186	7.47895
0.100	750.1	99.606	0.00104315	1.69402	417.44	2674.95	2257.51	1.30256	7.35881
0.200	1500.1	120.21	0.00106052	0.885735	504.68	2706.24	2201.56	1.53010	7.12686
0.300	2250.2	133.53	0.00107318	0.605785	561.46	2724.89	2163.44	1.67176	6.99157
0.400	3000.2	143.61	0.00108356	0.462392	604.72	2738.06	2133.33	1.77660	6.89542
0.500	3750.3	151.84	0.00109256	0.374804	640.19	2748.11	2107.92	1.86060	6.82058
0.600	4500.4	158.83	0.00110061	0.315575	670.50	2756.14	2085.64	1.93110	6.75917
0.70		164.95	0.00110797	0.272764	697.14	2762.75	2065.61	1.99208	6.70698
0.80		170.41	0.00111479	0.240328	721.02	2768.30	2047.28	2.04599	6.66154
1.00		179.89	0.00112723	0.194349	762.68	2777.12	2014.44	2.13843	6.58498
1.20		187.96	0.00113850	0.163250	798.50	2783.77	1985.27	2.21630	6.52169
1.40		195.05	0.00114892	0.140768	830.13	2788.89	1958.76	2.28388	6.46752
1.60		201.38	0.00115868	0.123732	858.61	2792.88	1934.27	2.34381	6.42002
1.80		207.12	0.00116792	0.110362	884.61	2795.99	1911.37	2.39779	6.37760
2.00		212.38	0.00117675	0.0995805	908.62	2798.38	1889.76	2.44702	6.33916
2.50		223.96	0.00119744	0.0799474	961.98	2802.04	1840.06	2.55443	6.25597
3.00		233.86	0.00121670	0.0666641	1008.37	2803.26	1794.89	2.64562	6.18579
3.50		242.56	0.00123498	0.0570582	1049.78	2802.74	1752.97	2.72539	6.12451
4.00		250.36	0.00125257	0.0497766	1087.43	2800.90	1713.47	2.79665	6.06971
4.50		257.44	0.00126966	0.0440593	1122.14	2798.00	1675.85	2.86133	6.01980
5.0		263.94	0.00128641	0.0394463	1154.50	2794.23	1639.73	2.92075	5.97370
6.0		275.59	0.00131927	0.0324487	1213.73	2784.56	1570.83	3.02744	5.89007
7.0		285.83	0.00135186	0.0273796	1267.44	2772.57	1505.13	3.12199	5.81463
8.0		295.01	0.00138466	0.0235275	1317.08	2758.61	1441.53	3.20765	5.74485
10.0		311.00	0.00145262	0.0180336	1407.87	2725.47	1317.61	3.36029	5.61589
12.0		324.68	0.00152633	0.0142689	1491.33	2685.58	1194.26	3.49646	5.49412
14.0		336.67	0.00160971	0.0114889	1570.88	2638.09	1067.21	3.62300	5.37305
16.0		347.36	0.00170954	0.00930813	1649.67	2580.80	931.13	3.74568	5.24627
18.0		356.99	0.00183949	0.00749867	1732.02	2509.53	777.51	3.87167	5.10553
20.0		365.75	0.00203865	0.00585828	1827.10	2411.39	584.29	4.01538	4.92990
22.0		373.71	0.00275039	0.00357662	2021.92	2164.18	142.27	4.31087	4.53080
22.064		373.946	0.00310559	0.00310559	2087.55	2087.55	0	4.41202	4.41202

The steam h-s diagram (SI unit) is inserted in the back cover. (Source: JSME Steam Tables(1999))

9-11 Compressed Water and Superheated Steam Table (1)

Pressure(MPa) Saturation temperature(℃)		Temperature (℃)										
		150°	200°	250°	300°	350°	400°	450°	500°	550°	600°	650°
	v	39.043	43.663	48.281	52.898	57.515	62.131	66.747	71.363	75.979	80.594	85.210
0.005	h	2783.37	2879.82	2977.61	3076.86	3177.64	3280.01	3384.03	3489.73	3597.14	3706.31	3817.24
(32.875)	s	9.0097	9.2251	9.4216	9.6027	9.7713	9.9293	10.0783	10.2197	10.3543	10.4830	10.6065
	v	19.514	21.826	24.136	26.446	28.755	31.064	33.372	35.680	37.988	40.0296	42.604
0.010	h	2783.02	2879.59	2977.45	3076.73	3177.54	3279.94	3383.96	3489.67	3597.10	3706.27	3817.20
(45.808)	s	8.6892	8.9048	9.1014	9.2827	9.4513	9.6093	9.7584	9.8997	10.0343	10.1631	10.2866
	v	9.7488	10.907	12.064	13.220	14.375	15.530	16.684	17.839	18.993	20.147	21.301
0.020	h	2782.32	2879.14	2977.12	3076.49	3177.35	3279.78	3383.84	3489.57	3597.01	3706.19	3817.14
(60.059)	s	8.3680	8.5842	8.7811	8.9624	9.1311	9.2892	9.4383	9.5797	9.7143	9.8431	9.9666
	v	3.8899	4.3563	4.8207	5.2841	5.7470	6.2095	6.6718	7.1339	7.5959	8.0578	8.5196
0.050	h	2780.20	2877.77	2976.16	3075.76	3176.78	3279.32	3383.45	3489.24	3596.74	3705.96	3816.94
(81.317)	s	7.9412	8.1591	8.3568	8.5386	8.7076	8.8658	9.0150	9.1565	9.2912	9.4200	9.5436
	v	2.7738	3.1084	3.4410	3.7725	4.1035	4.4342	4.7646	5.0949	5.4250	5.7550	6.0850
0.070	h	2778.77	2876.86	2975.51	3075.27	3176.39	3279.01	3383.20	3489.03	3596.55	3705.80	3816.80
(89.932)	s	7.7833	8.0024	8.2006	8.3827	8.5518	8.7102	8.8595	9.0010	9.1357	9.2646	9.3882
	v	1.9367	2.1725	2.4062	2.6389	2.8710	3.1027	3.3342	3.5656	3.7968	4.0279	4.2590
0.100	h	2776.59	2875.48	2974.54	3074.54	3175.82	3278.54	3382.81	3488.71	3596.28	3705.57	3816.60
(99.606)	s	7.6147	7.8356	8.0346	8.2171	8.3865	8.5451	8.6945	8.8361	8.9709	9.0998	9.2234
	v	0.95989	1.0805	1.1989	1.3162	1.4330	1.5493	1.6655	1.7814	1.8973	2.0130	2.1287
0.20	h	2769.09	2870.78	2971.26	3072.08	3173.89	3276.98	3381.53	3487.64	3595.37	3704.79	3815.93
(120.21)	s	7.2809	7.5081	7.7100	7.8940	8.0643	8.2235	8.3733	8.5151	8.6501	8.7792	8.9029
	v	0.63403	0.71644	0.79645	0.87534	0.95362	1.0315	1.1092	1.1867	1.2641	1.3414	1.4186
0.30	h	2761.18	2865.95	2967.93	3069.61	3171.96	3275.42	3380.25	3486.56	3594.46	3704.02	3815.26
(133.53)	s	7.0791	7.3132	7.5181	7.7037	7.8749	8.0346	8.1848	8.3269	8.4622	8.5914	8.7152
	v	0.0010905	0.42503	0.47443	0.52260	0.57014	0.61729	0.66421	0.71095	0.75757	0.80410	0.85056
0.50	h	632.27	2855.90	2961.13	3064.60	3168.06	3272.29	3377.67	3484.41	3592.64	3702.46	3813.91
(151.84)	s	1.8419	7.0611	7.2726	7.4614	7.6345	7.7954	7.9464	8.0891	8.2247	8.3543	8.4784
	v	0.0010904	0.29999	0.33636	0.37141	0.40578	0.43976	0.47348	0.50704	0.54048	0.57382	0.60709
0.70	h	632.39	2845.29	2954.12	3059.50	3164.13	3269.14	3375.08	3482.25	3590.82	3700.90	3812.57
(164.95)	s	1.8417	6.8884	7.1071	7.2995	7.4745	7.6366	7.7884	7.9317	8.0678	8.1976	8.3220
	v	0.0010902	0.20600	0.23274	0.25798	0.28249	0.30659	0.33044	0.35411	0.37766	0.40111	0.42450
1.00	h	632.57	2828.27	2943.22	3051.70	3158.16	3264.39	3371.19	3479.00	3588.07	3698.56	3810.55
(179.89)	s	1.8414	6.6955	6.9266	7.1247	7.3028	7.4668	7.6198	7.7640	7.9007	8.0309	8.1557
	v	0.0010898	0.13244	0.15200	0.16970	0.18658	0.20301	0.21918	0.23516	0.25102	0.26678	0.28248
1.50	h	632.88	2796.02	2923.96	3038.27	3148.03	3256.37	3364.65	3473.57	3583.49	3694.64	3807.17
(198.30)	s	1.8408	6.4537	6.7111	6.9199	7.1035	7.2708	7.4259	7.5716	7.7093	7.8404	7.9657

v = specific volume (m^3/kg), h = specific enthalpy (kJ/kg), s = specific entropy (kJ/(kg·K)) (Source: JSME Steam Tables(1999))

The steam h-s diagram (SI unit) is inserted in the back cover.

Compressed Water and Superheated Steam Table (2)

Pressure(MPa) Saturation temperature(℃)		Temperature (℃)										
		150°	200°	250°	300°	350°	400°	450°	500°	550°	600°	650°
	v	0.0010895	0.0011561	0.11148	0.12550	0.13859	0.15121	0.16354	0.17568	0.18769	0.19961	0.21146
2.00	h	633.19	852.57	2903.23	3024.25	3137.64	3248.23	3358.05	3468.09	3578.88	3690.71	3803.79
(212.38)	s	1.8403	2.3301	6.5474	6.7685	6.9582	7.1290	7.2863	7.4335	7.5723	7.7042	7.8301
	v	0.0010888	0.0011550	0.070622	0.081175	0.090555	0.099377	0.10788	0.11619	0.12437	0.13244	0.14045
3.0	h	633.81	852.98	2856.55	2994.35	3116.06	3231.57	3344.66	3457.04	3569.59	3682.81	3796.99
(233.86)	s	1.8391	2.3285	6.2893	6.5412	6.7449	6.9233	7.0853	7.2356	7.3767	7.5102	7.6373
	v	0.0010875	0.0011530	0.0012499	0.045347	0.051971	0.057840	0.063325	0.068583	0.073694	0.078703	0.083637
5.0	h	635.06	853.80	1085.66	2925.64	3069.29	3196.59	3317.03	3434.48	3550.75	3666.83	3783.28
(263.91)	s	1.8369	2.3254	2.7909	6.2109	6.4515	6.6481	6.8208	6.9778	7.1235	7.2604	7.3901
	v	0.0010862	0.0011511	0.0012463	0.029494	0.035265	0.039962	0.044190	0.048159	0.051966	0.055664	0.059284
7.0	h	636.30	854.64	1085.65	2839.83	3016.85	3159.10	3288.17	3411.25	3531.53	3650.62	3769.41
(285.83)	s	1.8347	2.3223	2.7861	5.9335	6.2303	6.4501	6.6351	6.7997	6.9505	7.0909	7.2232
	v	0.0010842	0.0011482	0.0012412	0.0013980	0.022442	0.026439	0.029785	0.032813	0.035655	0.038377	0.041016
10	h	638.18	855.92	1085.72	1343.10	2923.96	3097.38	3242.28	3375.06	3501.94	3625.84	3748.32
(311.00)	s	1.8315	2.3177	2.7791	3.2484	5.9458	6.2139	6.4217	6.5993	6.7584	6.9045	7.0409
	v	0.0010817	0.0011444	0.0012346	0.0013820	0.013232	0.017241	0.020105	0.022546	0.024763	0.026844	0.028834
14	h	640.71	857.67	1085.95	1338.97	2752.92	3002.23	3175.60	3324.06	3460.99	3591.94	3719.67
(336.67)	s	1.8272	2.3117	2.7701	3.2315	5.5595	5.9457	6.1945	6.3931	6.5648	6.7192	6.8615
	v	0.0010798	0.0011417	0.0012299	0.0013711	0.0017270	0.013038	0.015784	0.017994	0.019948	0.021752	0.023458
17	h	642.61	859.02	1086.23	1336.38	1666.59	2917.78	3120.89	3283.61	3429.11	3565.86	3697.79
(352.29)	s	1.8241	2.3073	2.7635	3.2197	3.7701	5.7533	6.0449	6.2627	6.4451	6.6064	6.7534
	v	0.0010779	0.0011390	0.0012254	0.0013611	0.0016649	0.0099496	0.012720	0.014793	0.016571	0.018184	0.019694
20	h	644.52	860.39	1086.58	1334.14	1645.95	2816.84	3061.53	3241.19	3396.24	3539.23	3675.59
(365.75)	s	1.8209	2.3030	2.7572	3.2087	3.7288	5.5525	5.9041	6.1445	6.3390	6.5077	6.6596
	v	0.0010749	0.0011346	0.0012181	0.0013459	0.0015988	0.0060048	0.0091752	0.011142	0.012735	0.014140	0.015430
25	h	647.73	862.73	1087.33	1331.06	1623.86	2578.59	2950.38	3165.92	3339.28	3493.69	3637.97
(……)	s	1.8158	2.2959	2.7469	3.1915	3.6803	5.1399	5.6755	5.9642	6.1816	6.3638	6.5246
	v	0.0010720	0.0011304	0.0012113	0.0013322	0.0015529	0.0027964	0.0067381	0.0086903	0.010175	0.011444	0.012590
30	h	650.96	865.14	1088.26	1328.66	1608.80	2152.37	2820.91	3084.79	3279.79	3446.87	3599.68
(……)	s	1.8107	2.2890	2.7371	3.1756	3.6435	4.4750	5.4419	5.7956	6.0403	6.2374	6.4077
	v	0.0010691	0.0011264	0.0012048	0.0013197	0.0015175	0.0021056	0.0049589	0.0069334	0.0083477	0.0095231	0.010566
35	h	654.22	867.61	1089.35	1326.81	1597.54	1988.43	2670.97	2998.02	3218.08	3999.02	3560.87
(……)	s	1.8058	2.2823	2.7276	3.1608	3.6131	4.2140	5.1945	5.6331	5.9093	6.1229	6.3032
	v	0.0010663	0.0011224	0.0011986	0.0013083	0.0014884	0.0019107	0.0036927	0.0056249	0.0069853	0.0080891	0.0090538
40	h	657.49	870.12	1090.59	1325.41	1558.74	1931.13	2511.77	2906.69	3154.65	3350.43	3521.76
(……)	s	1.8009	2.2758	2.7185	3.1469	3.5870	4.1141	4.9447	5.4746	5.7859	6.0170	6.2079

v = specific volume (m^3/kg), h = specific enthalpy (kJ/kg), s = specific entropy (kJ/(kg·K)) 〔Source: JSME Steam Tables(1999)〕

The steam h-s diagram (SI unit) is inserted in the back cover.

9-12 Viscosity μ (μPa·s), Kinematic Viscosity ν (mm^2/s) and Thermal Conductivity λ (mW/(m·K)) of Compressed Water and Superheated Steam

Pressure(MPa) Saturation temperature(℃)		Temperature (℃)										
		100°	150°	200°	250°	300°	350°	400°	450°	500°	550°	600°
	μ	12.27	14.18	16.18	18.22	20.29	22.37	24.45	26.52	28.57	30.61	32.62
0.1	ν	20.81	27.47	35.14	43.84	53.54	64.23	75.86	88.43	101.9	116.2	131.4
(99.606)	λ	24.78	28.80	33.37	38.28	43.49	48.97	54.71	60.69	66.90	73.30	79.90
	μ	281.9	182.5	16.05	18.14	20.24	22.34	24.44	26.52	28.58	30.62	32.63
0.5	ν	0.2940	0.1990	6.822	8.607	10.58	12.74	15.09	17.61	20.32	23.19	26.24
(151.84)	λ	678.0	683.9	34.24	38.81	43.90	49.32	55.03	60.98	67.16	73.55	80.13
	μ	282.0	182.6	15.89	18.05	20.18	22.31	24.42	26.52	28.59	30.63	32.65
1	ν	0.2941	0.1991	3.274	4.200	5.207	6.303	7.488	8.762	10.12	11.57	13.09
(179.89)	λ	678.3	684.2	36.06	39.70	44.49	49.80	55.44	61.35	67.51	73.87	80.43
	μ	282.5	183.1	134.7	17.67	19.97	22.20	24.38	26.52	28.62	30.69	32.72
3	ν	0.2944	0.1994	0.1556	1.248	1.621	2.011	2.423	2.861	3.326	3.817	4.334
(223.86)	λ	679.4	685.6	664.7	45.95	47.81	52.11	57.30	62.97	68.97	75.22	81.68
	μ	283.1	183.6	135.2	106.4	19.80	22.13	24.37	26.55	28.68	30.77	32.81
5	ν	0.2947	0.1997	0.1559	0.1330	0.8978	1.150	1.410	1.681	1.967	2.267	2.582
(263.94)	λ	680.5	686.9	666.4	619.1	55.03	55.22	59.53	64.81	70.58	76.67	83.02
	μ	284.4	184.9	136.4	107.8	86.46	22.15	24.49	26.73	28.91	31.03	33.09
10	ν	0.2953	0.2004	0.1566	0.1338	0.1209	0.4971	0.6474	0.7963	0.9487	1.106	1.270
(311.00)	λ	683.2	690.2	670.7	625.5	548.1	68.55	67.25	70.56	75.34	80.83	86.76
	μ	285.7	186.1	137.6	109.1	88.33	22.94	24.93	27.13	29.29	31.40	33.46
15	ν	0.2960	0.2012	0.1574	0.1345	0.1217	0.2633	0.3907	0.5012	0.6100	0.7205	0.8338
(342.16)	λ	685.9	693.4	674.9	631.5	558.7	104.1	79.94	78.50	81.38	85.85	91.13
	μ	278.1	187.3	138.8	110.4	90.05	69.31	26.03	27.81	29.85	31.90	33.92
20	ν	0.2967	0.2019	0.1581	0.1353	0.1226	0.1154	0.2590	0.3538	0.4416	0.5286	0.6169
(365.75)	λ	688.6	696.5	678.9	637.2	568.3	454.1	103.4	89.76	89.10	91.91	96.22
	μ	288.4	188.6	140.0	111.6	91.65	72.76	29.17	28.95	30.64	32.55	34.49
25	ν	0.2974	0.2027	0.1588	0.1360	0.1233	0.1163	0.1752	0.2657	0.3414	0.4145	0.4877
(……)	λ	691.2	699.6	682.9	642.7	577.2	474.1	160.0	106.3	99.02	99.22	102.1
	μ	289.7	189.8	141.1	112.8	93.15	75.46	43.95	30.85	31.72	33.36	35.17
30	ν	0.2981	0.2034	0.1595	0.1367	0.1241	0.1172	0.1229	0.2079	0.2757	0.3394	0.4025
(……)	λ	693.8	702.7	686.7	648.0	585.5	490.6	328.1	131.5	111.9	108.0	109.0
	μ	291.3	191.2	142.5	114.3	94.85	78.16	57.12	34.88	33.53	34.59	36.14
36	ν	0.2990	0.2043	0.1604	0.1375	0.1250	0.1181	0.1173	0.1627	0.2227	0.2782	0.3327
(……)	λ	696.9	706.3	691.2	654.2	594.7	507.4	378.5	180.7	132.3	121.0	118.6
	μ	292.4	192.2	143.4	115.2	95.93	79.75	61.27	39.01	35.11	35.58	36.89
40	ν	0.2996	0.2049	0.1610	0.1381	0.1255	0.1187	0.1171	0.1441	0.1975	0.2485	0.2984
(……)	λ	699.0	708.6	694.2	658.1	600.5	517.3	398.5	225.0	149.7	131.2	125.9

〔Source: JSME Steam Tables(1999)〕

9-13 Thermodynamic and Transport Properties of Water, Sea Water and Heavy Water

Pressure : Saturation pressure

Fluid	Temperature t (K)	Density ρ (kg/m³)	Specific Heat c_p (kJ/(kg•K))	Viscosity μ (Pa•s)	Kinematic Viscosity ν (m²/s)	Thermal Conductivity λ (W/(m•K))	Thermal Diffusivity a (m²/s)	Prandtl Number Pr ••
Water				$\times 10^{-4}$	$\times 10^{-6}$		$\times 10^{-6}$	
	273.16	999.78	4.217	17.914	1.792	0.5619	0.1333	13.44
	280	999.93	4.199	14.354	1.435	0.5760	0.1372	10.46
	300	996.62	4.179	8.544	0.8573	0.6104	0.1466	5.850
	320	989.43	4.180	5.772	0.5834	0.6369	0.1540	3.788
	340	979.44	4.188	4.225	0.4314	0.6568	0.1601	2.694
	360	967.21	4.202	3.267	0.3378	0.6710	0.1651	2.046
	380	953.08	4.224	2.630	0.2759	0.6800	0.1689	1.634
	400	937.22	4.257	2.185	0.2331	0.6842	0.1715	1.359
	440	900.51	4.360	1.620	0.1799	0.6796	0.1731	1.039
	480	856.66	4.533	1.290	0.1506	0.6587	0.1696	0.888
	520	803.90	4.833	1.073	0.1335	0.6218	0.1600	0.834
	560	738.06	5.426	0.908	0.1230	0.5675	0.1417	0.868
	600	649.30	6.980	0.756	0.1165	0.4917	0.1085	1.073
Sea water				$\times 10^{-4}$	$\times 10^{-6}$		$\times 10^{-6}$	
	298.16	1021	4.003	9.59	0.939	0.606	0.0148	6.33
	303.16	1020	4.007	8.64	0.847	0.613	0.0150	5.65
	313.16	1017	4.011	7.07	0.695	0.627	0.0154	4.52
	323.16	1013	4.019	5.94	0.586	0.638	0.0157	3.73
Heavy water (D_2O)				$\times 10^{-4}$	$\times 10^{-6}$		$\times 10^{-6}$	
	280	1105.8	4.225	18.564	1.679	0.5747	0.1230	13.6
	300	1104.0	4.232	10.480	0.9493	0.5977	0.1279	7.42
	320	1097.0	4.211	6.920	0.6308	0.6145	0.1330	4.74
	340	1086.5	4.189	4.962	0.4567	0.6262	0.1376	3.32
	360	1073.2	4.171	3.817	0.3557	0.6333	0.1415	2.51
	380	1057.7	4.164	2.794	0.2908	0.6360	0.1444	2.01
	400	1040.1	4.170	2.553	0.2455	0.6343	0.1462	1.68

(Source: JSME Data Book: Thermophysical Properties of Fluids (1983). Converted into SI unit from The Office of Saline Water U.S. Department of Interior, Saline Water Conversion Engineering Data Book, 1965)

9-14 Thermal Efficiency of Simple Rankine Cycle

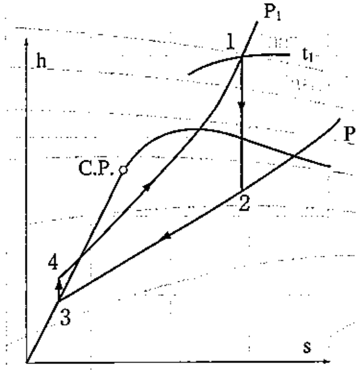


Figure 1 h-s Diagram of Rankine Cycle

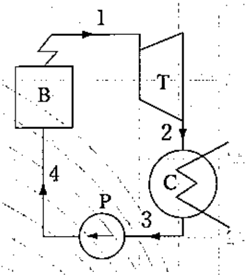


Figure 2 Rankine Cycle System

Now assume that 1 kg of water or steam exists and the pressure, temperature, specific volume ,specific enthalpy, and specific entropy are represented by P (kPa), t (℃), υ (m³/kg), h(kJ/kg), and s(kJ/(kg•K)) respectively.

The simple Rankine cycle is composed of the following four processes. See Figures 1 and 2.

(i) Low-pressure saturation water 3 is compressed under adiabatic condition to high-pressure water 4.
(ii) High-pressure water 4 is superheated at constant pressure to high temperature and high-pressure steam 1.
(iii) high temperature and high-pressure steam 1 is expanded under adiabatic condition to low-pressure steam 2.
(iv) Low-pressure steam 2 is cooled at constant pressure to saturated water 3.

The process (1) is performed by using a condensate pump and a feed water pump P. The work to be added to water is $Wp = h_4 - h_3 \fallingdotseq (P_4 - P_3) \times \upsilon_3$.

The process (ii) is performed by using a boiler B. The heat added to water or steam is $(h_1 - h_4)$ (kJ/kg).

The process (iii) is performed by using a turbine T. The work obtained from steam is $(h_1 - h_2)$ (kJ/kg).

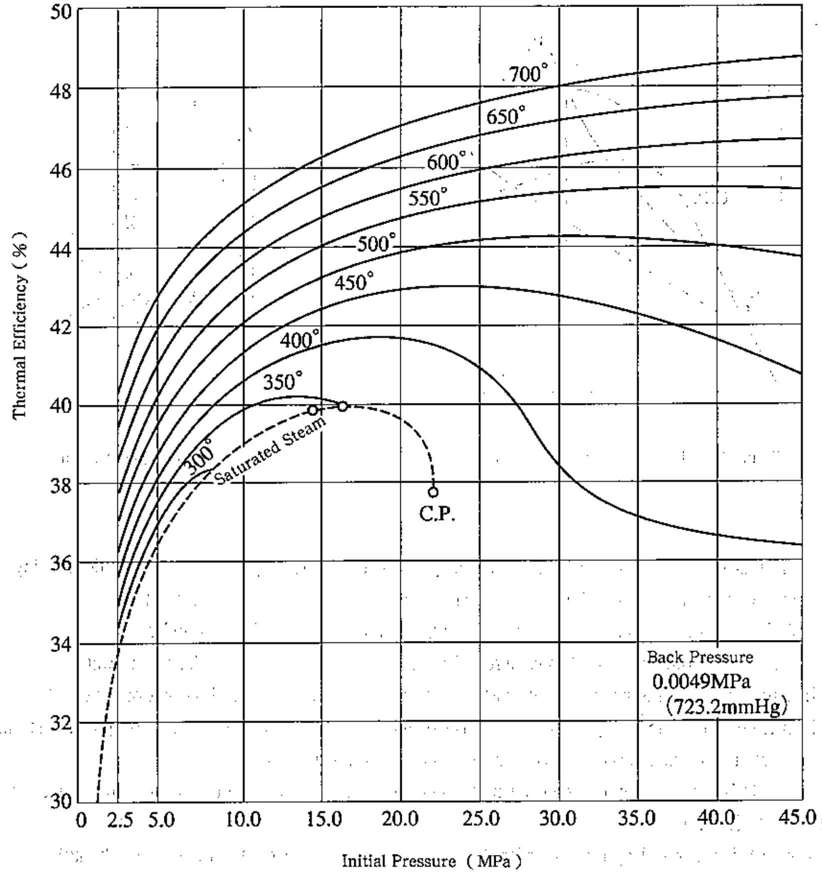
The process (iv) is performed by using a condenser C. The heat removed from steam is $(h_2 - h_3)$ (kJ/kg).

Then, the thermal efficiency of the simple Rankine cycle becomes $\eta_R = \{(h_1 - h_2) - (h_4 - h_3)\}/(h_1 - h_4) = 1 - (h_2 - h_3)/(h_1 - h_4)$.

When state 2 is in the wet steam region, $\eta_R = 1 - (s_1 - s_3) T_2/(h_1 - h_4)$. T_2 is saturation temperature [K] to P_2. When P_1, t_1, and P_2 are given, h_1 and h_3 can be directly calculated from steam tables, and h_2 is obtained using the Mollier chart. When state 2 is wet region, $h_2 = h_3 + (s_1 - s_3) T_2$. It can be found with $h_4 \fallingdotseq h_3 + (P_4 - P_3) \times \upsilon_3$

Fig. 3 shows the thermal-efficiency of a simple Rankine cycle η_R for the initial pressure P_1 and the initial temperature t_1 under a constant back-pressure ($P_2 \fallingdotseq 0.0049$MPa, vacuum 723.2mmHg) In general, the thermal efficiency becomes the higher, the higher the initial pressure and the initial temperature are, and the lower the back pressure is. For increasing a thermal efficiency, it is necessary to raise the initial pressure and the initial temperature should be increased according to the initial pressure. For the reheat and regenerative cycle, refer to Chapter 14.

Figure 3 Thermal Efficiency of Simple Rankine Cycle



9-15 Thermal Efficiency of Simple Brayton Cycle

The Brayton cycle (gas turbine cycle) is divided into the open cycle gas turbine, that uses the air taken from the atmosphere as a working gas and discharges again the flue gas after heating in a combustion chamber and working in a turbine to the atmosphere, and the closed cycle gas turbine, that uses the working gas circulated within the cycle. The description here assumes the open cycle. Besides, the cycle shall be ideal and the gas shall change the state adiabatically in a compressor and a turbine.

Now assume that 1 kg of air exists and the pressure, temperature, specific enthalpy, and specific entropy are represented by P (kPa), t (℃), T (K), h (kJ/kg), and s (kJ/(kg• K)) respectively.

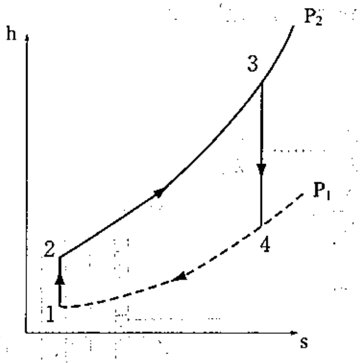


Figure 1 h-s Diagram of Brayton Cycle

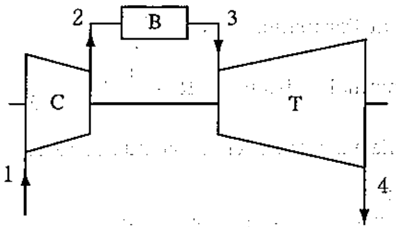


Figure 2 Brayton Cycle System

(i) The air taken in from the atmosphere is compressed under adiabatic condition from point 1 to 2.

(ii) The high pressure air is heated at constant pressure from point 2 to 3 in a combustion chamber.

(iii) The high pressure and high temperature gas is expanded under adiabatic condition from point 3 to 4 in a turbine.

(iv) The gas 4 from the turbine is exhausted.

In process (ii), the heat (q_1) added to the air is obtained by $q_1 = h_3 - h_2 = c_p (t_3 - t_2)$.
In process (iv), the discharged heat (q_2) is obtained by $q_2 = h_4 - h_1 = c_p (t_4 - t_1)$.
In process (i), the work added to the air by a compressor is $h_2 - h_1$.
In process (iii), the work obtained from the gas expanded within a turbine is $h_3 - h_4$.

Thermal efficiency $\eta_B = \{(h_3-h_4)-(h_2-h_1)\}/(h_3-h_2)$

$$= (q_1-q_2)/q_1 = 1-q_2/q_1 = 1-(t_4-t_1)/(t_3-t_2) = 1-(T_4-T_1)/(T_3-T_2)$$

Since processes (i) and (iii) are adiabatic compression and adiabatic expansion, denoting the pressure ratio $P_2/P_1 = \pi$,

$$T_1/T_2 = (P_1/P_2)^{(k-1)/k} = (1/\pi)^{(k-1)/k},\ T_4/T_3 = (P_4/P_3)^{(k-1)/k} = (1/\pi)^{(k-1)/k}$$

Thus $\eta_B = 1-(1/\pi)^{(k-1)/k}$ and the efficiency becomes the higher, the larger the pressure ratio is. (Figure 3)

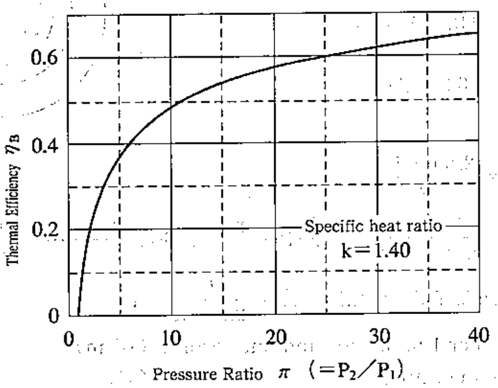


Figure 3 Thermal Efficiency to Pressure Ratio

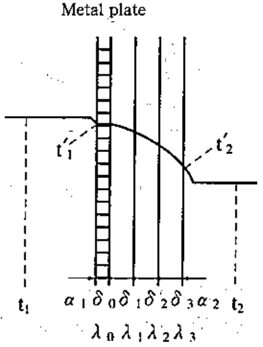
9-16 Calculation of Thermal Insulation

(1) For flat plates

Heat Dissipation $Q = \frac{(t_1 - t_2)}{R}$

Thermal resistance $R = \frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \frac{\delta_0}{\lambda_0} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \cdots\cdots + \frac{\delta_m}{\lambda_m}$

Surface temperature of heat insulating material $t_2' = \frac{Q}{\alpha_2} + t_2$



Where;

Q: Heat dissipation per 1 m^2 of flat metal plate and one second. (W/m^2)
t_1 : Internal fluid temperature (℃)
t_2 : Ambient temperature (℃)
α_1 : Heat transfer coefficient for internal fluid to metal wall $(W/(m^2 \cdot K))$
α_2 : Heat transfer coefficient for ambient air from insulator surface $(W/(m^2 \cdot K))$
δ_0 : Metal plate thickness (m)
$\delta_1, \delta_2, \delta_3, \cdots\cdots \delta_m$: Thickness of insulators (m)
λ_0 : Thermal conductivity of metal plate $(W/(m \cdot K))$
$\lambda_1, \lambda_2, \lambda_3, \cdots\cdots \lambda_m$: Thermal conductivity of insulators $(W/(m \cdot K))$

For thermal conductivity of Heat insulating materials, refer to 4-16.

〔Calculation Examples〕

Where $t_1 = 350℃$, $t_2 = 35℃$, $\alpha_2 = 10\ W/(m^2 \cdot K)$ (10 or so usually), $1/\alpha_1$ and δ_0/λ_0 are small and can be omitted. Assuming,

the 1st layer of insulators $\lambda_1 = 0.06\ (W/(m \cdot K))$
$\delta_1 = 0.095$ (m)
the 2nd layer of insulators $\lambda_2 = 0.05\ (W/(m \cdot K))$
$\delta_2 = 0.055$ (m)

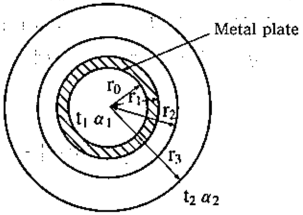
the total thermal resistance,

$$R = \frac{1}{10} + \frac{0.095}{0.06} + \frac{0.055}{0.05} = 2.78\ ((m^2 \cdot K)/W)$$

Thus, the heat dissipation and the insulator surface temperature are obtained as follows;

$$Q = \frac{350 - 35}{2.78} \fallingdotseq 113\ (W/m^2)$$

$$t_2' = \frac{113}{10} + 35 \fallingdotseq 46.3\ (℃)$$



(2) For pipes

Heat Dissipation $Q = \frac{2\pi(t_1 - t_2)}{R}$

Thermal resistance $R = \frac{1}{\alpha_1 r_0} + \frac{1}{\alpha_2 r_{n+1}} + \frac{1}{\lambda_0} \log_e \frac{r_1}{r_0} + \frac{1}{\lambda_1} \log_e \frac{r_2}{r_1} + \cdots\cdots + \frac{1}{\lambda_n} \log_e \frac{r_{n+1}}{r_n}$

Surface temperature of heat insulating material $t_2' = \frac{Q}{2\pi r_{n+1} \alpha_2} + t_2$

Q : Heat dissipation per 1 m of tube and one second. (W/m)
t_1 : Internal fluid temperature (℃)
t_2 : Ambient temperature (℃)

α_1 : Heat transfer coefficient for internal fluid to metal wall $(W/(m^2 \cdot K))$
α_2 : Heat transfer coefficient for ambient air from insulator surface $(W/(m^2 \cdot K))$
r_0 : Inner radius of pipe (m)
$r_1, r_2, r_3 \cdots\cdots r_n$: Inner radius of insulators (m)
r_{n+1} : Outer radius of the last insulation layer (m)

〔Calculation Examples〕

$t_1 = 400℃$, $t_2 = 20℃$, $\alpha_2 = 10\ W/(m^2 \cdot K)$

$\frac{1}{\alpha_1 r_0}$ and $\frac{1}{\lambda_0} \log_e \frac{r_1}{r_0}$ values are small, they are omitted here. The heat dissipation and surface temperature of the insulator material in this case are calculated as follows:

Outer radius of pipe: $r_1 = 0.057$ (m) , Thermal conductivity of insulator: $\lambda_1 = 0.06\ (W/(m \cdot K))$
Outer radius of last insulation layer: $r_2 = 0.133$ (m)

If the above values are assumed, R can be calculated as follows:

$$R = \frac{1}{10 \times 0.133} + \frac{1}{0.06} \log_e \frac{0.133}{0.057} \fallingdotseq 14.9((m \cdot K)/W)$$

Thus Q and t_2' are obtained as follows:

$$Q = \frac{2\pi(400 - 20)}{14.9} \fallingdotseq 160\ (W/m)$$

$$t_2' = \frac{160}{2\pi \times 0.133 \times 10} + 20 \fallingdotseq 39.1\ (℃)$$

(3) Economical Thickness of Insulated Layer

In the standards of thermal insulation, the following formula(JIS A9501-1990)is used to calculate the economical thickness of insulated layer. The F_1 or F_2 minimum value is assumed as the thickness of insulation layer.

For pipes: $F_1 = \frac{\pi}{4}(d_1^2 - d_0^2) aN \times 10^3 + bQh \times 10^{-3}$

For flat plates: $F_2 = xaN \times 10^3 + bQh \times 10^{-3}$

Where, F_1 = Yearly total cost of insulation for pipe (¥/m)
F_2 = Yearly total cost of insulation for flat plate (¥/m^2)

$$N = \frac{n(1+n)^m}{(1+n)^m - 1}$$

a = Insulation cost (¥1000/m^3)
b = Energy cost (¥/kJ)
d_1 = Outer diameter of insulator (m), d_0 = Inner diameter of insulator (m)
h = Yearly working hours (s), x = Insulator thickness (m)
Q = Heat dispersion (W/m for pipes and W/m^2 for flat plates)
N = Redemption n = Yearly interest rate m = Working years

This insulation cost curves can be represented by the following approximate equation.

$$a = 1.2\ (12000 \times x^{-k} + 100)$$

Where, a = Insulation cost (¥1000/m^3), x = Insulator thickness (mm), k = Constant

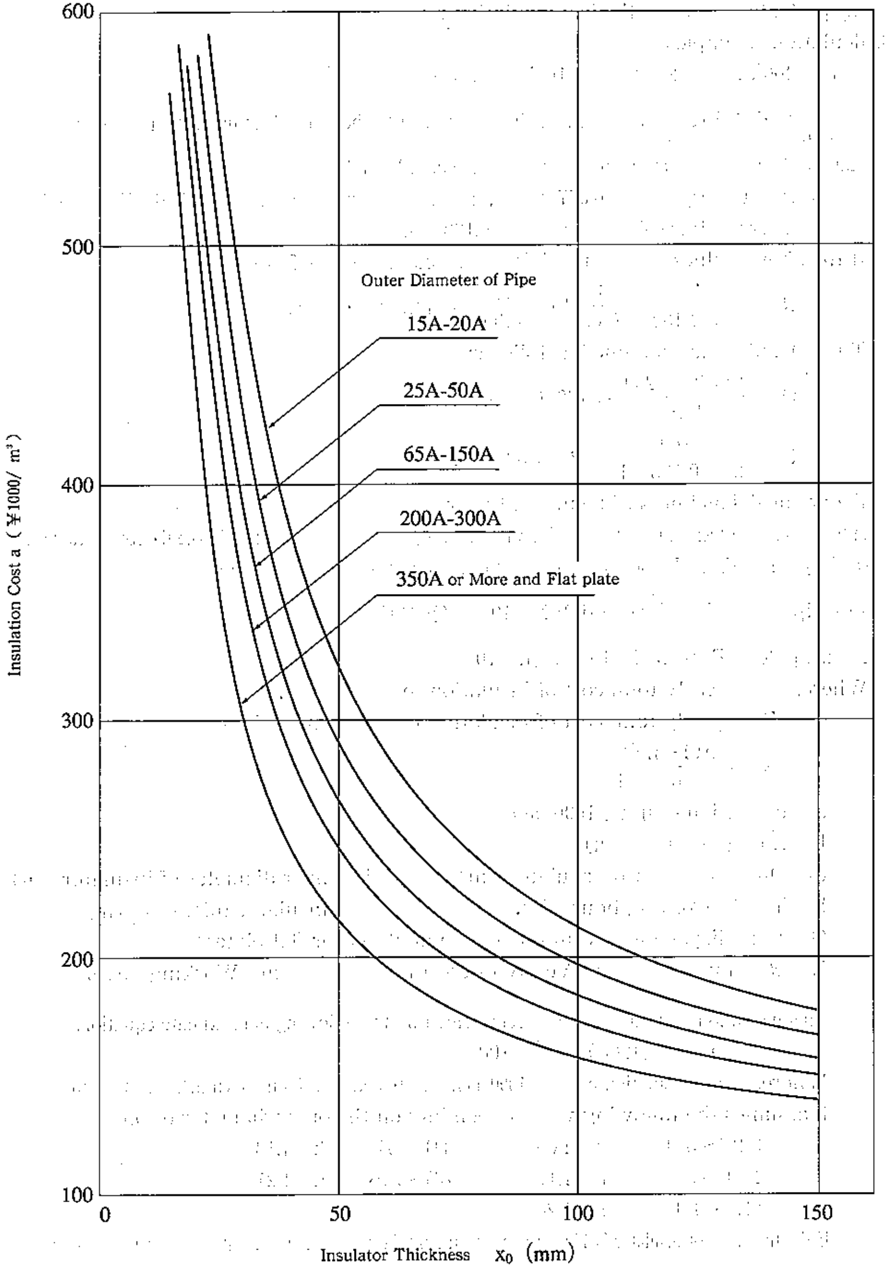
k assumes the following value depending on the outer diameter of pipe.

1/2B～3/4B	k = 1.09,	1B～2B	k = 1.13
2½B～6B	k = 1.17,	8B～12B	k = 1.21
14B～flat	k = 1.28		

If the thickness of insulator is 150mm or more, the insulation cost is represented by the 150mm cost.

JIS A9501-1990

Relationship between Insulator Thickness and Insulation Cost



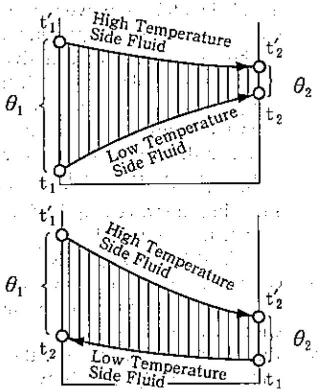
9-17 Convective Heat Transfer

The heat transfer rate in the heat exchanger Q (w) can be calculated as follows:

$$Q = W(h_2-h_1) = W'(h'_2-h'_1)$$

$$Q = K\theta_m A$$

$$\theta_m = \frac{\theta_1-\theta_2}{\log_e \dfrac{\theta_1}{\theta_2}}$$



Where,

W : Low temperature side flow rate (kg/s)
h_1, h_2 : Inlet and outlet enthalpy of low temperature side fluid (J/kg)
W′ : High temperature side flow rate (kg/s)
h'_1, h'_2 : Inlet and outlet enthalpy of high temperature side fluid (J/kg)
A : Effective heating surface area (m²)
θ_m : Logarithmic mean temperature difference (℃)
θ_1 : Temperature difference at the inlet of high temperature side fluid (℃)
θ_2 : Temperature difference at the outlet of high temperature side fluid (℃)
K : Overall heat transfer coefficient (W/(m²•K))

In general, K takes the following values.

Fluids	K(W/(m²•K))	Remarks
Liquid to Liquid	30～60	Sticky liquid, laminar flow, and natural convection
	115～290	Sticky liquid and forced convection
	140～350	Water and natual convection
	290～930	Water and turbulent flow
	930～1750	Water and forced convection
	930～2300	Membrane type, high velocity flow, plate type heat exchanger and spiral type heat exchanger
Liquid to Gas	6～17. 5	Air and natural convection
	11. 5～58	Air and forced convection
	58～580	High pressure (300at) gas and double tube
Gas to Gas	3. 5～11. 5	Natual convection
	11. 5～35	Forced convevtion

K takes the following values for boilers.

Item		K (W/m²•K)	High temperature side gas velocity (m/s)	Low temperature side fluid velocity (m/s)
Air pre-heater	Normal case	11. 5～16	5～7	5～7
	Particular case	29～35	20	20
Economizer	Smooth surfasce casting tube	14～18. 5	5～7	0.1～0.2
	Casting tube with fin: 80mm I.D. fin outer size: 220mm	9. 3～14	5～7	0.1～0.2
	Casting tube with fin: 60mm I.D. fin outer size: 140～150mm	14～21	5～7	0.1～0.2
	Steel tube	21～30	5～7	0.4～0.6
Superheater	Normal case	23～42	12～20	—

Note: (1) The K value will be larger when temperature or the flow velocity, especially the steam velocity is large.
(2) For the condenser and the feedwater heater, refer to Chapter 15.

[Source: Converted into SI unit from JSME Data Book : Heat Transfer, 3rd Edition (1975)]

9-18 Heat Transfer by Thermal Radiation

(a) Black body ——A body that absorbs all thermal radiation incident on the surface of an object.

(b) Emissive power——A body with a temperature radiates heat with various wave lengths from its surface. The total volume of the energy E (W/m^2) emitted from the unit surface of the body per unit time is called (total) emissive power of the body at that temperature. The thermal radiation E_λ, with a specific wave length λ (per unit wave length) is called monochromatic emissive power.

The monochromatic emissive power from the black body with absolute temperature T [K] can be calculated with the following equation (Plank's formula).

$$E_{b\lambda} = C_1/\lambda^5(e^{C_2/\lambda T}-1),\ C_1 = 3.742\times 10^{-16}(W\cdot m^2),\ C_2 = 1.4388\times 10^{-2}(m\cdot K)$$

This monochromatic emissive power calculated for every wave length is integrated to obtain the (total) radioactivity of the black body.

$$E_b = \int_0^\infty E_{b\lambda} d\lambda = \sigma T^4,\ \sigma = \text{Stefan-Boltzmann Constant} = 5.67\times 10^{-8}(W/(m^2\cdot K^4))$$

Denoting the wave length of the maximum thermal radiation to λ_m (μm), the following relation will be satisfied (Wien's law).

$$\lambda_m T = 2.894\times 10^3(\mu m\cdot K)$$

(c) Gray body——The emissive power E of an existing body is smaller than that of a black body E_b when both temperatures are the same. A body of which ratio E/E_b is independent to it's temperature is called gray body.

(d) Emissivity——The ratio of the gray body emissive power E to the black body emissive power E_b is called gray body emissivity ε.

$$\varepsilon = E/E_b$$

(e) Absorptivity——Of the thermal radiation incident on a body, the rates of thermal radiation that are absorbed, transmitted, and reflected are called absorptivity α, transmissivity τ and reflectivity ρ respectively. The relation of $\alpha + \tau + \rho = 1$ is found among them. In case of a solid body and liquid, however, $\tau = 0$ is assumed in many cases, thus $\alpha + \rho = 1$.

(f) Kirchhoff's law——The monochromatic emissivity ε_λ and the monochromatic absorptivity α_λ of a body are equal under the same temperature. In case of a gray body, therefore, the emissvity ε is equal to the absorptivity α covering each wave length radiation.

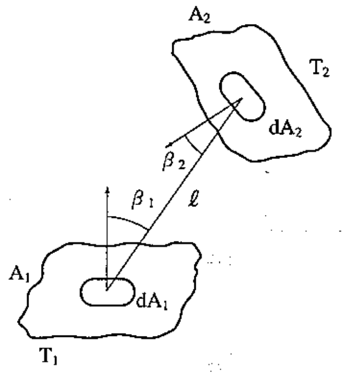
This value is called blackness.When the above equation $\varepsilon = E/E_b$ is used, $E/\alpha = E_b$. In other words, the ratio between the emissive power E and the absorptivity α of a gray body is fixed regardless of the gray body type, and is equal to the emissive power E_b of the black body under the same temperature.

(g) Emissivity of each type material surface

Temperature / Material	Temperature (℃)				Temperature / Material	Temperature (℃)			
	Room temperature	540	1093	1650		Room temperature	540	1093	1650
Pure metal	0.04	0.07	0.14	0.25	Rolled steel plate	0.56	—	—	—
Lamp black	0.97	0.97	0.97	0.97	Black cast iron	0.7~0.8	—	—	—
White surface	0.95	0.70	0.45	0.35	Steel ingot	—	—	0.95	—
Black painted surface	0.95	0.85	0.80	0.75	Rusted steel	0.79	0.79	—	—
Aluminum paint	0.4~0.7	—	—	—	Pottery	0.92	—	—	—
Grinded iron	0.06	0.12	0.22	0.26	Refractory materials	0.9	0.3~0.8	0.3~0.9	0.2~0.9
Grinded cast steel	0.07	0.14	0.23	0.28	Molten mild steel	—	—	—	0.28

〔Reference: JSME Data Book: Heat Transfer, 3rd Edition (1975) and 4th edition (1986)〕

(h) Solid thermal radiation



dA_1, dA_2=Surface area element (m^2) of two bodies $A_1$and A_2.

ε_1, ε_2 = Emissivity of both area elements

T_1, T_2=Absolute temperature (K) of both elements. $T_1 > T_2$

ℓ =Distance between both elements (m)

β_1, β_2=Angle that allows the normal line to both elements to become a straight line connecting both elements (rad)

The radiant heat transfer from surface A_1 to surface A_2 can be calculated as follows:

$$Q_{12} = \sigma A_1 \varphi_{12}(T_1{}^4 - T_2{}^4)(W)$$

φ_{12} =Geometric factor (view factor) for surface A_2 is seen from surface A_1

$$\varphi_{12} = (1/A_1)\int_{A1}\int_{A2}(\cos\beta_1 \cos\beta_2/\pi\ell^2)dA_1 dA_2$$

Examples of φ_{12} will be shown below

①. When surfaces A_1 and A_2 are parallel and infinity, $1/\varphi_{12} = 1/\varepsilon_1 + 1/\varepsilon_2 - 1$,

If both ε_1 and ε_2 are greater than 0.8, $\varphi_{12} \fallingdotseq \varepsilon_1\varepsilon_2$ will be assumed.

②. When surface A_1 is enclosed by surface A_2, $1/\varphi_{12} = 1/\varepsilon_1 + (A_1/A_2)(1/\varepsilon_2 - 1)$,

In case of $A_1 \ll A_2, \varphi_{12} \fallingdotseq \varepsilon_1$ will be assumed.

(i) Flame radiation——Flame is roughly classified into non-luminous flame and luminous flame. Non-luminous flame is transparent blue flame. Mainly, it emits high temperature $CO_2$and H_2 luminous spectrum radiation. Luminous flame mainly emits continuous spectrum radiation of carbon grains floating in the flame. Both flame phenomena are extremely complicated, so it is difficult to calculate the radiant heat transfer Q accurately. As for boiler furnaces, the approximate value can be known by selection the coefficient C properly in the equation below.

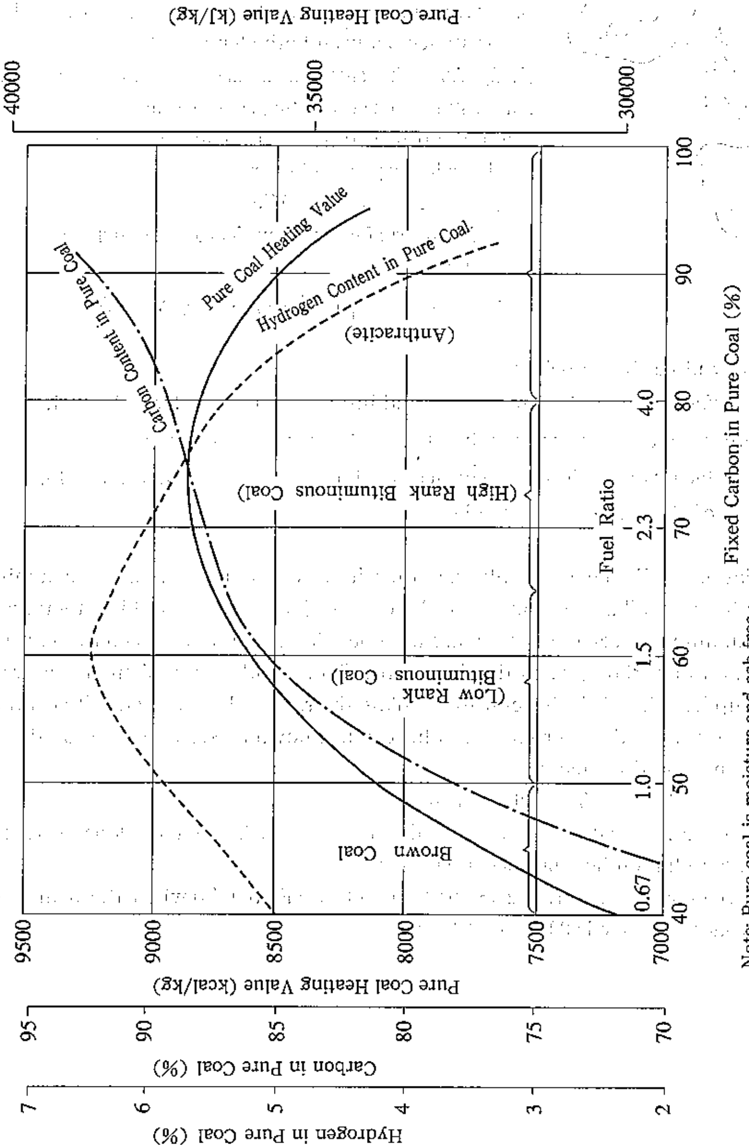
$$Q = CA[(T_g/100)^4 - (T_w/100)^4](W/m^2)$$

T_g =Combustion chamber outlet gas temperature (K), T_w =Water-wall tube surface temperature (K)

A =Effective radiation heat surface area (m^2)

C =Effective emissive factor, (12.5~16.8)×10^3 (J/m^2(K/100)^4)(when the heat release rate per furnace capacity is 80,000 to 230,000 W/m^3)

10-1 Coal Classification



Note: Pure coal is moisture-and ash-free
1kcal/kg = 4.1868 kJ/kg

10-2 Ultimate Analysis and Heating Values of Coal, Petroleum, Coke, and Oil

Fuel	Ultimate Analysis (%)							Theoretical Amount of Air (m_N^3/kg)	Theoretical Amount of combustion Gas (m_N^3/kg)	Max. CO_2 in Product (%)	Heating Value (kJ/kg)	
	C	H	O	S	N	Ash	Moisture				Higher	Lower
Carbon	100.0	—	—	—	—	—	—	8.9	8.9	21.0	33,910	33,910
Coke	75.7	0.4	0.0	1.0	0.0	19.0	3.9	7.2	7.3	20.8	26,170	25,960
Anthracite	79.6	1.5	1.3	0.4	0.4	13.3	3.5	7.5	7.6	20.2	28,970	28,510
Bituminous coal	62.3	4.7	11.8	2.2	1.3	16.8	0.9	6.5	6.9	18.7	25,920	24,830
Brown coal	52.8	4.8	14.6	0.6	0.9	8.6	17.7	5.5	6.1	18.6	21,940	20,470
Lignite	47.7	3.7	19.9	0.5	0.7	8.8	18.7	4.6	5.2	19.8	18,720	17,420
Delayed coke	90.2	3.5	0.54	4.2	1.3	0.24	6~8	9.1	9.2	19.3	35,590	—
Fluid coke	92.3	3.4	—	2.5	1.1	0.6	6~8	9.2	9.3	19.4	33,490	—
Minas crude oil	86.6	13.2	—	0.1	—	0.0	0.1	11.2	12.0	15.4	46,220	43,460
Iranian heavy crude oil	85.6	12.7	—	1.6	—	0.0	0.1	11.1	11.8	15.6	45,180	42,450
Khafji crude oil	84.8	12.3	—	2.9	—	0.0	0.0	10.9	11.6	15.7	44,590	42,040
Light naphtha	84.3	15.7	—	0.0	—	0.0	0.0	11.7	12.6	14.6	47,400	44,250
Whole naphtha	84.6	15.4	—	0.0	—	0.0	0.0	11.6	12.5	14.7	47,190	44,050
Kerosine	86.0	14.0	—	0.0	—	0.0	0.0	11.4	12.2	15.1	46,680	43,500
Light oil	85.8	13.7	—	0.5	—	0.0	0.0	11.3	12.1	15.2	46,010	43,120
Heavy oil A	86.2	13.2	—	0.6	—	0.0	0.0	11.2	11.9	15.4	45,590	42,710
Heavy oil B	85.6	12.2	0.3	1.7	0.2	0.0	—	10.9	11.6	15.8	44,050	41,280
Heavy oil C	86.7	12.0	—	1.3	—	0.0	0.1	11.0	11.5	15.8	44,590	42,040
〃	86.4	11.7	—	1.8	—	0.0	0.1	10.9	11.6	15.9	44,000	41,530
〃	86.0	11.6	—	2.3	—	0.0	0.1	10.8	11.5	15.9	43,790	41,410

10-3 Proximate and Ultimate Analysis of Japanese Coal (General Fuel Coal)

Coal Field	Brand Name	Higher Heating Value (kJ/kg)	Moisture Content (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Total Sulfur (%)	Ash Melting Point (℃)	Hardgrove Grindability Index	Ultimate Analysis (Moisture free basis)				
										Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulfur (%)
Taiheiyou	Taiheiyou Shintokuchu	26,580	0.3	13.1	46.8	29.8	0.17	1,330	36~42	65.7	5.2	11.9	1.0	–
	Taiheiyou Nichu	22,350	0.2	25.1	41.3	33.4	0.20	1,450		53.3	3.8	12.6	1.1	0.2
	Taiheiyou 62fun	26,500	9.1	13.4	41.2	36.3	0.22	1,280		77.9	6.2	14.4	1.4	0.3
	Taiheiyou Senfun	25,580	7.2	16.0	41.3	35.5	0.23	1,380	–	–	–	–	–	–
	Taiheiyou Nihun	19,760	5.8	32.4	33.6	28.2	0.25	1500	–	–	–	–	–	–
Matushima	Ikeshima 60fun	25,700	2.0	22.7	34.9	40.4	1.1	1,450	50	60.6	4.5	7.2	1.0	0.8
	Ikeshima 46fun	20,050	2.1	36.8	29.6	31.6	1.2	1,415	–	–	–	–	–	–

[Sourse: Proximate analysis··· "Coal Note" (1998) edited by Agency of Natural Resources and Engergy.
Ultimate Analysis··· analysis examples shown for reference.]

Note: Hardgrove grindability index = 13 + 6.93W. W indicates the mass (grams) obtained by shieving the sample coal (16 to 30 mesh 50 grams) using a 200-mesh shieve after it is crashed in a standard testing machine.

10-4 Proximate and Ulitimate Analysis for Overseas Coal (General Fuel Coal)

Country Name	Brand Name	Higher Heating Value (kJ/kg)	Moisture Content (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Total Sulfur (%)	Ash Melting Point (℃)	Hardgrove Grindability Index	Ultimate Analysis (Moisture free basis)				
										C (%)	H (%)	O (%)	N (%)	S (%)
USA	Colowyo	27,210	14	5	34	–	0.4	–	–	73.3	5.0	14.4	1.6	0.5
	King	26750	10	10	40	–	1.0	1,430	47	71.9	5.4	9.1	1.0	0.5
	Orchard Valley	25,950~26,370	10~12	9~10	30~33	–	0.8	1,350	47	70.8	4.5	10.9	1.1	0.3
	Pinnacle	28,050	9.8	10.2	37.6	42.5	0.54	–	–	69.5	5.0	11.2	1.2	0.5
	Plateau	26,750	10	8.5	41.5	40	0.65	1,480	45~50	68.5	4.8	16.4	1.3	0.8
	Sufco	27,210	10	10.1	38.5	46.5	0.55	1,200	48	70.8	4.8	12.1	1.3	1.2
	Skyline	27,420	9	9	40.0	42.0	0.50	1,190	48	71.5	4.6	11.7	1.3	0.9
	Valley Camp	27,210	10	8	41.0	41.0	0.6	–	–	73.6	5.4	11.8	1.5	0.5
Australia (to be continued)	Bays Water	28,550	8	13.5	33	51	1.1	1,470	48	71.7	4.4	7.9	1.4	0.9
	Bloomfield	28,050	8	15	32	49.5	1.25	1,560	48	71.0	4.7	6.6	1.7	1.0
	Blair Athol	27,290	16	8	27.2	57.3	0.3	1,580	60	74.5	4.1	11.8	1.7	0.4
	Drayton	28,260	9.5	14	34	49.5	0.95	1,500	48	72.3	4.9	7.9	1.6	1.0
	Hunter Valley	28,470	9	13.5	34	50	0.5	1,560	50	70.8	4.4	9.1	1.6	0.5
	Lemington	29,090	9	12.5	32.5	52	0.43	1,550	45~50	73.0	4.6	8.2	1.5	0.3
	Lithgow	28,470	8	14.8	30.5	52.2	0.59	Min1,550	47	71.3	4.4	7.3	1.5	0.6
	Muswell Brook	29,640	9	10.6	–	52.4	0.99	Min.1,550	45	70.1	4.6	8.4	1.5	0.6
	R.W.Miller Blend	27,840	9	15.5	31.5	50.5	0.40	1,560	50	69.5	4.2	7.9	1.7	0.4
	Ulan	29,090	9.0	12.5	31.5	53.5	0.82	1,400	50	73.3	4.5	7.1	1.5	0.6
	Wambo	28,470	9	12	33.0	52.5	0.60	1,480	50	70.9	4.7	8.1	1.6	0.4
	Warkworth	28,470	8	15	29	53.5	0.58	1,550	51	70.9	4.7	7.4	1.6	0.5

Country Name	Brand Name	Higher Heating Value (kJ/kg)	Moisture Content (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Total Sulfur (%)	Ash Melting Point (℃)	Hardgrove Grindability Index	Ultimate Analysis (Moisture free basis)				
										C (%)	H (%)	O (%)	N (%)	S (%)
Australia (continued)	Clutha	27,840	8.5	16	29	52	0.6	1,560	48〜50	73.8	4.0	5.9	1.3	0.3
	Western Main	28,340	9	14	29	54.5	0.7	—	49	67.9	4.2	9.3	1.5	0.6
	Wallarah	28,260	9	13.5	30	53.0	0.28	1,560	50	71.0	4.1	8.1	1.5	0.3
	Moura	30,310	9.5	9.5	30.5	57.5	0.5	1,490	53	73.3	4.5	6.8	1.6	0.6
	Saxonvale	28,260	9	15.0	31.0	51.5	0.55	Min.1,550	53	70.8	4.3	6.4	1.5	0.5
	Rhondda	28,050	9	16.0	31.0	50.0	0.34	1,600	52	70.6	5.6	14.0	0.9	0.3
Canada	Obed	25,330	8	13.5	37	44	0.55	1,350	40〜45	65.7	4.6	13.6	1.35	0.58
	Coal Valley	26,580	8	10	35	50.5〜51.5	0.3	1,250	45	69.0	5.4	13.8	1.0	0.3
Soviet Russia	Kuznetsky G-6	30,140	10	10.1	36.2	51.4	0.4	1,450	61	79.1	5.6	2	2.3	0.3
	Neryungrinsky SS	26,790	9	15.5	18.3	63.2	0.3	1,450	80	63.7	3.3	1.6	0.7	0.1
	Kuznetsky GK	30,140	7.8	9.5	34.1	—	0.3	1,350	65	75.1	5.4	6.4	2.5	0.5
China	Tatung	28,470	8(max)	12(max)	26.0	—	1.0(max)	Min.1,300	—	73.6	5.1	7.6	1.1	0.2
	Waipey	27,210	12	10.5	28.5〜31.5	—	0.35	—	—	—	—	—	—	—
South Africa	Ermelo	25,200	9	12.3	30.9	53.8	1.09	Min.1,360	50	69.9	4.5	9.5	1.5	0.9
	Optimum	29,000	8	10.0	31.7	54.7	0.59	Min.1,400	50	72.6	4.9	8.8	1.8	0.6
	Kleinkopje	27,300	9	15.7	24.9	57.2	0.56	1,400	50	69.3	3.7	7.4	1.5	0.7
	Rietspruit	24,250	9	14.6	24.6	57.3	0.67	Min.1,370	50	69.8	3.7	8.4	1.4	0.5
	Witbank	24,820	8	16	22〜25	55〜59	1.0	1,300	50	70.0	4.2	6.9	1.8	0.7
Indonesia	Kutai	28,470	9.6	3.9	41.0	43.8	0.35	1,400	42	77.3	6.7	12.6	1.6	—
	Ombilin	29,200	11	5.5	38.0	50.5	0.5	1,600	40	76.2	5.2	11.2	1.4	0.5
	Bukit Baiduri	26,790	14	4.0	39	47	0.7	1,420	—	—	—	—	—	—

(Source: For proximate analysis, "Coal Note" (1998) edited by the Agency of Natural Resources and Energy, and "Coal Almanac" published by Telex Report Co.(1991)
Ultimate analyses are examples for reference.)

10-5 Standard Specification for Fuel Oils

(1) Standard Specifications for Kerosene (JIS K2203−1996)

(a) Kerosene is classified into two kinds as shown below.

No.1…Used for lamps and burners for heating or general purpose of kitchens

No.2…Used as fuel for petroleum engines, and for solvent and cleaning.

(b) The quality of Kerosene shall contain neither water nor sediment and conform to the following Specifications.

Item / Kind	Reaction	Flash Point (℃)	95% Distillation Temp. (℃)	Sulfur Content (mass %)	Smoke Point (㎜)	Corrosion Copper Strip (50℃, 3h)	Color (Saybolt)
No.1	Neutral	Min.40	Max.270	Max.0.015	Min.23	Max. 1	Min.+25
No.2	Neutral	Min.40	Max.300	Max.0.50	—	—	—
JIS Test Method	K 2252	K 2265	K 2254	K 2541	K 2537	K 2513	K 2580

Note: (1) The smoke point of the No. 1 oil for cold weather shall be 21 or more.

(2) Standard Specifications for Light Oil (JIS K2204−1996)

(a) Light oil is classified into the following 5 kinds according to the pour point; special No.1, No.1, No.2, No.3, and special No.3.

(b) The quality of light oil shall contain neither water nor sediment and conform to the following Specifications.

Kind	Flash Point (℃)	90% Distillation Temp. (℃)	Pour-Point (℃)	Cold Filter Plugging Point (℃)	Carbon Residue, 10% bottom (mass %)	Cetane Index (2)	Kinematic Viscosity (30℃) (㎟/s)	Sulfur Content (mass %)
Special No.1	Min.50	Max.360	Max.+ 5	—	Max.0.1	Min.50	Min.2.7	Max.0.2
No.1	Min.50	Max.360	Max.− 2. 5	Max.− 1		Min.50	Min.2.7	
No.2	Min.50	Max.350	Max.− 7. 5	Max.− 5		Min.45	Min.2.5	
No.3	Min.45	Max.330$^{(1)}$	Max.− 20	Max.− 12		Min.45	Min.2.0	
Special No.3	Min.45	Max.330	Max.− 30	Max.− 19		Min.45	Min.1.7	
JIS Test Method	K 2265	K 2254	K 2269	K 2288	K 2270	K 2230	K 2283	K 2541

Note: (1) It shall be 350℃ or less when the kinematic viscosity (30℃) is 4.7㎟/s or less.

(2) A cetane value may be used instead of the cetane index.

(3) Standard Specifications for Heavy Oil (JIS K2205−1991)

(a) Heavy oil is classified as follows :

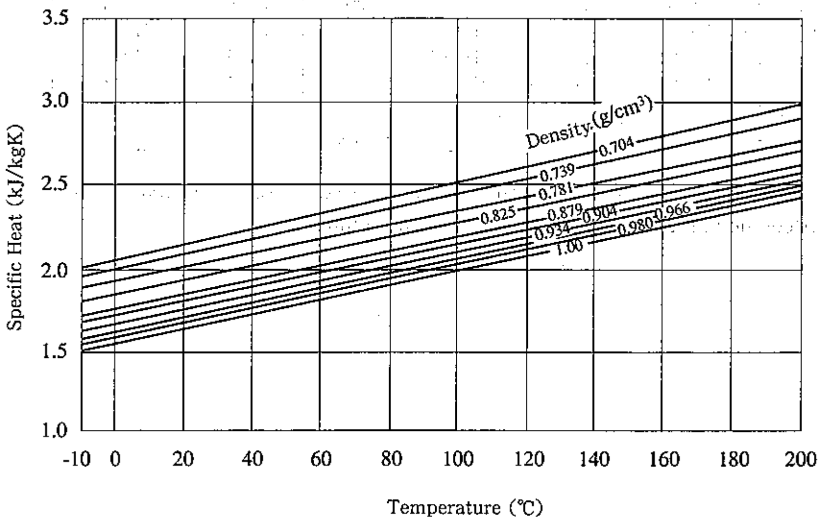
Type 1 (heavy oil A) No. 1 and No.2, Type 2 (heavy oil B), Type 3 (heavy oil C) No. 1 to No.3

(b) The quality of heavy oil shall satisfy the following Specifications.

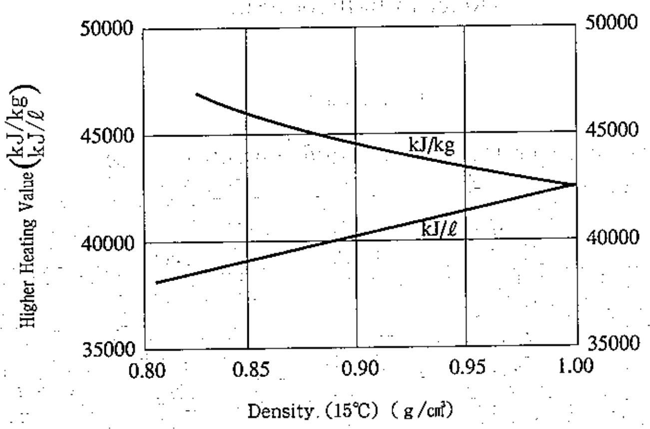
Spec. Kind		Reaction	Flash Point ℃	Kinematic Viscosity (50℃) ㎟/s	Pour Point ℃	Carbon Residue mass%	Moisture Content vol %	Ash Content mass %	Sulfur Content mass %
Type 1	No.1	Neutral	Min.60	Max.20	1) Max. 5	Max. 4	Max.0.3	Max.0.05	Max.0.5
	No.2	Neutral	Min.60	Max.20	1) Max. 5	Max. 4	Max.0.3	Max.0.05	Max.2.0
Type 2		Neutral	Min.60	Max.50	1) Max.10	Max. 8	Max.0.4	Max.0.05	Max.3.0
Type 3	No.1	Neutral	Min.70	Max.250	−	−	Max.0.5	Max.0.1	Max.3.5
	No.2	Neutral	Min.70	Max.400	−	−	Max.0.6	Max.0.1	−
	No.3	Neutral	Min.70	More than 400 and 1000 or less	−	−	Max.2.0	−	−
JIS Test methods		K 2252	K 2265	K 2283	K 2269	K 2270	K 2275	K 2272	K 2541

Note: (1) The pour point of Type 1 and 2 heavy oils used for cold weather shall be 0℃ or less. The pour point of Type 1 heavy oil for warm weather shall be 10℃ or less.

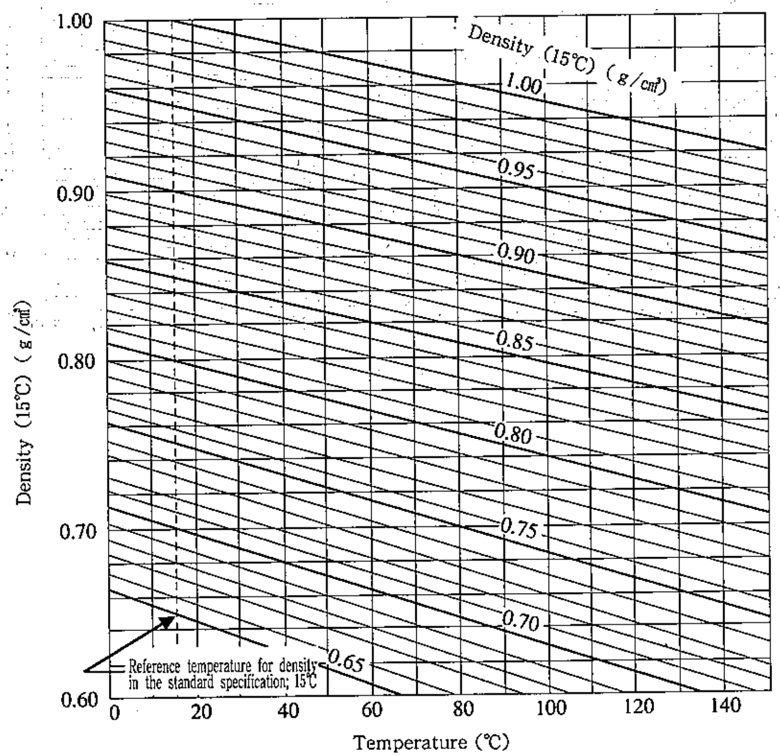
10-6 Relationship among Density, Temperature and Specific Heat of Heavy Oil



10-7 Relationship between Density and Heating Value of Heavy Oil

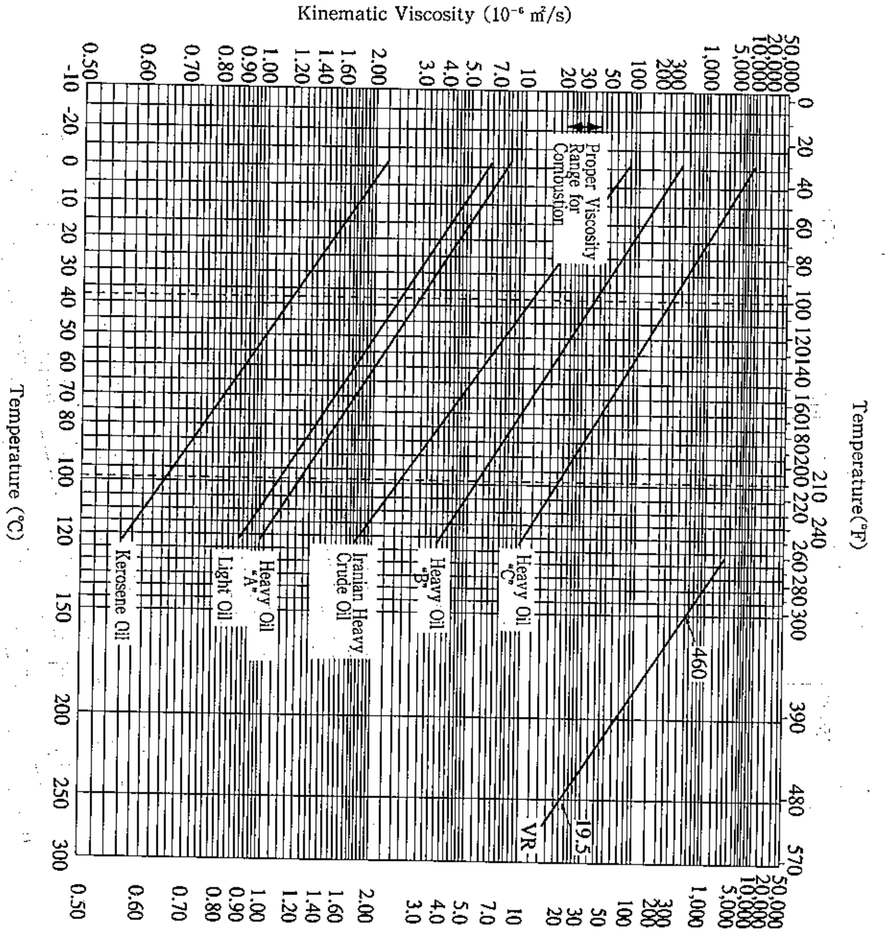


10-8 Density-Temperature Relationship for Fuel Oil



10-9 Viscosity-Temperature Relationship for Fuel Oil

(Refer to 10-10 for SSU.)



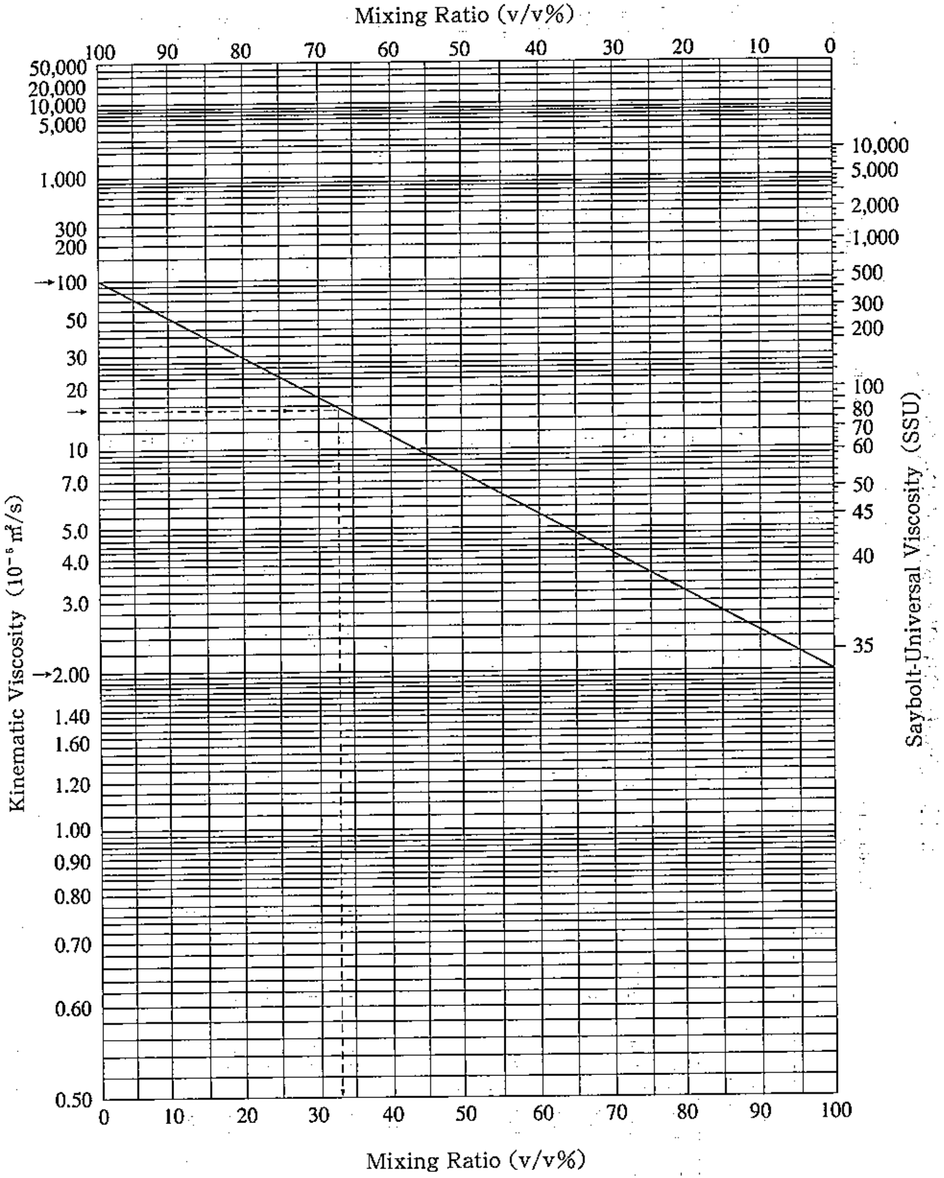
10-10 Fuel Oil Viscosity Conversion Table

10^{-6} m²/s	SSU		RW 30℃ & 50℃	10^{-6} m²/s	SSU		RW 30℃ & 50℃	10^{-6} m²/s	SSU		RW 30℃ & 50℃	10^{-6} m²/s	SSU		RW 30℃ & 50℃
	100° F	210° F			100° F	210° F			100° F	210° F			100° F	210° F	
2.0	32.6	32.8	31	10.0	58.9	59.3	52	40	186.3	187.6	164	80	370.8	373.4	326
2.2	33.3	33.6	31	10.5	60.7	61.1	53	41	190.8	192.1	168	81	375.4	378.0	330
2.4	34.1	34.3	32	11.0	62.4	62.9	55	42	195.3	196.7	172	82	380.0	382.7	335
2.6	34.8	35.0	32	11.5	64.2	64.7	56	43	199.8	201.2	176	83	384.7	387.4	339
2.8	35.4	35.6	33	12.0	66.0	66.5	58	44	204.4	205.9	180	84	389.3	392.0	343
3.0	36.0	36.3	33	12.5	67.9	68.4	60	45	209.1	210.5	184	85	393.9	396.7	347
3.2	36.7	36.9	34	13.0	69.8	70.2	61	46	213.7	215.2	188	86	398.6	401.4	351
3.4	37.3	37.6	34	13.5	71.7	72.2	63	47	218.3	219.8	193	87	403.2	406.0	355
3.6	39.7	38.2	35	14.0	73.6	74.1	65	48	222.9	224.5	197	88	407.9	410.7	359
3.8	38.5	38.8	35	14.5	75.5	76.0	66	49	229.8	231.4	203	89	412.5	415.4	363
4.0	39.1	39.4	36	15.0	77.4	77.9	68	50	232.1	233.8	205	90	417.1	420.0	367
4.2	39.8	40.1	36	15.5	79.3	79.9	70	51	236.7	238.4	209	91	421.8	424.7	371
4.4	40.4	40.7	37	16.0	81.3	81.9	71	52	241.4	243.0	213	92	426.4	429.4	375
4.6	41.1	41.4	37	16.5	83.3	83.9	73	53	246.0	247.7	217	93	431.0	434.0	379
4.8	41.7	42.0	38	17.0	85.3	85.9	75	54	250.6	252.3	221	94	435.7	438.7	384
5.0	42.4	42.6	38	17.5	87.4	88.0	77	55	255.2	257.0	225	95	440.3	443.4	388
5.2	43.0	43.3	39	18.0	89.4	90.1	79	56	259.8	261.6	229	96	444.9	448.0	391
5.4	43.6	43.9	39	18.5	91.5	92.1	80	57	264.4	266.3	233	97	449.6	452.7	396

(Continued)

10^{-6} m²/s	SSU		RW 30°C & 50°C
	100°F	210°F	
5.6	44.3	41.6	40
5.8	44.9	45.2	40
6.0	45.6	45.9	41
6.2	46.2	46.5	42
6.4	46.9	47.2	42
6.6	47.5	47.8	43
6.8	48.1	48.5	43
7.0	48.8	49.1	44
7.2	49.4	49.8	44
7.4	50.1	50.5	45
7.6	50.8	51.1	45
7.8	51.4	51.8	46
8.0	52.1	52.5	46
8.2	52.8	53.1	47
8.4	53.5	53.8	47
8.6	54.1	54.5	48
8.8	54.8	55.2	49
9.0	55.5	55.9	49
9.2	56.2	56.6	50
9.4	56.9	57.3	50
9.6	57.6	57.9	51
9.8	58.2	58.6	51
19.0	93.6	94.2	82
19.5	95.7	96.3	84
20	97.8	98.4	86
21	102.0	102.8	90
22	106.4	107.1	93
23	110.7	111.4	97
24	115.0	115.8	101
25	119.3	120.1	105
26	123.7	124.5	109
27	128.1	129.0	113
28	132.5	133.4	117
29	136.9	137.9	120
30	141.3	142.3	124
31	145.7	146.8	128
32	150.2	151.2	132
33	154.7	155.8	136
34	159.2	160.3	140
35	163.7	164.9	144
36	168.2	169.4	148
37	172.7	173.9	152
38	177.3	178.5	156
39	181.8	183.0	160
58	269.1	270.9	237
59	273.7	275.6	241
60	278.3	280.2	245
61	282.9	284.9	249
62	287.5	289.5	253
63	292.1	294.2	257
64	296.7	298.8	261
65	301.4	303.5	266
66	306.0	308.1	270
67	310.6	312.8	274
68	315.2	317.4	278
69	319.8	322.1	282
70	324.4	326.7	286
71	329.1	331.4	290
72	333.7	336.0	294
73	338.3	340.7	298
74	343.0	345.4	302
75	347.6	350.0	306
76	352.2	354.7	310
77	356.9	359.4	314
78	361.5	361.0	318
79	366.1	368.7	322
98	454.2	457.4	400
99	458.8	462.0	404
100	463.5	466.8	408
This coefficient is used for multiplication for 100 (10^{-6} m²/s) or more.	4.6347	4.6678	4.08
Remark	10^{-6} m²/s : Kinematic viscosity SSU : Saybolt-Universal viscosity RW : Redwood viscosity RW30°C and RW 50°C are almost the same. For 100 (10^{-6} m²/s) or more, calculation shall be as shown below. SSU (@100°F) = 4.6347 × 10^{-6} m²/s SSU (@210°F) = 4.6678 × 10^{-6} m²/s RW = 4.08 × 10^{-6} m²/s		

10-11 Viscosity of Fuel Oil Mixed



(Example)
Ratio (v/ v%) : 67% of heavy oil "A" (100 mm²/s@50℃) is mixed with 33% of heavy oil "B" (2.0 mm²/s@50℃) to obtain 15 mm²/s (@50℃) heavy oil.

10-12 Crude Oil Characteristics Table

Region Name	Middle East									South Area				North America	Middle South America	Africa		Old Seviet
Country Name	Saudi Arabia			Kuwait	Neutral Area		Iran		Abu Dhabi	Brunei	Sumatra			USA	Venezuela	Libya	Nigeria	Old Seviet
Crude Oil Name (1) / Characteristics	Arabian Light (Arabia)	Arabian Medium (Khursaniyah)	Arabian Heavy (Safaniyah)	Kuwait	Khafji	Wafra	Iran. Light (Agha-jari)	Iran. Heavy (Gachsaran)	Murban	Seria	Sumatra	Minas	Juri	San-joaquin	Tia-juana	Libya Light	Nigeria	Ekhabi
Specific gravity 15/ 4℃	0.853	0.875	0.889	0.868	0.886	0.907	0.855	0.865	0.822	0.840	0.790	0.844	0.927	0.964	0.902	0.832	0.860	0.863
API specific gravity 60°F	34.3	30.0	27.7	31.4	28.1	24.4	33.9	32.0	40.5	36.8	47.5	36.1	21.0	15.3	25.3	38.5	33.0	32.3
Kinematic viscosity @ 50℃ (2) (10^{-6} m²/s)	5.5*	59.3	66.0	7.9	15.0	3.9**	6.4**	6.6	3.0*	2.6**	1.1**	9.8	107.0	205.0	30.3*	—	4.7*	3.1
Pour-point (℃)	−35	−20	−40	−30	−12.5	−10>	−20	−18	−29	10	−25>	35	10	−15	−50	—	14	−2.5
Sulfur content (wt%)	1.72	2.53	2.95	2.52	2.92	3.90	1.54	1.55	0.71	0.07	0.04	0.09	0.26	1.00	1.59	0.32	0.14	0.30
Carbon Residue (wt%)	3.7	5.5	8.5	4.3	7.8	—	—	5.2	1.3	0.2	0.2	2.6	6.5	—	—	1.8	1.5	1.4
Distillation characteristic (3) (℃) Initial boiling point	27	48	30	28	26	37	40	35	28	60	30	52	83	45	27	46	24	37
10% point	103	120	114	121	114	128	114	100	91	116	76	167	233	235	137	109	94	117
20% point	155	172	182	177	176	196	169	150	134	144	101	227	312	270	209	155	133	150
30% point	206	224	249	233	239	260	209	205	173	177	114	284	360***	—	269	202	175	193
40% point	256	279	285	289	275	328	258	266	219	213	130	—	—	—	—	247	210	237
50% point	300	326	—	334	295	—	300	—	266	244	151	—	—	—	—	292	231	272
60% point	—	—	—	364	—	—	—	—	—	268	178	—	—	—	—	—	275	—
70% point	—	—	—	—	—	—	—	—	—	295	213	—	—	—	—	—	—	—
80% point	—	—	—	—	—	—	—	—	—	334	255	—	—	—	—	—	—	—

Note : (1) The crude oil name in ( ) is the old name. (2) *37.8℃. **30℃. (3) ***29% point

10-13 Composition, Heating Value, etc. of Gas Fuel (Example)

Gas Fuel		Composition (%)										Theoretical Amount of air (m³/m³)	Theoretical Amount of Combustion gas (m³/m³)	Max. CO_2 in product (%)	Heating Value (kJ/ m_N^3)	
		H_2	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	CO_2	CO	O_2	N_2				Higher	Lower
Natural Gas	Alaska (Kenai)	—	99.8	0.1	0.0	0.0	0.0	—	—	—	0.1	9.52	10.52	11.7	39,780	35,800
	Brunei (Lumut)	—	88.6	5.2	3.6	1.6	0.0	—	—	—	0.0	10.81	11.88	12.1	44,800	40,610
	Abu Dhabi (Das)	—	80.4	17.5	2.0	0.0	0.0	—	—	—	0.1	11.05	12.16	12.3	46,060	41,870
	Indonesia (Badak)	—	89.6	5.7	3.3	1.4	0.0	—	—	—	0.0	10.70	11.78	12.1	44,380	41,030
	Indonesia (Arun)	—	86.1	8.8	4.1	1.0	0.0	—	—	—	0.0	10.96	12.06	12.2	45,220	41,450
	Malaysia (Sarawak)	—	91.6	4.1	2.7	1.5	—	—	—	—	0.1	10.45	11.58	12.1	44,170	39,820
	Australia (Karratah)	—	89.0	7.4	2.5	1.1	0.0	—	—	—	0.0	10.65	11.72	12.1	44,380	40,190
	Japan (Niigata)	—	96.4	2.4	0.4	0.3	0.1	0.4	—	—	—	9.81	10.83	11.9	40,950	36,930
Blast furnace gas		2.8	—	—	—	—	—	21.9	21.9	—	53.4	0.59	1.46	28.1	3,100 (2930~3220)	3,060
Converter gas		1.1	—	—	—	—	—	13.1	76.0	—	9.8	1.84	2.45	36.5	9,760	9,710
Coke-oven gas		55.2	28.1	$C_mH_n = 3.1$				2.7	8.0	0.3	2.6	4.61	5.30	10.9	21,350	18,840
Producer gas		12.1	3.6	$C_mH_n = 0.4$				4.8	25.5	0.2	53.4	1.29	2.10	18.3	6,490	6,070

Gas Fuel		Composition (%)				Theoretical Amount of air (m³/m³)	Theoretical Amount of Combustion gas (m³/m³)	Max. CO_2 in product (%)	Heating Value (kJ/ m_N^3)	
		C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}				Higher	Lower
Liquefied petroleum gas	JIS type 2 No.1 standard product	2.0	96.0	2.0	—	23.81	25.81	13.8	100,440	93,580
	JIS type 2 No.4 standard product	—	3.0	95.0	2.0	30.88	30.94	15.4	133,390	123,010

10-14 Crude Oil/Heavy Oil Timken Withstand Load and Vapor Pressure

Item / Measuring Temperature / Type	Timken Withstand Load (N)		Vapor Pressure (MPa [abs])	
	40℃	80℃	40℃	80℃
Minus Crude Oil	17.7	17.7	0.015	0.02
Khafji Crude Oil	88.3	88.3	0.07	−
Heavy Oil "C"	154.9	132.4	−	0.007

10-15 Calculation of Coal Heating Value

(1) Ultimate analysis result (Dulong Type Formula)

Higher heating value $H_h = \frac{1}{100}\{34080c + 144020(h - \frac{o}{8}) + 9420s\}$ (kJ/kg)

$= \frac{1}{100}\{8140c + 34400(h - \frac{o}{8}) + 2250s\}$ (kcal/kg)

Where, c, h, o, and s are carbon, hydrogen, oxygen, and sulfur contents (mass %) in the fuel used.

(2) Proximate analysis result (Kosaka's equation)

$H_h = 340cf + (402 - 4.1868 \times \alpha \cdot w) \cdot (Vm + w)$ (kJ/kg)

$= 81cf + (96 - \alpha \cdot w) \cdot (Vm + w)$ (kcal/kg)

Where, H_h is higher heating value, cf is fixed carbon (%), Vm is volatile content (%), and w is water content (%). α is a coefficient that depends on the water content and as follows;

$\alpha = 6.5$ for $w < 5.0$, $\alpha = 5.0$ for $w \geqq 5.0$

(3) Calculation of H_ℓ from H_h

Lower heating value $H_\ell = H_h - 25(9h + w)$ (kJ/kg)

$= H_h - 5.9(9h + w)$ (kcal/kg)

Where, h and w are the hydrogen and water contents (mass %) in the fuel used.

(4) Heating value of coal

The heating value of coal is the amount of heat (kJ) generated when a unit quantity (1kg) burns completely, and is defined as the following two kinds;

1) Higher heating value (H_h) or Gross calorific value (G_c)

The condensation latent heat (about 2512 kJ/kg) of the steam formed from water content (w) and hydrogen (h) in coal as a result of combustion is included.

2) Lower heating value (H_ℓ) or Net calorific value (N_c)

Lower heating value is defined by deducting the latent heat from Higher heating value. And the lower heating value is calculated by the formula of the above (3).

(5) Heating values of various fuels

The typical heating values of various fuels, such as coal, oil, and gas, are as follows. Usually, they are expressed with H_h and H_ℓ is calculated by the above-mentioned formula.

Average Higher Heating Value per Unit of Various Fuels

Fuel	Average Higher Heating Value	Unit
Crude oil	46,050	kJ/ℓ
General coal (domestic, equilibrated humidity coal)	26,500	kJ/kg
General coal (overseas, equilibrated humidity coal)	27,920	kJ/kg
LNG	54,430	kJ/kg
LPG	50,240	kJ/kg
City gas	46,050	kJ/m^3_N
Natural gas	43,800	kJ/m^3_N

[Source: "Fuel and Combustion", Thermal and Nuclear Power Engineering Society]

10-16 Specifications for New Fuels (Example)

(1) Water slurry of Bitumen (Orimulsion®)

API Specific Gravity	Viscosity 10^{-3}Pa•s at 30℃(100S^{-1})	Pour-Point ℃	Higher Heating Value (kJ/kg)	Water Content (wt%)	Ash Content (wt%)	Carbon Residue (wt%)
under 10	Max. 900	Min. 2	29310～31400	28～30	Max. 0.2	10～12

Ultimate Analysis (wt%)				Metal Content (ppm)			
C	H	N	S	V	Ni	Fe	Na
59.0～60.5	7.2～7.8	0.43～0.58	2.1～2.9	320～340	68～80	12～17	Max. 80

[Source : MC BITOR Co., Catalog]

(2) CWM

Coal Content (wt%)	Viscosity 10^{-3}Pa•s at 25℃ (100S^{-1})	Ash Content (wt%)	Sulfur Content (wt%)	Higher Heating Value (kJ/kg)	Density (g/㎤)
About 68	800～1200	approx. 8.5	approx. 0.4	approx. 20100	approx. 1.25

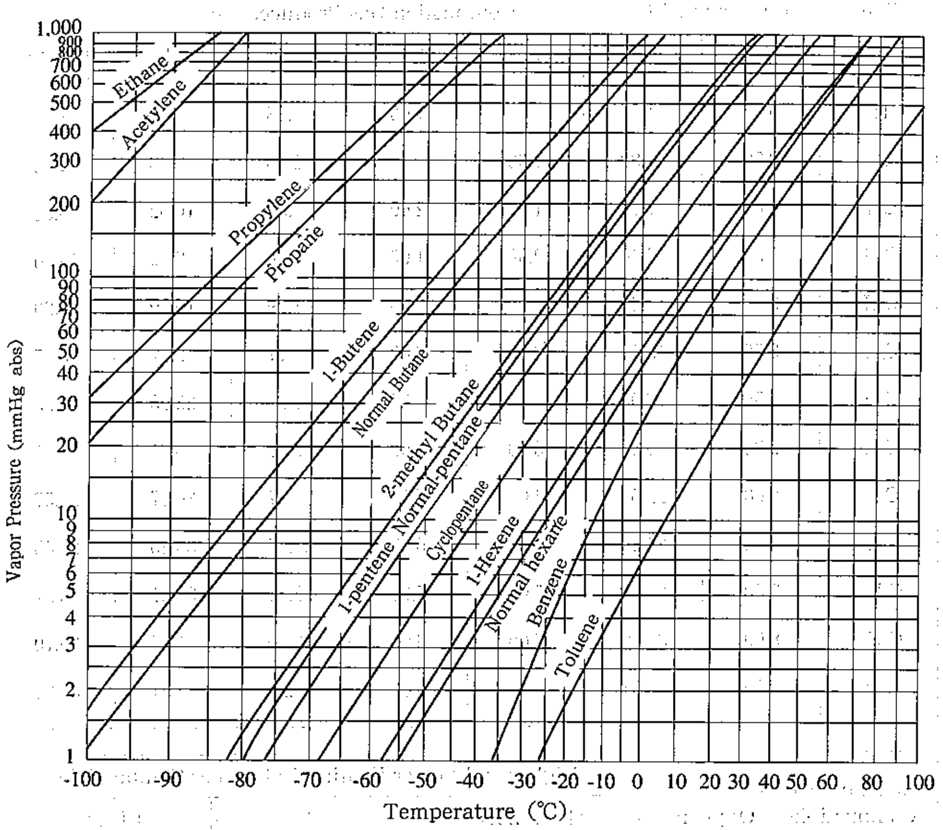
(3) COM

Coal Content (wt%)	Viscosity 10^{-3}Pa•s at 64℃ (20S^{-1})	Ash Content (wt%)	Sulfur Content (wt%)	Higher Heating Value (kJ/kg)	Density (g/㎤)
About 49	Max. 2200	Max. 8.5	Max. 1.3	Min. 35170	approx. 1.10

10-17 Characteristics of Element Related to Combustion

Element	Molecular Formula	Molecular Weight	Per mol of Element (mol)			Density	Heating Value			
			Stoichiometric O_2	CO_2 H_2O (*SO_2) in Product		(kg/m^3_N)	(kJ/m^3_N)		(kJ/kg)	
							Higher	Lower	Higher	Lower
Carbon	C	12	1.0	1.0	—	—	—	—	33,910	33,910
Sulfur	S	32	1.0	1.0*	—	—	—	—	9,250	9,250
Oxygen	O_2	32	−1.0	—	—	1.4289	—	—	—	—
Nitrogen	N_2	28	—	—	—	1.2505	—	—	—	—
Air		29	—	—	—	1.2928	—	—	—	—
Carbon dioxide	CO_2	44	—	1.0	—	1.9768	—	—	—	—
Steam	H_2O	18	—	—	1.0	0.8039	—	—	—	—
Sulfur dioxide	SO_2	64	—	1.0*	—	—	—	—	—	—
Hydrogen	H_2	2	0.5	—	1.0	0.0899	12,770	10,760	141,970	119,620
Hydrogen sulfide	H_2S	34	1.5	1.0*	1.0	1.5390	24,790	22,780	16,120	14,820
Carbon monoxide	CO	28	0.5	1.0	—	1.2502	12,640	12,640	10,130	10,130
Saturated Hydro-carbon										
Methane	CH_4	16	2.0	1.0	2.0	0.7157	39,730	35,840	55,560	50,030
Ethane	C_2H_6	30	3.5	2.0	3.0	1.3415	69,630	63,760	51,920	47,520
Propane	C_3H_8	44	5.0	3.0	4.0	1.9673	99,100	91,270	50,370	46,390
Normal Butane	C_4H_{10}	58	6.5	4.0	5.0	2.5931	128,450	118,610	49,530	45,760
Isobutane	C_4H_{10}	58	6.5	4.0	5.0	2.5931	128,070	118,240	49,400	45,590
Normal pentane	C_5H_{12}	72	8.0	5.0	6.0	3.2188	157,880	146,080	49,070	45,380
Iso pentane	C_5H_{12}	72	8.0	5.0	6.0	3.2188	157,510	145,700	48,940	45,260
Cyclopentane	C_5H_{10}	70	7.5	5.0	5.0	3.1289	148,210	138,370	47,350	44,210
Unsaturated hydro-carbon										
Ethylene	C_2H_4	28	3.0	2.0	2.0	1.2516	63,010	59,080	50,330	47,190
Propylene	C_3H_6	42	4.5	3.0	3.0	1.8773	91,900	86,000	48,940	45,800
1-Butene	C_4H_8	56	6.0	4.0	4.0	2.5031	121,300	113,460	48,480	45,340
Cis-2-butene	C_4H_8	56	6.0	4.0	4.0	2.5031	121,000	113,170	48,360	45,220
Trans-2-butene	C_4H_8	56	6.0	4.0	4.0	2.5031	120,830	112,960	48,270	45,130
Isobutene	C_4H_8	56	6.0	4.0	4.0	2.5031	120,580	112,710	48,150	45,050
1-pentene	C_5H_{10}	70	7.5	5.0	5.0	3.1289	150,720	140,890	48,150	45,050
Cis-2-pentene	C_5H_{10}	70	7.5	5.0	5.0	3.1289	150,430	140,630	48,060	44,920
Trans-2-pentene	C_5H_{10}	70	7.5	5.0	5.0	3.1289	150,220	140,430	48,020	44,880
2-methyl-1-butene	C_5H_{10}	70	7.5	5.0	5.0	3.1289	150,050	140,220	47,940	44,800
3-methyl-1-butene	C_5H_{10}	70	7.5	5.0	5.0	3.1289	150,350	140,550	48,060	44,920
2-methyl-butene	C_5H_{10}	70	7.5	5.0	5.0	3.1289	149,760	139,920	47,860	44,720
Acetylene	C_2H_2	26	2.5	2.0	1.0	1.1616	58,030	56,060	49,950	48,270
Aromatic Hydro-carbon										
Benzene	C_6H_6	78	7.5	6.0	3.0	3.4848	147,380	141,510	42,290	40,610
Toluene	C_7H_8	92	9.0	7.0	4.0	4.1106	176,220	168,310	42,870	40,950

10-18 Vapor Pressure-Temperature Relationship for Hydro-carbon



10-19 Stoichiometry of Combustion and Heating values

Combustible Element	Combustion Product	Unit	Per 1 kg of Combustible Element					
			Oxygen Consumed (A)	Air Consumed (B)	Nitrogen Gas in Consumed Air (C)	Combustion Product Mass (D)	Combustion Gas (C+D)	
							Composition	Mass
C	CO_2	kg	2.66	11.49	8.90	3.67	CO_2+N_2	12.57
		m^3_N	1.87	8.89	7.02	1.87		8.89
	CO	kg	1.33	5.78	4.45	2.23	$CO+N_2$	6.78
		m^3_N	0.93	4.45	3.52	1.87		5.39
H_2	H_2O	kg	8.00	34.78	26.78	9.00	H_2O+N_2	35.78
		m^3_N	5.60	26.66	21.06	11.20		32.26
S	SO_3	kg	1.00	4.35	3.35	2.00	SO_2+N_2	5.35
		m^3_N	0.70	3.33	2.63	0.70		3.33

Fuel	Per 1 m_N^3 Fuel						
	Air Consumed (m_N^3)		Combustion Gas Produced (m_N^3)				Dry Gas (m_N^3 / m_N^3)
	O_2	N_2	CO_2	H_2O	N_2	計	
H_2	0.50	1.88	—	1.00	1.88	2.88	1.88
CO	0.50	1.88	1.00	—	1.88	2.88	2.88
CH_4	2.00	7.52	1.00	2.00	7.52	10.52	8.52
C_2H_2	2.50	9.40	2.00	1.00	9.40	12.40	11.40
C_2H_4	3.00	11.29	2.00	2.00	11.29	15.29	13.29
C_2H_6	3.50	13.17	2.00	3.00	13.17	18.17	15.17
C_3H_6	4.50	16.93	3.00	3.00	16.93	22.93	19.93
C_3H_8	5.00	18.81	3.00	4.00	18.81	25.81	21.81
C_4H_8	6.00	22.57	4.00	4.00	22.57	30.57	26.57
C_4H_{10}	6.50	24.45	4.00	5.00	24.45	33.45	28.45
C_5H_{10}	7.50	28.21	5.00	5.00	28.21	38.21	33.21
C_5H_{12}	8.00	30.10	5.00	6.00	30.10	41.10	35.10
C_6H_6	7.50	28.21	6.00	3.00	28.21	37.21	34.21

Reaction Formula Combustible + Oxygen= Combustion Product	Higher and Lower Heating Values per Combustible					
	(kJ/kmol)		(kJ/kg)		(kJ/ m_N^3)	
	Higher	Lower	Higher	Lower	Higher	Lower
$C+O_2=CO_2$	407,000	407,000	33,900	33,900	—	—
$C+\frac{1}{2}O_2=CO$	122,300	122,300	10,200	10,200	—	—
$S+O_2=SO_2$	296,700	296,700	9,250	9,250	—	—
$CO+\frac{1}{2}O_2=CO_2$	283,400	283,400	10,130	10,130	12,640	12,640
$H_2+\frac{1}{2}O_2=H_2O$	286,200	241,100	142,000	119,600	12,770	10,760
$CH_4+2\,O_2=CO_2+2\,H_2O$	891,000	800,900	55,600	49,950	39,860	35,800
$C_2H_6+3\frac{1}{2}O_2=2\,CO_2+3\,H_2O$	1,560,800	1,425,700	51,960	47,440	70,420	64,350
$C_2H_4+3\,O_2=2\,CO_2+2\,H_2O$	1,424,000	1,333,500	50,790	47,560	64,020	59,950
$C_6H_6+7\frac{1}{2}O_2=6\,CO_2+3\,H_2O$	3,278,000	3,143,200	41,990	40,280	146,370	140,340

---

(1) Equations for theoretical amount of air and actual amount of air

(a) Equation for theoretical amount of air (A_o)

(i) Solid/liquid fuel

$$A_o = 11.49c + 34.5\ (h - \tfrac{o}{8})\ + 4.3s\ \ (\text{kg/kg fuel})$$

$$A_o = 8.89c + 26.7\ (h - \tfrac{o}{8})\ + 3.33s\ \ (m_N^3/\text{kg fuel})$$

(ii) Gas fuel

$$A_o = \frac{1}{0.21}\{0.5[H_2] + 0.5[CO] + \Sigma(x + 0.25y)[C_xH_y] - [O_2]\}\ (m_N^3/m_N^3\ \text{fuel})$$

Where, c, h, o, and s indicate the mass ratio of each element in the fuel. [ ] indicates volume ratio, and [C_xH_y] denotes volume ratio of various hydrocarbons such as CH_4, C_2H_4, C_3H_6 etc.

(b) Equation for actual amount of air (A)

$A = m\ A_o$ where m is the air ratio.

(2) Amount of exhaust Gas

(a) Equation for theoretical amount of dry gas (V_{do})

(i) Solid/liquid fuel

$$V_{do} = 8.89c + 21.1\ (h - \tfrac{o}{8})\ + 3.3s + 0.80n\ \ (m_N^3/\text{kg fuel})$$

(ii) Gas fuel

$$V_{do} = 0.79A_o + [CO_2] + [CO] + \Sigma x[C_xH_y] + [N_2]\}\ (m_N^3/m_N^3\ \text{fuel})$$

(b) Equation for actual amount of combustion gas (V)

Actual amount of dry gas $V_d = V_{do} + (m-1)A_o$

Actual amount of combustion gas $V = V_d + V_w = V_{do} + (m-1)A_o + V_w$

V_w indicates the amount of vapor generated in the combustion per unit of fuel.

$$V_w = 11.2h + 1.24w\ \ (m_N^3/\text{kg solid, liquid fuel}).$$

$$V_w = [H_2] + \Sigma 0.5y[C_xH_y]\quad (m_N^3/m_N^3\ \text{Gas fuel}).$$

where, w is the water content in the unit of fuel (kg/kg).

(3) Exhaust gas content and amount

$$(O_2) = 0.21(m-1)A_o/V_d$$

$$(N_2) = (0.8n + 0.79mA_o)/V_d$$

$$(CO_2)_{\max} = \frac{(CO_2)+(CO)}{1 - \frac{(O_2)}{0.21} + \frac{0.79}{0.21}\cdot\frac{1}{2}(CO)} = \frac{0.21\{(CO_2)+(CO)\}}{0.21 - (O_2) + 0.395(CO)}$$

$$\text{In case of } (CO) \fallingdotseq 0,\ (CO_2)_{\max} = \frac{(CO_2)}{1-(O_2)/0.21}$$

( ) indicates the volume ratio of each element in the dry exhaust gas.

(a) For solid/liquid fuel

$$V_d = \frac{1.87c + 0.70s}{(CO_2)+(CO)}$$

$$(CO_2) = (1.87c + 0.70s)/V_d$$

$$(CO_2)_{\max} = (1.87c + 0.70s)/V_{do}$$

$$= \frac{1.87c + 0.70s}{8.89c + 21.1(h - \frac{o}{8}) + 3.33s + 0.80n}$$

In case of $n \fallingdotseq 0,\ s \fallingdotseq 0$

$$(CO_2)_{max} = \frac{1.87c}{8.89c + 21.1(h - \frac{o}{8})} = \frac{0.21}{1 + 2.37\{h - \frac{o}{8}\}/c}$$

In general, in case of solid／liquid fuel, N_2 in the fuel is negligible, then,

$$m = \frac{(N_2)/79}{\frac{(N_2)}{79} - \frac{\{(O_2) - 0.5(CO)\}}{21}}$$

or $$m = \frac{1 - (CO_2) - 1.5(CO)}{\frac{1 - (CO_2)_{max}}{0.79} \times \frac{(CO_2) + (CO)}{(CO_2)_{max}}} + 0.21$$

In case of $(CO) \fallingdotseq 0,\ H_2 = 0$. Consequently, $(CO_2)_{max} \fallingdotseq 0.21$, then,

$$m = \frac{(CO_2)_{max}}{(CO_2)}$$

In case of $(N_2) = 0.79,\ m = \dfrac{0.21}{0.21 - (O_2)}$

(b) For gas fuel

$$(CO_2) = \{(CO_2) + [CO] + \Sigma x[C_xH_y]\}/V_d$$

$$(CO_2)_{max} = \frac{[CO_2] + [CO] + \Sigma x[C_xH_y]}{0.79A_o + [CO_2] + [CO] + \Sigma x[C_xH_y] + [N_2]}$$

[ ] indicates the volume ratio of each element to the fuel.

$$m = \frac{\{(N_2) \cdot V_d - [N_2]\}/0.79}{\frac{(N_2)V_d - [N_2]}{0.79} - \frac{\{(O_2) - 0.5(CO)\}V_d}{0.21}}$$

(4) Experimental formulas to find theoretical amount of air/combustion gas from heating value.

The relationships among the theoretical amount of air (A_o) , theoretical amount of combustion gas (V_o) , and lower heating value (H_ℓ) are expressed as shown below……

$$A_o = a\ H_\ell + b$$
$$V_o = a'\ H_\ell + b'$$

The constants a, b, a', and b' are given in the following table (by Rosin's formulas)

		A_o		V_o		Unit	
		a	b	a'	b'	H_l	A_o, V_o
Solid fuel		$\frac{0.241}{1,000}$	0.5	$\frac{0.213}{1,000}$	1.65	kJ/kg	m^3_N/kg
Liquid fuel		$\frac{0.203}{1,000}$	2.0	$\frac{0.265}{1,000}$	0.0		
Gas fuel	H_l = 2090 ~ 12,560 kJ/m^3_N	$\frac{0.209}{1,000}$	0.0	$\frac{0.173}{1,000}$	1.0	kJ/m^3_N	m^3_N/m^3_N
	H_l = 16,750 ~ 29,310 kJ/m^3_N	$\frac{0.260}{1,000}$	−0.25	$\frac{0.270}{1,000}$	0.25		

Note: Actual amount of combustion gas $V = V_o + (m-1)A_o$

In the above table, the gas fuel having lower heating value H_l =2,090～12,560 kJ/m^3_N mainly corresponds to producer gas, blast furnace gas, etc. And the gas fuel having heating value H_l = 16,750 ~ 29,310kJ/m^3_N corresponds mainly to coke oven gas, oil gas, natural gas, etc. The gases of H_l > 29,310kJ/m^3_N are assumed to be out of the applicable range of the above experimental formulas. However, those gases show such trend as illustrated in Figure 1. The solid line in Figure 1 indicates the theoretical amount of combustion gas, while the dotted line indicates the theoretical amount of air. In any cases, lines in the H_l > 29,310kJ/m^3_N range are extrapolated from those of Rosin's formulas in the range of H_l =16,750～29,310 kJ/m^3_N with the same gradient.

Figure 1

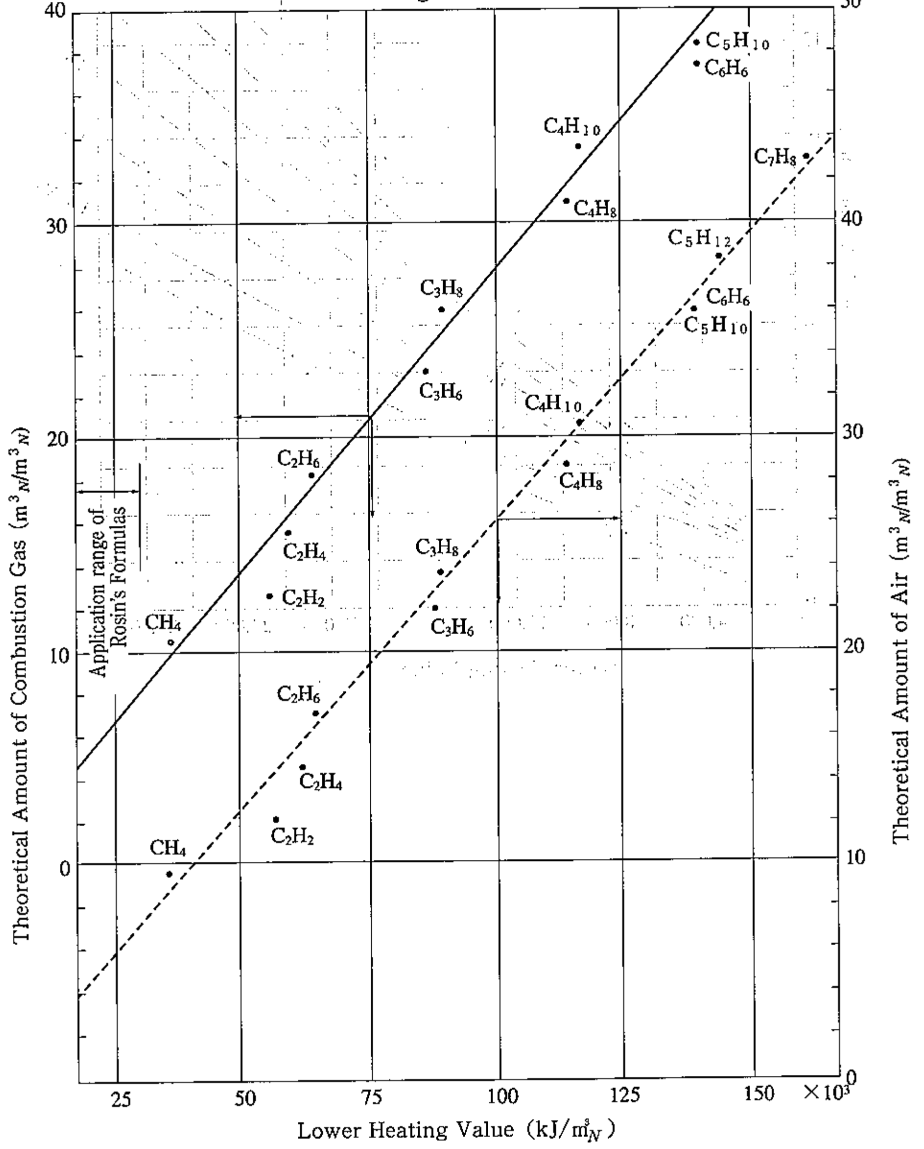
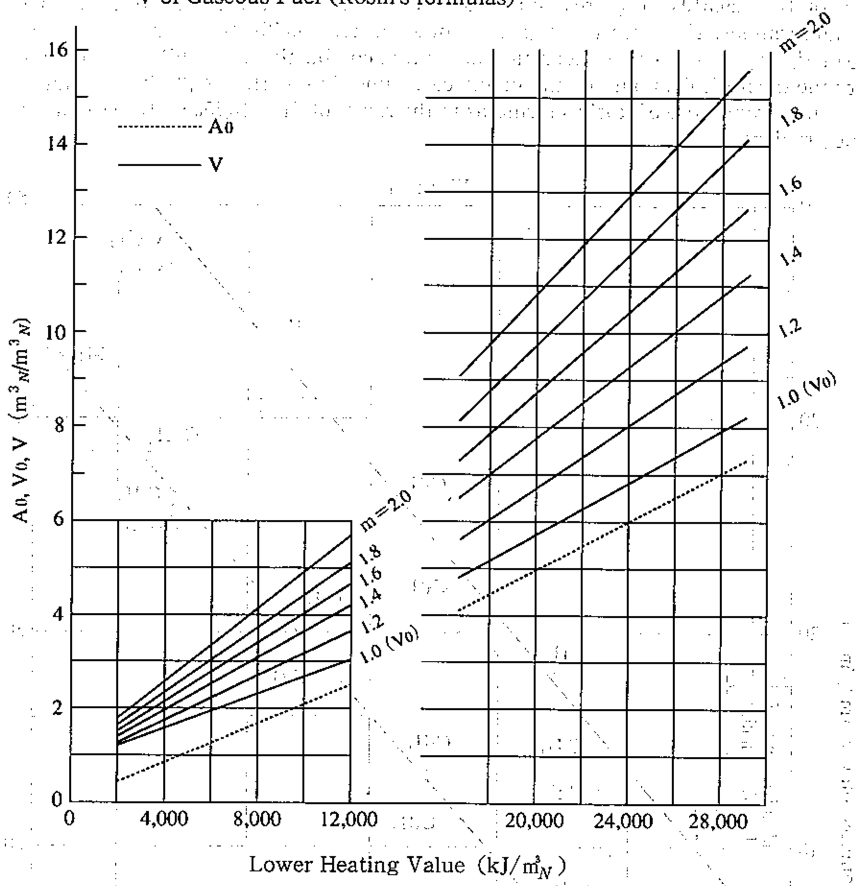
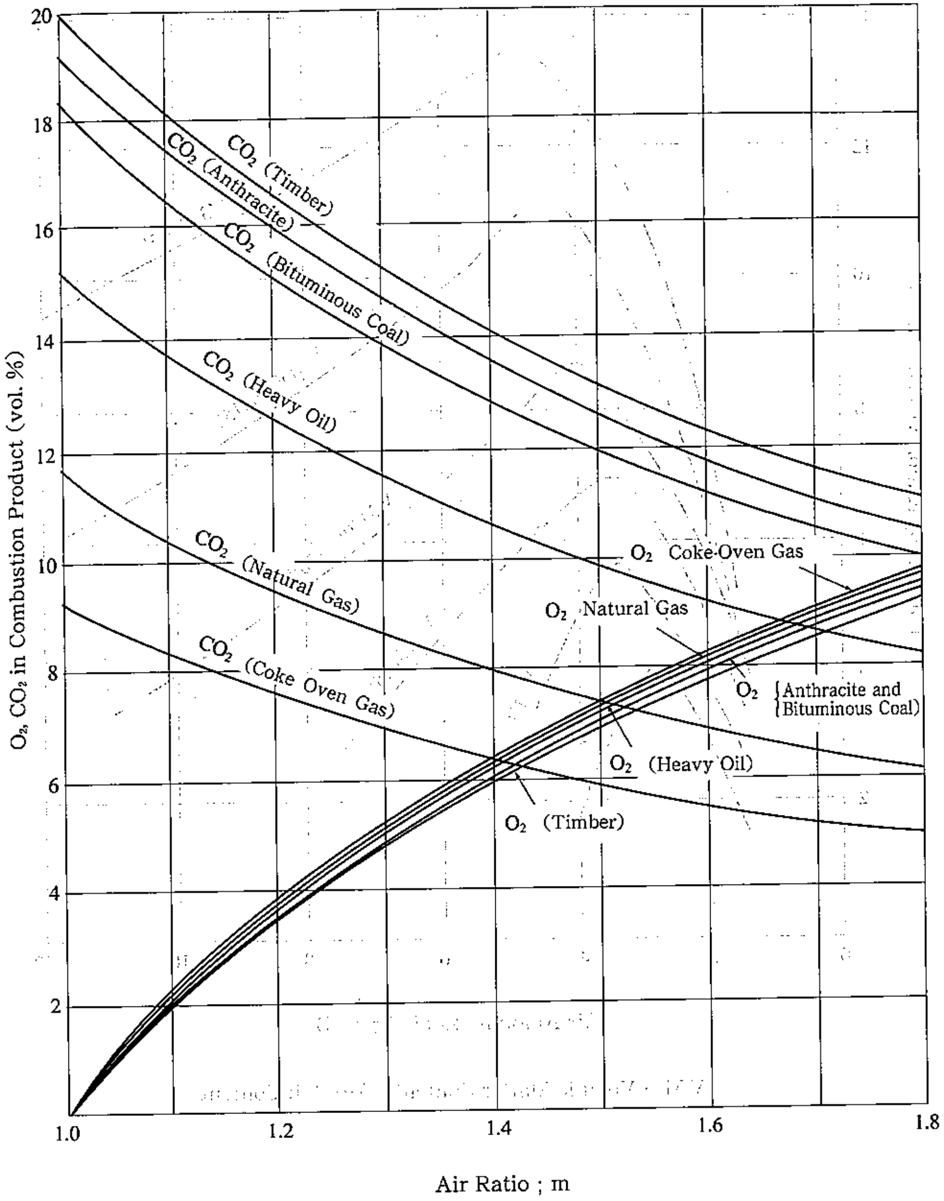


Figure 2

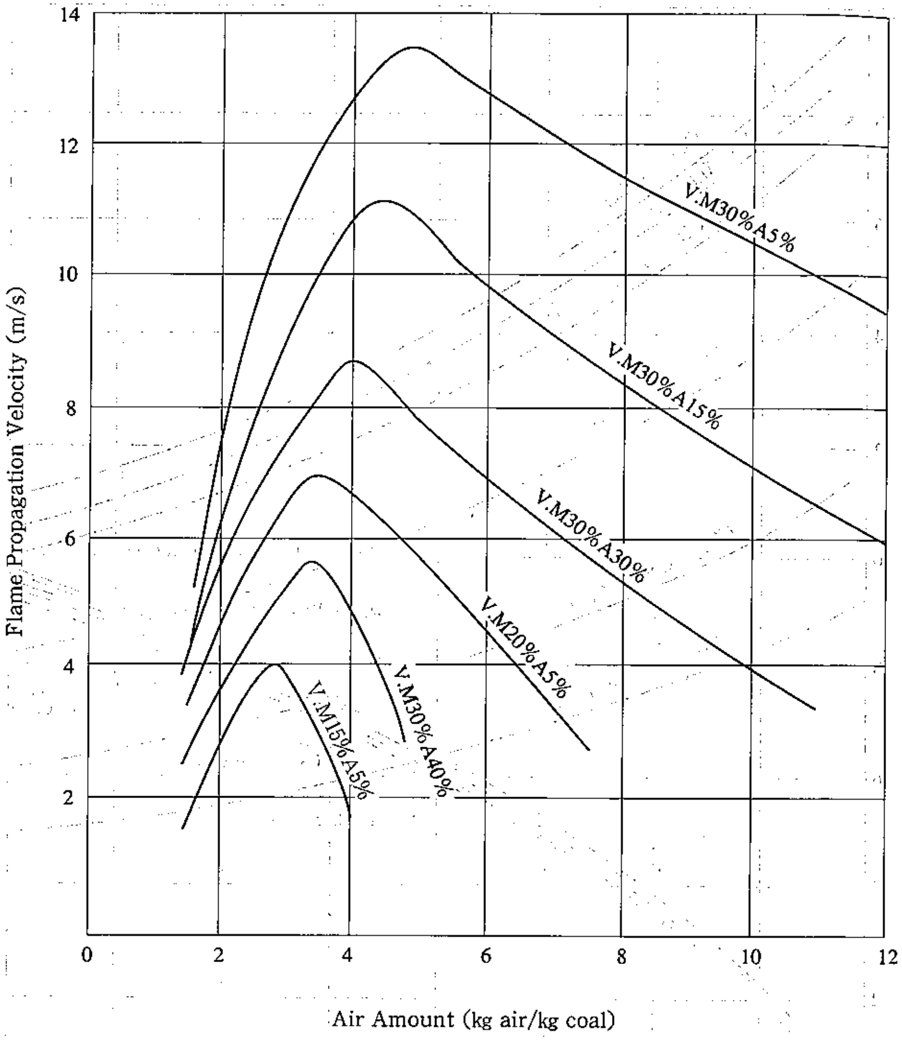
Relationships H_l vs. A_0, V_0, V of Gaseous Fuel (Rosin's formulas)



10-20 Relationship between Air Ratio and O_2, CO_2 Product for each Fuel



10-21 Air Amount and Flame Propagation Velocity



V.M··· Volatile Matter Content A··· Ash Content

10-22 LNG Transportation and Storage

(1) LNG receiving terminal

LNG is transported by ship. It is unloaded using an unloading arm, then transferred into a LNG tank through a LNG pipe. This LNG is fed out by a LNG pump and transformed into the gas of ordinary temperature in a vaporizer. Then, the gas is supplied to a boiler, for thermal power plant etc.

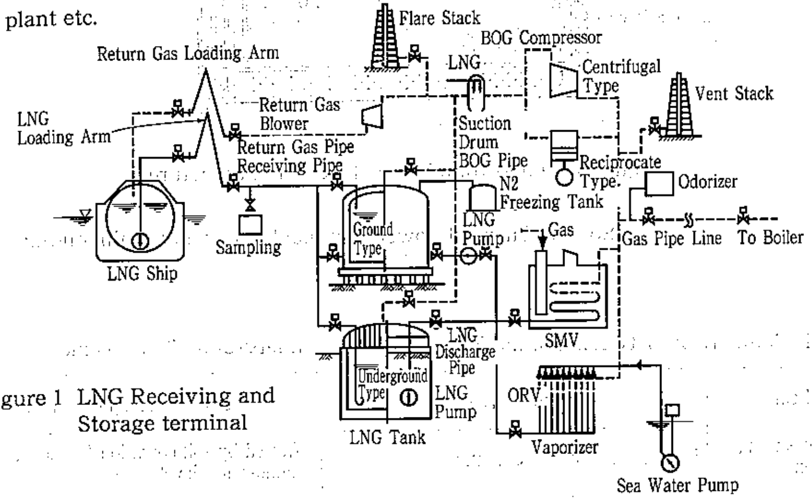


Figure 1 LNG Receiving and Storage terminal

〔Sourse: Thermal Power Handbook, Denryoku Shinpou-Sha (1992)〕

(2) LNG Tank

The LNG tank is double-structured with an inner shell and outer shell. The inner shell is made of materials for low temperature service such as 9% nickel steel, aluminum alloy, stainless steel, etc. The outer shell is made of carbon steel. Heat insulation materials such as granular pearlite, glass wool, etc. are filled in the space between outer and inner plates of the roof, and side wall sections. The bottom section is reinforced and insulated with pearlite concrete, pearlite blocks, etc.

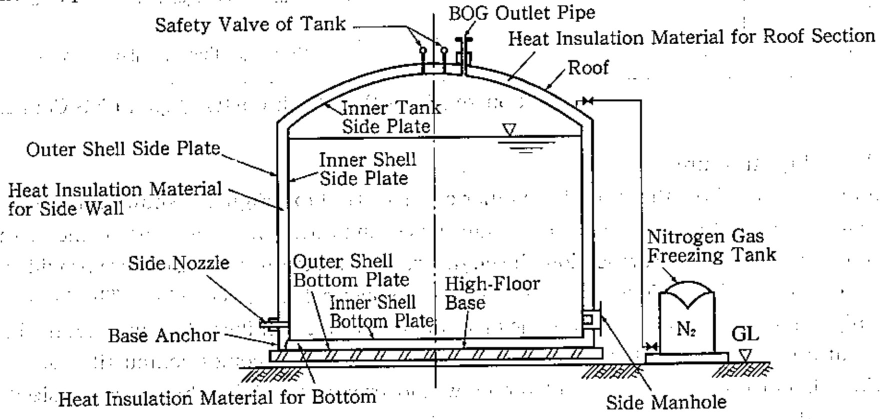


Figure 2 Ground Type LNG Tank Structure

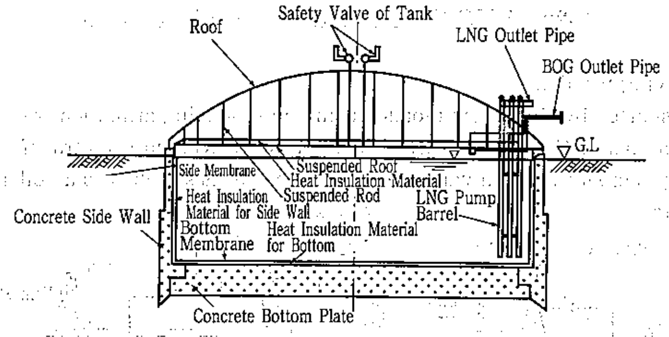


Figure 3 Underground Type LNG Tank Structure

〔Source: Thermal Power Handbook, Denryoku Shinpou-Sha (1992)〕

Table 1 Comparison between Ground Type Tank and Underground Type Tank

Item	Ground Type Tank	Underground Type Tank
Work executing condition	Less affected by soil Condition	Affected by soil condition (geology, ground-water level, etc.)
Dike	Necessary	Not necessary
Seismic design	Large seismic force	Small seismic force
Appearance	There is a feeling of coercion rather than an under ground type.	Since it is buried under ground, there is no feeling of coercion rather than a ground type.
Distance between tanks	1/2D (Gas utility Act of Japan for example)	1/4D (Gas utility Act of Japan for example)
Construction period	base	8 to 16 months longer than the ground type
Construction cost	base	Slightly higher than the above ground type

〔Sourse : LNG Handbook (1981) , Japan LNG Council.〕

(3) LNG ship structure

Figures 4 and 5 show the typical structher of an LNG ship. Figure 4 shows a membrane type ship. A freight section to accommodate LNG tanks occupies most part of the central section of the ship. The crew section, the engine room, the steering room, etc. are provided in the rear section. Figure 5 shows an independent spherical tank type ship. The layout of this ship is almost the same as that of the membrane type one. Unlike petroleum, etc., the LNG temperature is as low as −162 ℃ and once it is vaporized, it becomes combustible gas and is diffused. For this reason safety of the crew and protection of freight are emphasized in designing the structure and layout of an LNG ship.

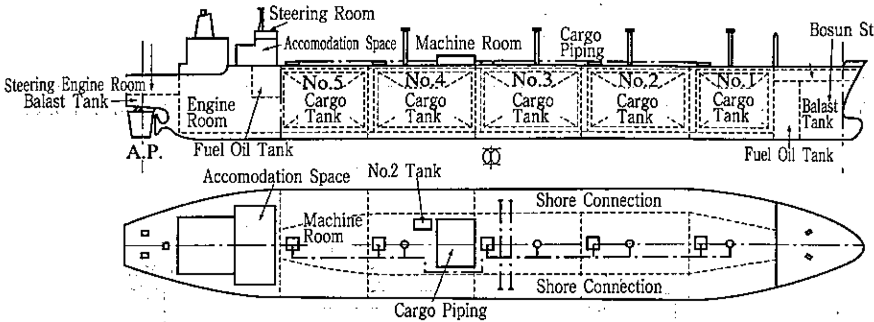


Figure 4 Membrane Type LNG Carrier

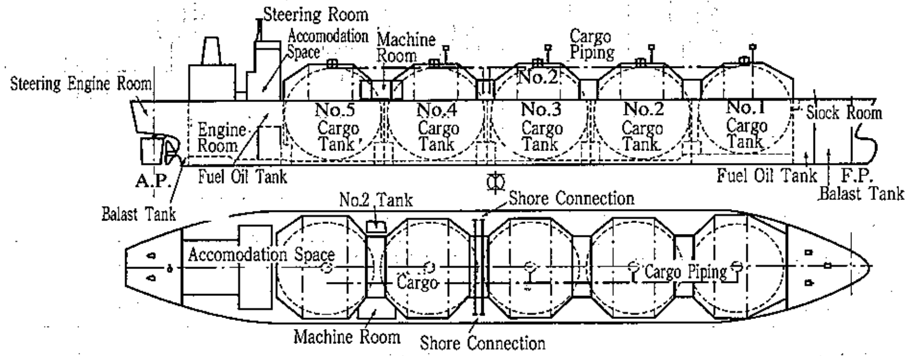


Figure 5 Independent Spherical Tank Type LNG Carrier 〔Sourse: LNG Handbook(1981), Japan LNG Council〕

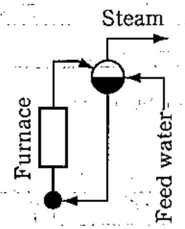
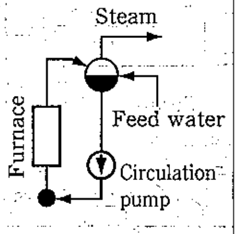
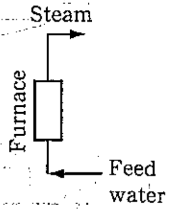
Table 2 LNG Tank Types

Type		Secondary barrier requirement	Design vapor pressure (Po)	Definition	Application example to LNG carrier
Integral tank		Not required, Hull itself is required to be double.	In principle, ($P_0 \leqq 0.025$MPa (gage)), but it may be increased up to ($P_0 \leqq 0.069$MPa (gage))	Tank forming a part of hull and subject to same load as hull is subjected.	Not to be allowed to use.
Membrane type tank		Perfect secondary barrier required		This tank is non-self supporting type and comprises of membrane supported by the adjacent hull structure through heat insulation material.	Gas transport type membrane tank, Techni gas type membrane tank.
Semi-membrane type tank		Perfect secondary barrier required (partial secondary barrier required when independent tank type B is obtained)		When loaded, this tank is a non-self supporting type one. It comprises side and bottom plates supported by the adjacent ship structure through heat insulation material, and curved sections	IHI flat tank, BS type tank
Independent type tank	Type A	Perfect secondary barrier required	$P_0 \leqq 0.069$MPa (gage)	This tank is a self-supporting type one, which is independent from the hull structure. Design standard applied is the same as that for the deep water tank.	Conti type square independent tank
	Type B	Partial secondary barrier required	Not limited specially (in case of rectangular ones, ($P_0 \leqq 0.069$MPa(gage))	This tank is a self-supporting type one, which is independent from the hull structure. Precise stress analysis, model test, break-down structure analysis are carried out in designing this type tank.	Moss type spherical independent tank, Senar type spherical independent tank, Hitachi CBI type spherical independent tank
	Type C	Not required	Determined by the shape, material, etc. of the tank.	This tank is a self-supporting type one, which is independent from the hull structure. Tank is shaped into a body of rotation and designed based on pressure vessel Code.	None

〔Sourse: LNG Handbook (1981), Japan LNG Council.〕

11-1 Type of Boilers

(1) Type of Electric Utility Boilers

Type		Natural circulation boiler	Forced circulation boiler	Once-through boiler
Model of water circulating method				
Circulation ratio		14～4	～4	1
Pressure	Subcritical	4.41～18.63MPa◎	18.63MPaClass◎	○
	Supercritical	—	—	◎

Note: (1) Below the critical pressure (22.064MPa) it is called the subcritical pressure, and more than the critical pressure it is called the supercritical pressure. ◎ Mark shows higher application.

(2) Circulation ratio = Furnace water flow／Steam flow (Feed water flow)

〔Source: Boiler, Thermal and Nuclear Power Engineering Society (1998/12)〕

(2) Characteristics

(a) Natural circulation boiler

At the subcritical pressure, the density difference of saturated water and saturated steam (fluid of the mixing of steam and water) is used for circulation. The saturated water in a steam drum flows down and the fluid of the mixing of steam and water in furnace water cooled wall piping raises. The boiler water circulation takes place naturally by heating the furnace.

(b) Forced circulation boiler

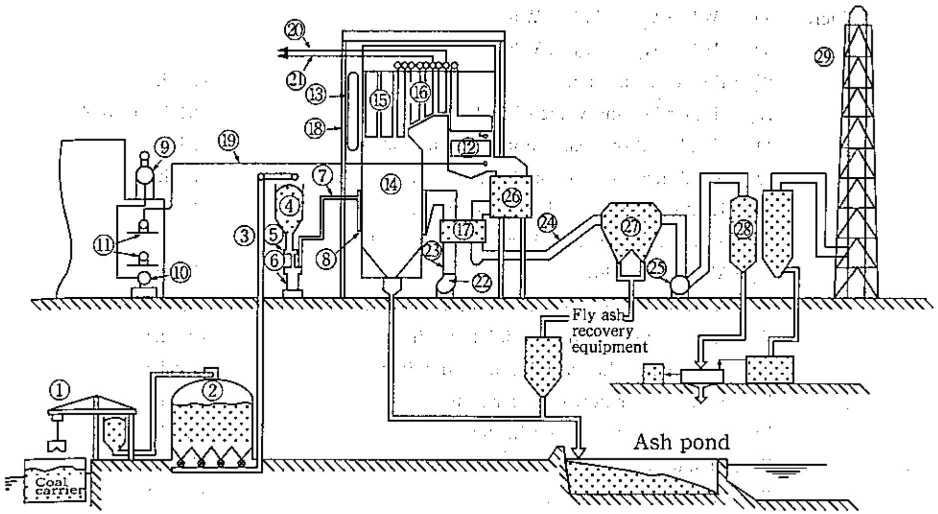
At the subcritical pressure, the density difference of saturated water and saturated steam becomes smaller with pressure rise, and natural circulation power is reduced. In order to compensate these phenomena, a boiler circulation pump is installed in the middle of a down water flow pipe, and it circulates compulsorily.

(c) Once-through boiler

Water circulation in a furnace water cooled wall is not carried out, but the feed water forced to the economizer is heated in the process which passes a furnace water cooled wall and a superheater, and a steam raised to the regulating temperature is supplied to a turbine from outlet of superheater. Supercritical pressure boiler is this type inevitably.

11-2 Outline Structure of Boiler Plants

An example of coal fired supercritical variable pressure once-through boiler plant



Main structual equipment of boiler plant (Coal fireling)

System	No.	Name of each equipment
Coal unload and stock system	①	Coal unload system
	②	Coal silo
	③	Coal conveyer
	④	Coal bunker
Combustion system	⑤	Coal feeder
	⑥	Coal pulverizer
	⑦	Pulverized fuel pipe
	⑧	Burner
Feed water system	⑨	Deaerator
	⑩	Feed water pump
	⑪	Feed water heater
Boiler	⑫	Economizer
	⑬	Steam separator
	⑭	Furnace
	⑮	Superheater
	⑯	Reheater
Boiler	⑰	Air preheater
	⑱	Boiler structural steel
Main pipes	⑲	Feed water pipe
	⑳	Main steam pipe
	㉑	Reheat steam pipe
Draft system	㉒	Forced draft fan
	㉓	Air duct
	㉔	Flue
	㉕	Induced draft fan
Exhaust gas process equipment	㉖	NOX removal equipment
	㉗	Electrostatic precipitator
	㉘	SOX removal equipment
Chimney	㉙	Chimney

〔Source: Boiler, Thermal and Nuclear Power Engineering Society, (1988/12)〕

11-3 Thermal Efficiency and Heat Loss of Boilers

(1) Boiler Thermal Efficiency

(a) Boiler thermal efficiency by heat input and output method: $\eta_B = \frac{Q_1 - Q_0}{W_F H_h + Q} \times 100\%$

Where, $Q_1 = W_1h_1 + W_2h_2 + W_7h_7 + W_8h_8$

$Q_0 = W_3h_3 + W_4h_4 + W_5h_5 + W_6h_6$

W_F : Fuel consumption (kg/h)

H_h : Higher heating value of fuel (kJ/kg of fuel)

Q_1 : Total heat of steam supplied from boiler (kJ/h)

Q_0 : Total heat of steam and water supplied to boiler (kJ/h)

Q : Heat consumed by heavy oil heater, steam air preheater, burner injection, etc. (kJ/h)

W_1 : Main steam flow (kg/h)

W_2 : Reheated steam flow at outlet of reheater (kg/h)

W_3 : Reheated steam flow at inlet of reheater (kg/h)

W_4 : Feed water flow at inlet of economizer (kg/h)

W_5 : Spray water flow of superheater (kg/h)

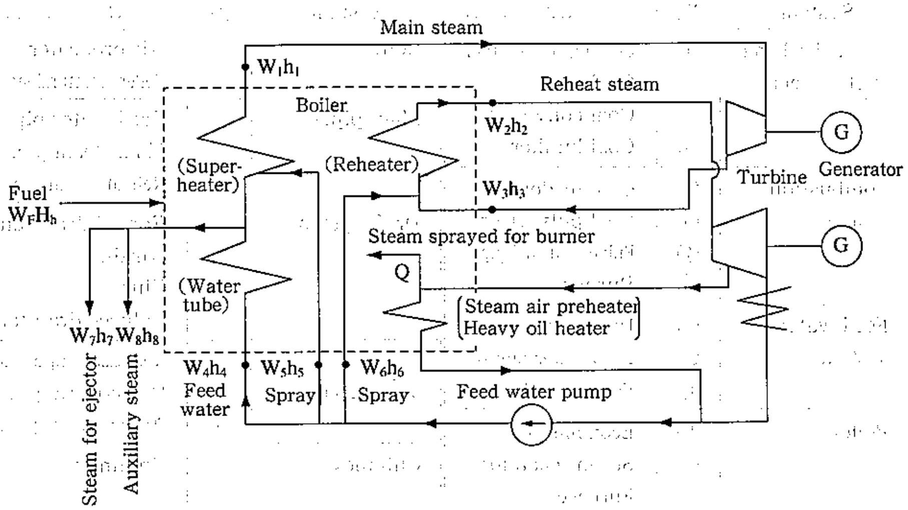
W_6 : Spray water flow of reheater (kg/h)

W_7 : Steam flow for ejector (kg/h)

W_8 : Auxiliary steam flow (kg/h)

$h_1 \cdots\cdots h_8$: Enthalpy of steam or water corresponding to $W_1 \cdots W_8$ (kJ/kg)

(b) Boiler thermal efficiency by heat loss method: $\eta_B = (1 - \frac{L_1 + L_2 + \cdots\cdots + L_9}{H_h + Q/W_F}) \times 100\%$



(2) Heat Loss of Boiler

(a) L_1 : Dry gas loss (see Fig. 1.)

$L_1 = C_{pg}G\ (T_g - T_a)$ (kJ/kg of fuel)

C_{pg} : Specific heat of dry gas (1.38kJ/m^3_NK)

G : Dry gas flow (at outlet of air heater) (m^3_N/kg of fuel)

T_g : Exhaust gas temperature (at outlet of air heater) (℃)

T_a : Atmospheric temperature (℃)

(b) L_2 : Evaporation heat loss of water content due to combustion of hydrogen in fuel (see Fig. 2.)

$L_2 = \frac{9h}{100}\{2500 + 1.88(T_g - T_a)\}$ (kJ/kg of fuel)

h : Hydrogen in fuel (%)

(c) L_3 : Evaporation heat loss of water content in fuel (see Fig. 2.)

$L_3 = \frac{w}{100}\{2500 + 1.88(T_g - T_a)\}$ (kJ/kg of fuel)

w : Water content in fuel (%)

(d) L_4 : Heat loss due to moisture in air

$L_4 = 1.88W_{ma}\ (T_g - T_a)$ (kJ/kg of fuel)

W_{ma} : Vapor quantity in air(kg/kg of dry air) × dry air quantity (kg/kg of fuel)

(e) L_5 : Heat loss due to incomplete combustion fuel (heat loss of incomplete combustion due to CO production)

$L_5 = 23{,}700 \times \frac{C}{100} \times \frac{CO}{CO_2 + CO}$ (kJ/kg of fuel)

C : Burnt carbon quantity (%)

CO_2, CO : Percentage CO_2 and CO in dry flue gas (% of volume)

(f) L_6 : Heat loss due to unburned fuel

$L_6 = 33{,}900 \times \frac{C'}{100}$ (kJ/kg of fuel)

C′ : Quantity of unburned carbon (%)

(g) L_7 : Heat loss due to steam injected from burners

$L_7 = W_S\{2{,}500 + 1.88(T_g - T_a)\}$ (kJ/kg of fuel)

W_S : Quantity of steam injected from burner per 1 kg of fuel (kg/kg of fuel)

(h) L_8 : Loss due to radiant heat from furnace walls (see Fig. 3) (kJ/kg of fuel)

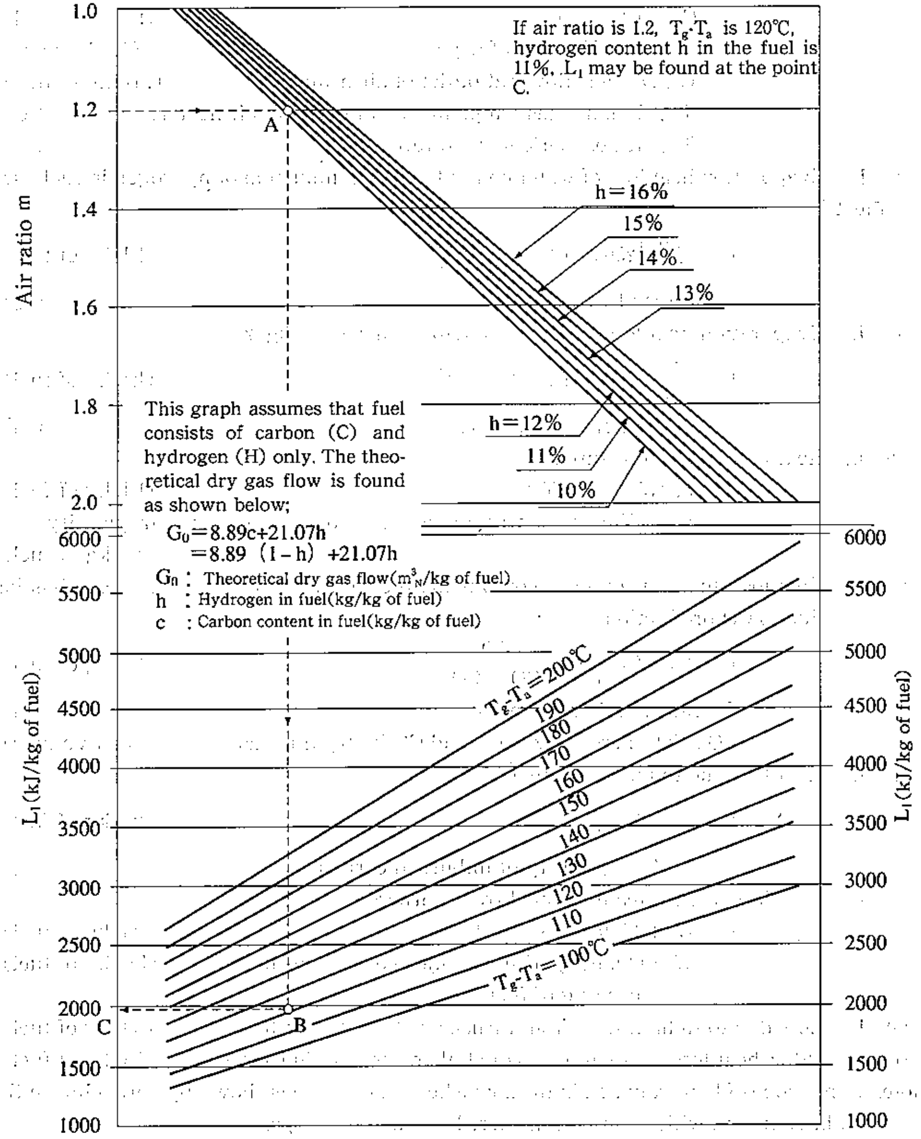
(i) L_9 : Other heat losses (Heat losses of clinker, ash splasing, etc.) (kJ/kg of fuel)

Note: 1. The scope of boiler applied in the above heat calculation is shown by dotted line in the above figure, which can be considered as standard scope.

2. There are two method to calculate boiler thermal efficiency, where heating value of fuel is based on higher heating value or lower heating value. The above shows the case of the former.

3. For finding the boiler thermal efficiency by the equation (a) in (1) above, Q may be subtracted it from the numerator in some cases, instead of adding it to the denominator.

Fig. 1 Heat Loss due to Dry Gas



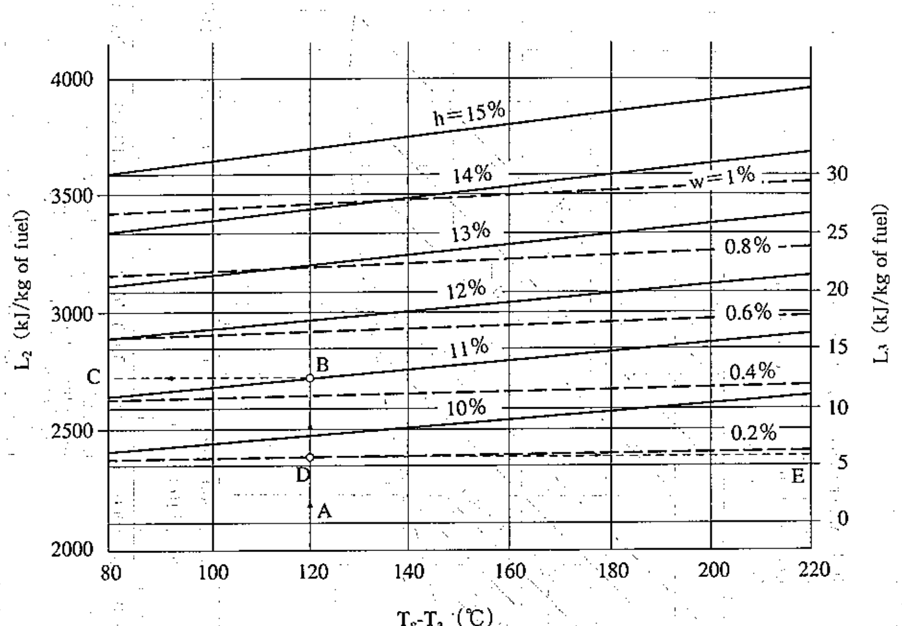
If air ratio is 1.2, T_g-T_a is 120℃, hydrogen content h in the fuel is 11%, L_1 may be found at the point C.

This graph assumes that fuel consists of carbon (C) and hydrogen (H) only. The theoretical dry gas flow is found as shown below;

$$G_0=8.89c+21.07h$$
$$=8.89\ (1-h)\ +21.07h$$

G_0 : Theoretical dry gas flow(m^3_N/kg of fuel)
h : Hydrogen in fuel(kg/kg of fuel)
c : Carbon content in fuel(kg/kg of fuel)

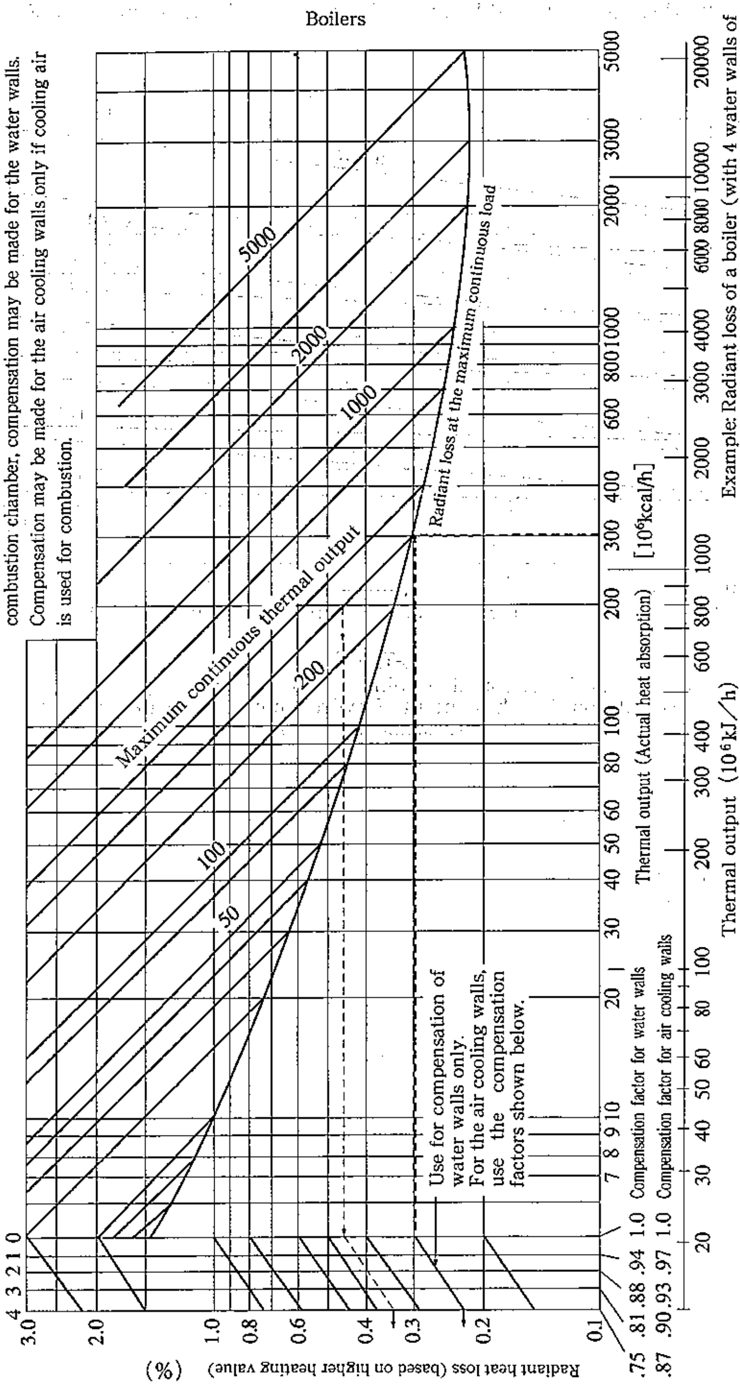
Fig. 2 Heat Losses L_2 and L_3 due to Hydrogen and Water Contents in Fuel



L_2 and L_3 are found at points C and E respectively, on the condition that the content of hydrogen h=11%, water content w=0.2%, and T_g−T_a =120℃

Fig. 3 Radiant Heat Loss L_8

If the water walls occupy 1/3 or more of the projection plane of the combustion chamber, compensation may be made for the water walls. Compensation may be made for the air cooling walls only if cooling air is used for combustion.

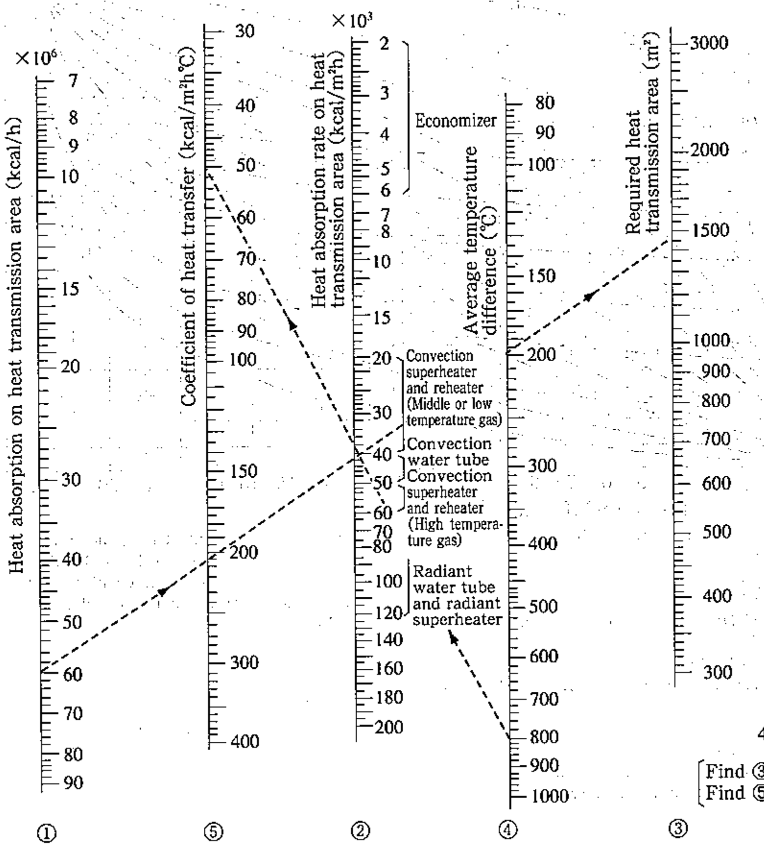


Example: Radiant loss of a boiler (with 4 water walls of the combustion chamber) having the total heat absorption of 300×10^6kcal/h at the maximum continuous rating

Total heat absorption 300×10^6kcal/h Loss: 0.22%
200×10^6kcal/h Loss: 0.34%

〔Cited from ASME PTC4.1 Steam Generating Units, 1969.〕

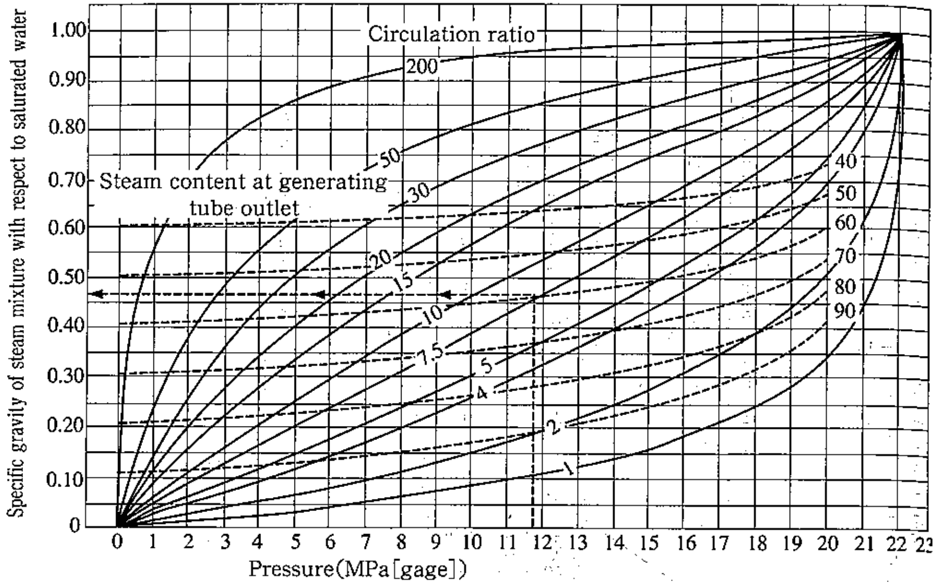
11-4 Heat Transmission Area of Boiler Heating Surfaces



4.1868kJ／kcal

〔Find ③ from ① and ②,
Find ⑤ from ④ and ②〕

11-5 Relationship between Steam Content at Generating Tube Outlet and Circulation Ratio



Specific gravity of steam mixture with respect to saturated water (γ_m)

$$\gamma_m = \frac{CR \cdot Vw}{Vs + Vw(CR-1)}$$

Steam content (F.D) at the outlet of generating tubes

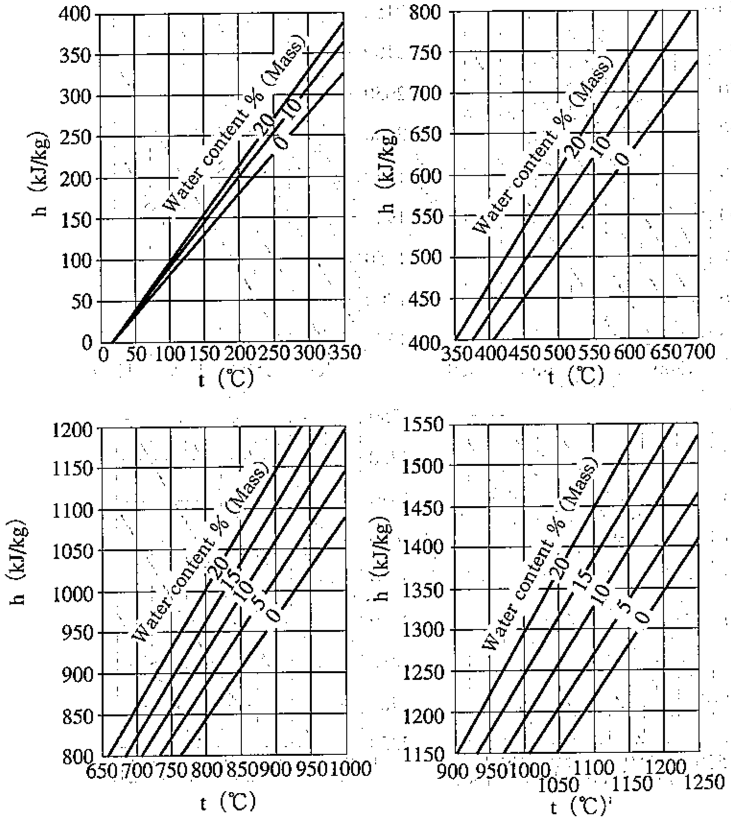
$$F.D. = \frac{Vs}{Vs + Vw(CR-1)}$$

(Relative speeds of water and steam are not taken into consideration.)

Where,
CR: Circulation ratio
Vs: Specific volume of saturated steam m^3/kg
Vw: Specific volume of saturated water m^3/kg

Example: If the steam content at the generating tube outlet of a 120 kgf/cm²G boiler is 60%, the specific gravity of steam mixture with respect to asturated water is 0.46 and the circulation ratio is 7.5

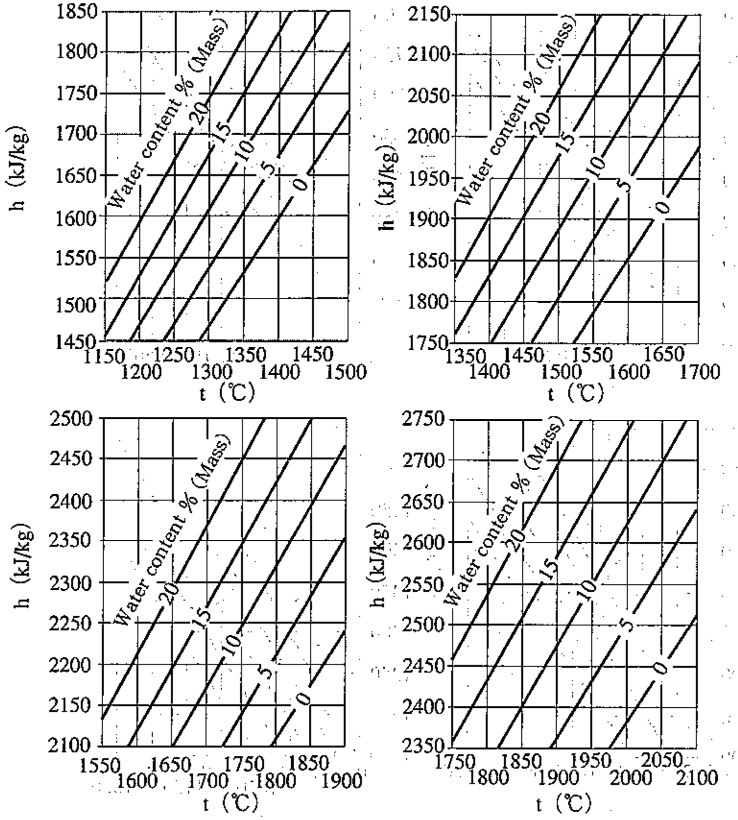
11-6 h-t Chart of Combustion Gases (1)



Example : Water contents in combustion gas
Heavy (crude) oil firing: 5to 8% (Mass)
Natural gas firing : 11to13% (Mass)
Blast furnace gas firing : 1to 3% (Mass)

Anthracite coal firing : 3to 5% (Mass)
Bituminous coal firing : 4to 7% (Mass)
Sub-bituminous coal firing: 6to 9% (Mass)
Brown coal firing : 8to12% (Mass)

h-t Chart of Combustion Gases (2)

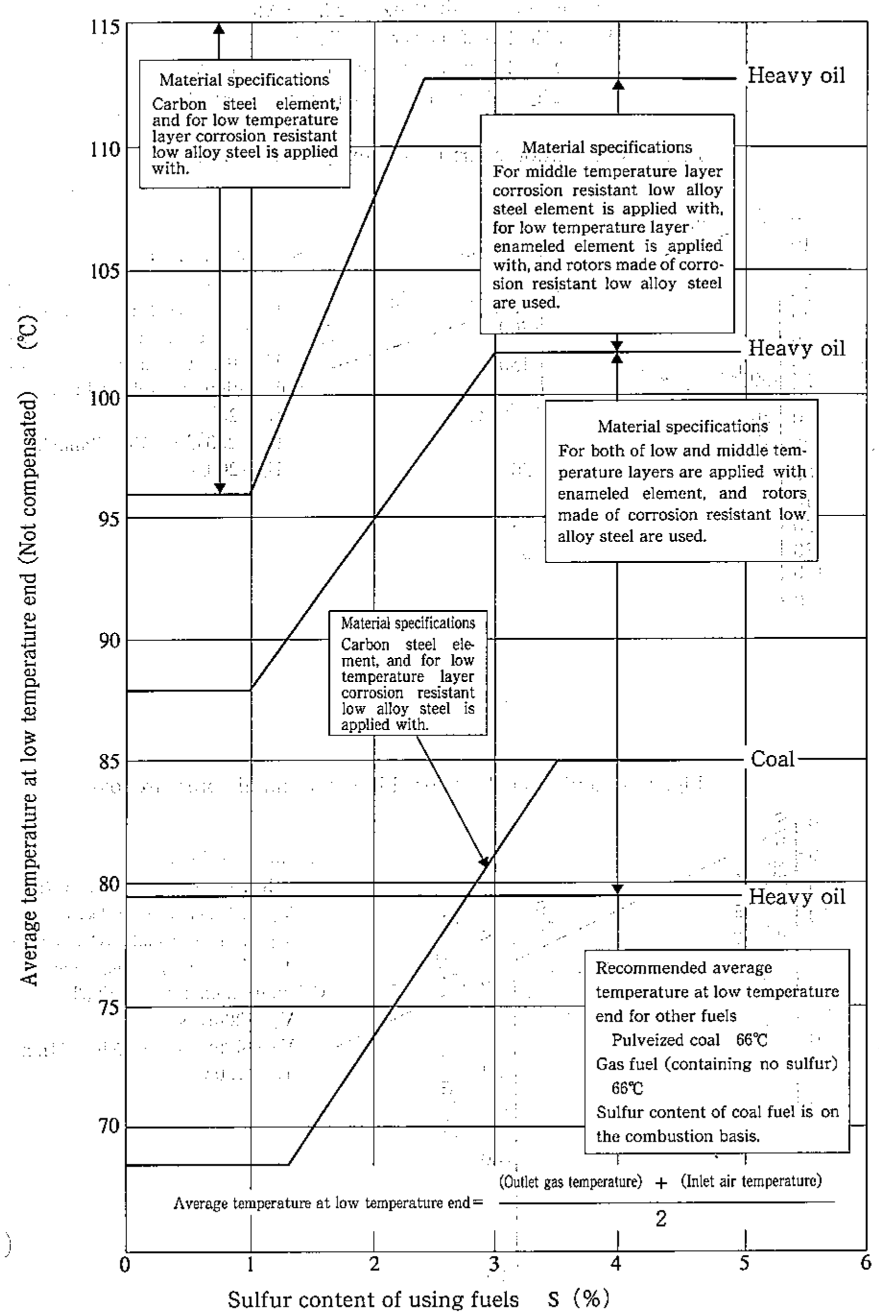


Example : Water contents in combustion gas

Heavy (crude) oil firing: 5to 8% (Mass)
Natural gas firing : 11to13% (Mass)
Blast furnace gas firing : 1to 3% (Mass)
Anthracite coal firing : 3to 5% (Mass)
Bituminous coal firing : 4to 7% (Mass)
Sub-bituminous coal firing: 6to 9% (Mass)
Brown coal firing : 8to12% (Mass)

11-7 Average Temperature at Low Temperature End of Ljungström Type Air Preheater

(Recommended values for preventing low temperature corrosion)



Material specifications
Carbon steel element, and for low temperature layer corrosion resistant low alloy steel is applied with.

Material specifications
For middle temperature layer corrosion resistant low alloy steel element is applied with, for low temperature layer enameled element is applied with, and rotors made of corrosion resistant low alloy steel are used.

Material specifications
For both of low and middle temperature layers are applied with enameled element, and rotors made of corrosion resistant low alloy steel are used.

Material specifications
Carbon steel element, and for low temperature layer corrosion resistant low alloy steel is applied with.

Recommended average temperature at low temperature end for other fuels
Pulveized coal 66℃
Gas fuel (containing no sulfur) 66℃
Sulfur content of coal fuel is on the combustion basis.

$$\text{Average temperature at low temperature end} = \frac{(\text{Outlet gas temperature}) + (\text{Inlet air temperature})}{2}$$

11-8 Calculating Charts for Chimney Inlet Gas Draft

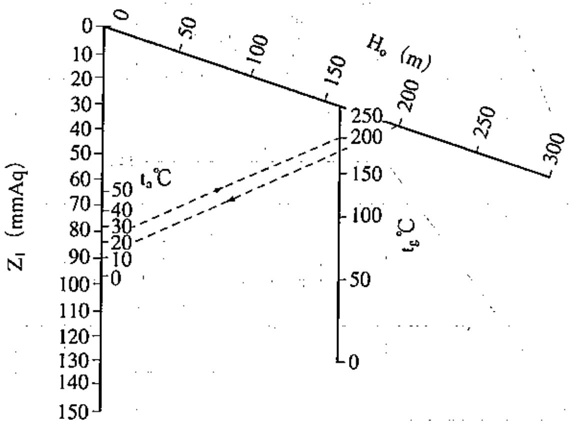
Chimney inlet gas draft$=Z_1-\Delta h_1-\Delta h_2$

Where, Z_1 : Draft power (see Fig. 1.)

Δh_1 : Dynamic pressure loss (see Fig. 2.)

Δh_2 : Friction loss in chimney (see Fig. 3.)

Fig. 1 Calculation chart for chimney draft power



Symbols in Fig. 1

Z_1 : Draft (mmAq)

t_a : Atmospheric temperature (℃)

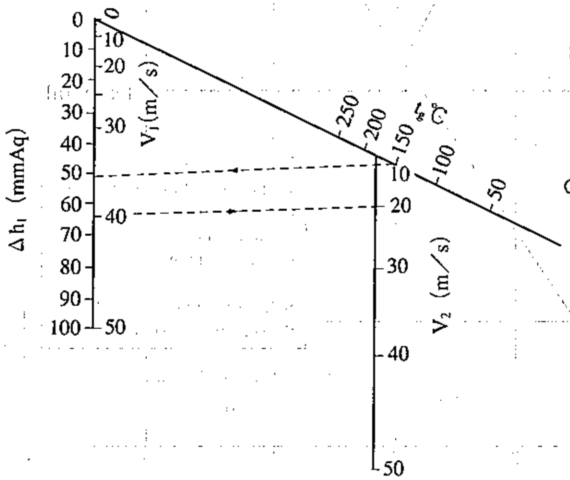
t_g : Gas temperature (℃)

H_o : Height of chimney (m)

Calculation example of Fig.1

t_a =20℃
t_g =200℃ } →Z_1=90mmAq
H_o=200m

Fig. 2 Calculation chart for chimney dynamic pressure loss



Symbols in Fig. 2

Δh_1 : Dynamic pressure loss (mmAq)

V_2 : Chimney inlet velocity (m/s)

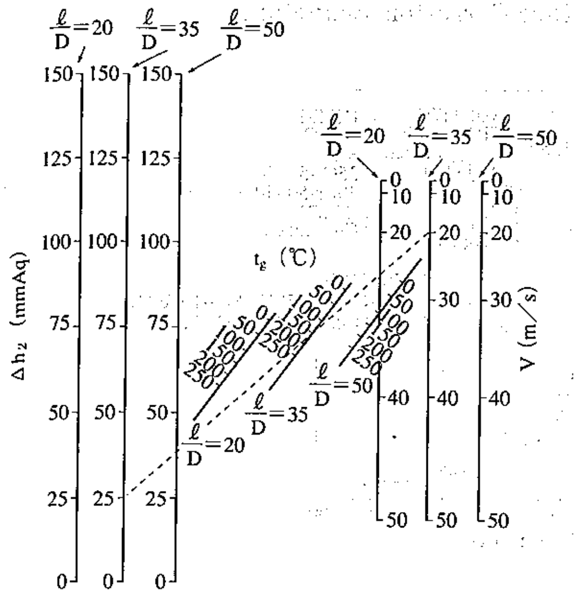
V_1 : Chimney outlet velocity (m/s)

t_g : Average gas temperature(℃)

Calculation example of Fig.2

V_2 =20m/s
V_1 =40m/s } →Δh_1=51mmAq
t_g =150℃

Fig. 3 Calculation chart for friction loss in chimney



Symbols in Fig. 3

Δh_2 : Friction loss in chimney (mmAq)

V : Average velocity in chimney (m/s)

t_g : Average gas temperature in chimney(℃)

$\frac{\ell}{D}$: $\frac{\text{Height of chimney}}{\text{Average internal diameter}}$

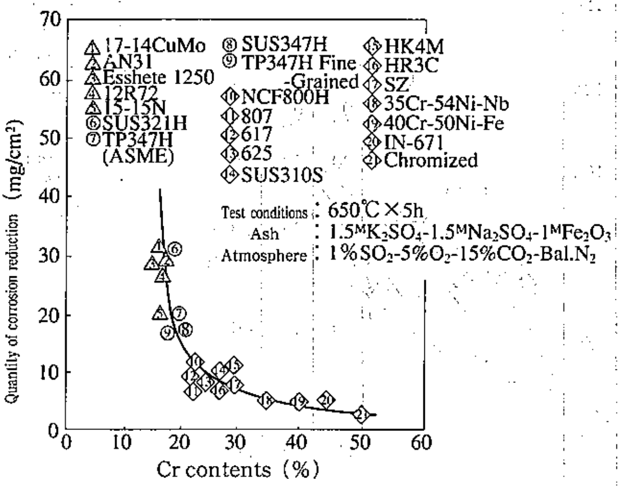
Calculation example of Fig. 3

V =20m/s
t_g =150℃ } →Δh_2=24mmAq
ℓ/D=35

11-9 Melting Points of Typical Contaminations on Tube Outer Surface

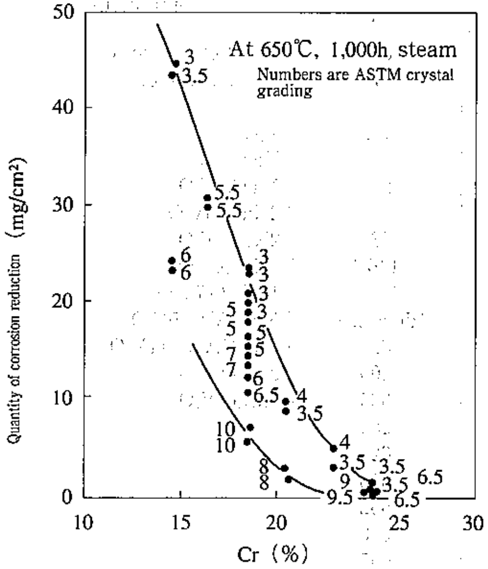
Components	Melting point (℃)	Components	Melting point (℃)
NaCℓ	800	FeO-FeS eutectic	940
KCℓ	776	Fe-FeS eutectic	965
CaCℓ₂ → $CaC\ell_2$	772	V_2O_5	690
		$Na_2O.V_2O_5$	630
$FeC\ell_3$	282	$Na_2O.3V_2O_5$	621
		$2Na_2O.3V_2O_5$	620
Na_2SO_4	884	$2Na_2O.V_2O_5$	640
K_2SO_4	1,076	$3Na_2O.V_2O_5$	850
$MgSO_4$	1,124	$10Na_2O.7V_2O_5$	573
	(decomp.)	$Na_2O.V_2O_4.5V_2O_5$	625
Na_2SO_4-NaCℓ eutectic	625	$5Na_2O.V_2O_4.11V_2O_5$	535
$Na_2S_2O_7$	400	$2MgO.V_2O_5$	835
$K_2S_2O_7$	335	$3MgO.V_2O_5$	1,190
$3K_2S_2O_7.Na_2S_2O_7$	280		
$Na_3Fe(SO_4)_3$	624		
$K_3Fe(SO_4)_3$	618		
$Na_3Fe(SO_4)_3.K_3Fe(SO_4)_3$	552		
$Na_3A\ell(SO_4)_3$	646		
$K_3A\ell(SO_4)_3$	695		

11-10 Relation of Cr Contents in Alloy and Quantity of High Temperature Corrosion Reduction



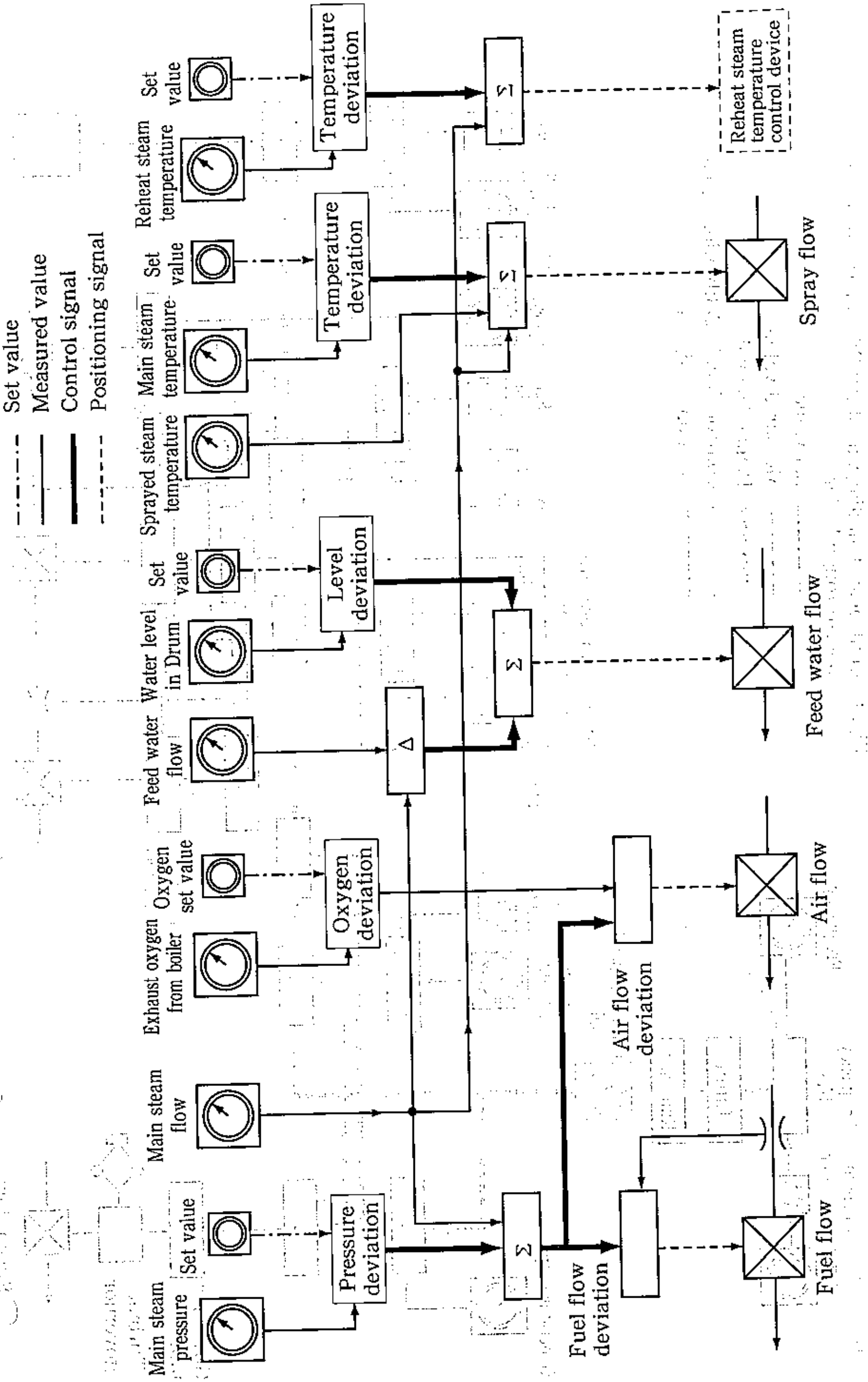
〔Source: Practicability of Materials for Super High Temperature and Pressure Boilers, by Yokoyama and Masuyama, Thermal and Nuclear Power Vol. 45/№11, (1994/11)〕

11-11 Relation of Cr Contents and Steam Oxidation



〔Source: Thermal and Nuclear Power Vol. 43/№10, p.12〕

11-12 Example of Drum Boiler Control Systems



11-13 Examples of Supercritical Pressure Boiler Control Systems (1)

Fig. 1 Control system diagram of IHI-FW supercritical pressure once-through boiler

-·-·- Set value
——— Measured value
■■■■ Demand signal
━━━ Control signal (Calibration signal)
- - - - Positioning signal

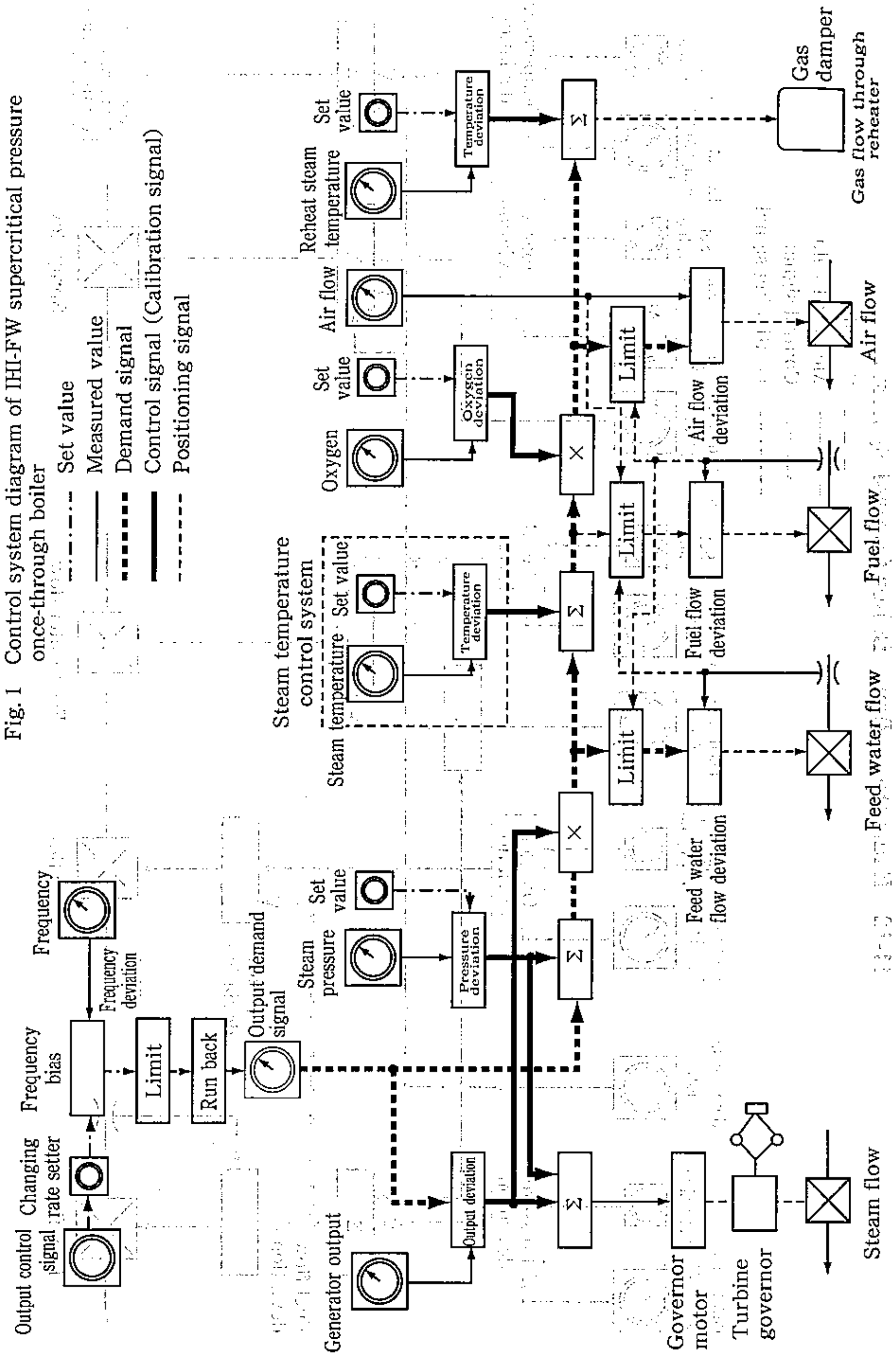
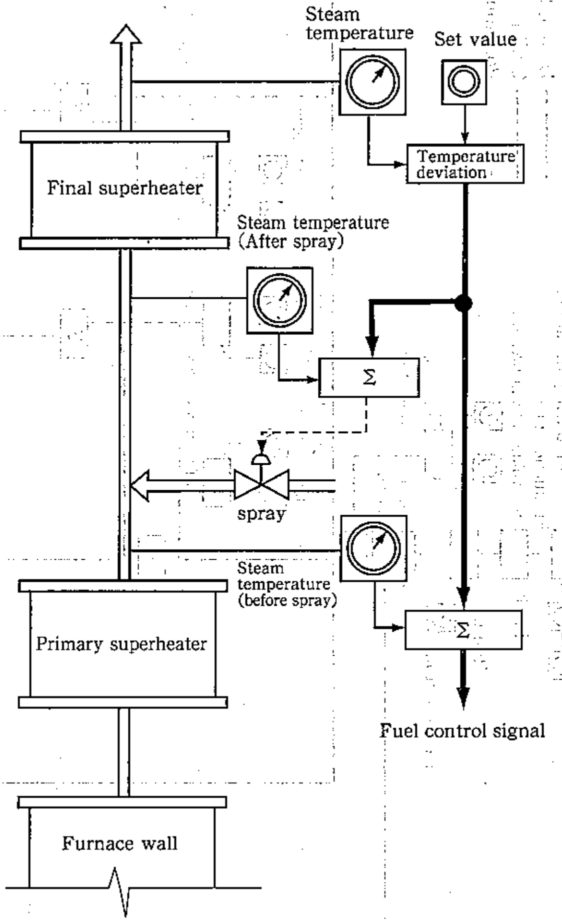
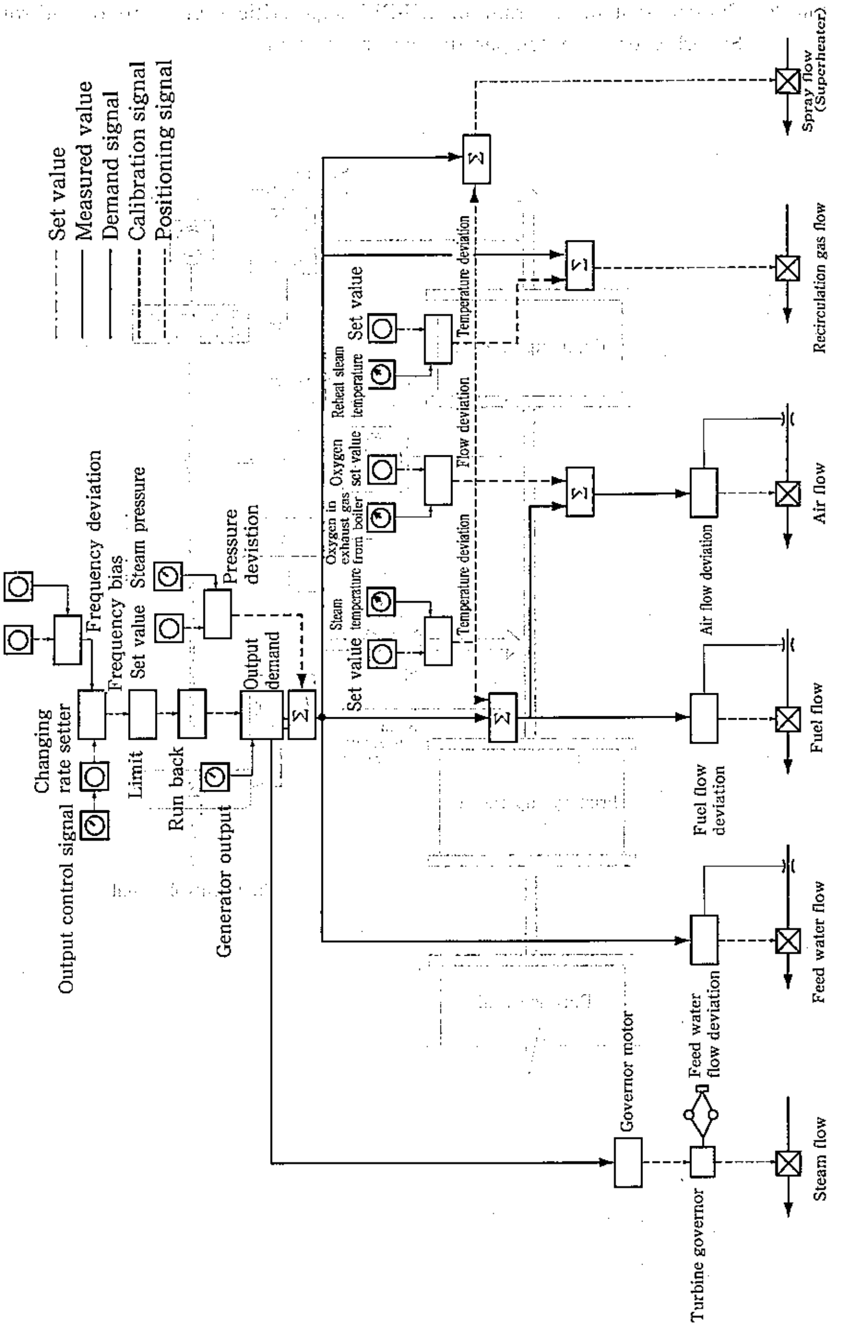


Fig. 2 Control system diagram of IHI-FW supercritical pressure once-through boiler: Superheater steam temperature control system



Examples of Supercritical Pressure Boiler Control Systems (2)

Fig. 3 Control system diagram of Babcock-Hitachi supercritical pressure once-through boiler



Examples of Supercritical Pressure Boiler Control Systems (3)

Fig. 4 Signal flow diagram of coordinated control system

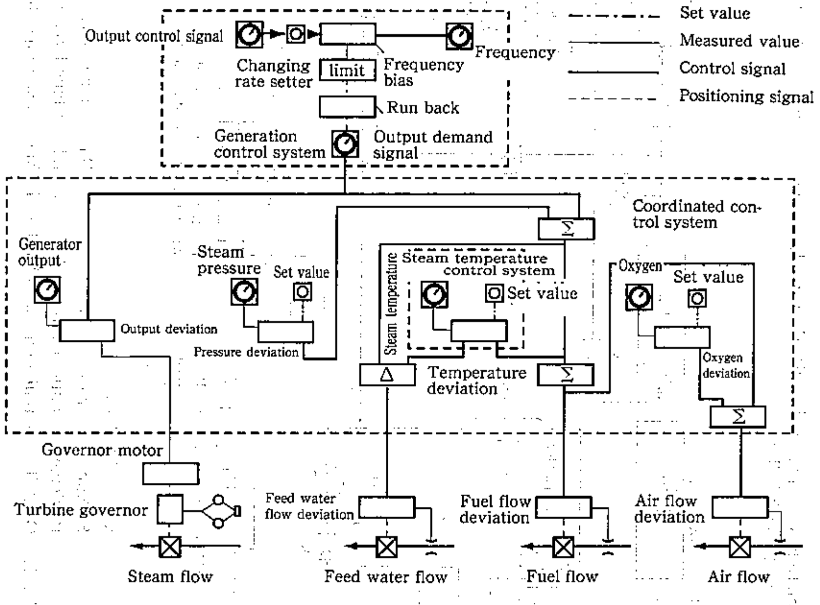
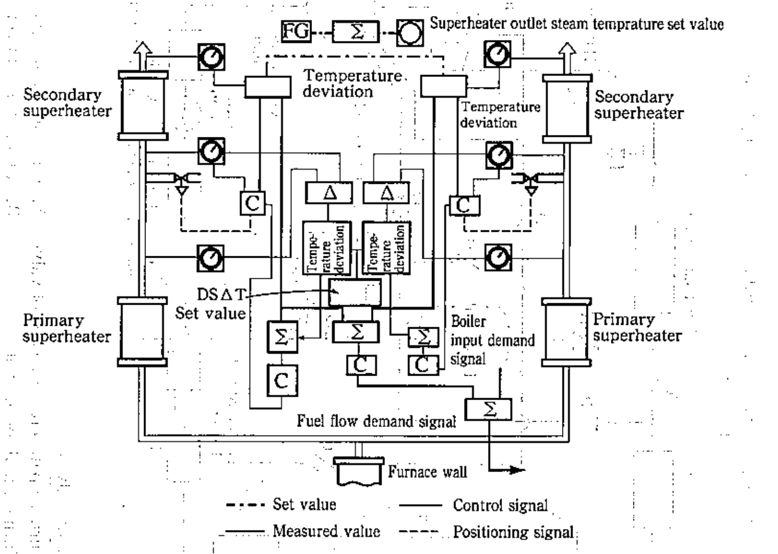


Fig. 5 Control system diagram of Mitsubishi variable pressure once-through boiler



Coordinated control system-Superheater steam temperature

11-14 Examples of Supercritical Pressure Boiler Start-up Systems (1)

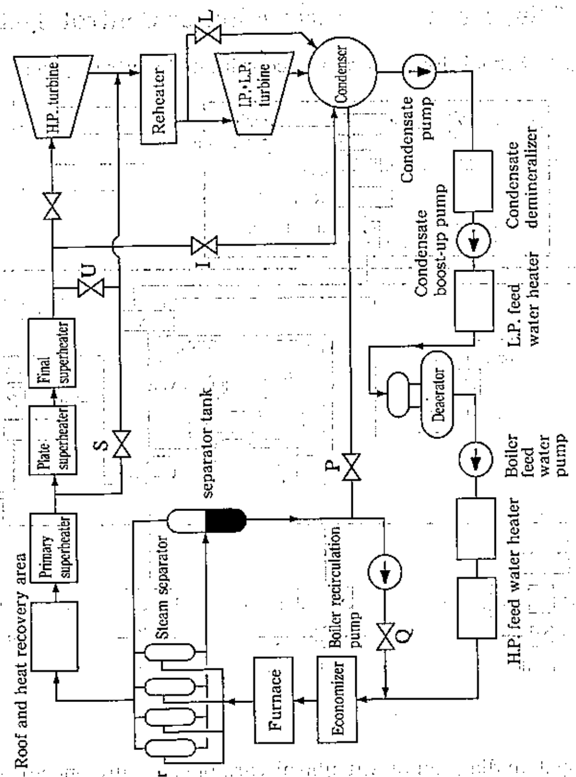


Fig. 2 Start-up system diagram of IHI-FW variable pressure operation supercritical once-through boiler

Name of Valves
S: Superheater bypass valve
P: Separator outlet control valve
Q: Boiler recirculation control valve
U: H.P. turbine bypass valve
L: L.P. turbine bypass valve
I: Main steam pipe drain valve

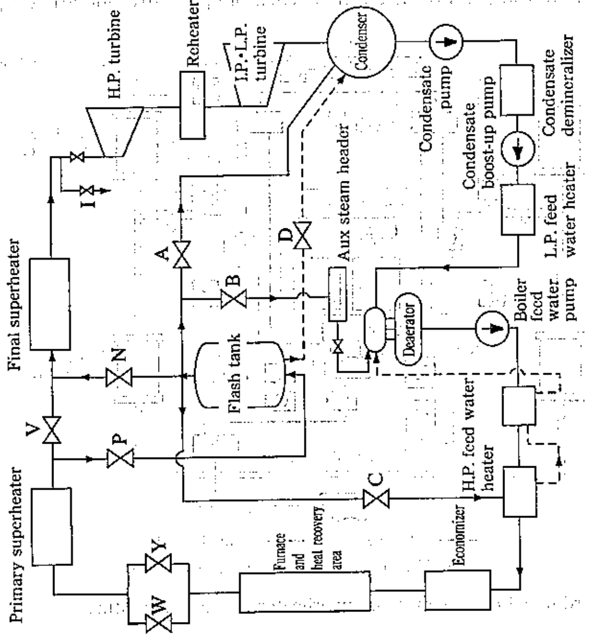
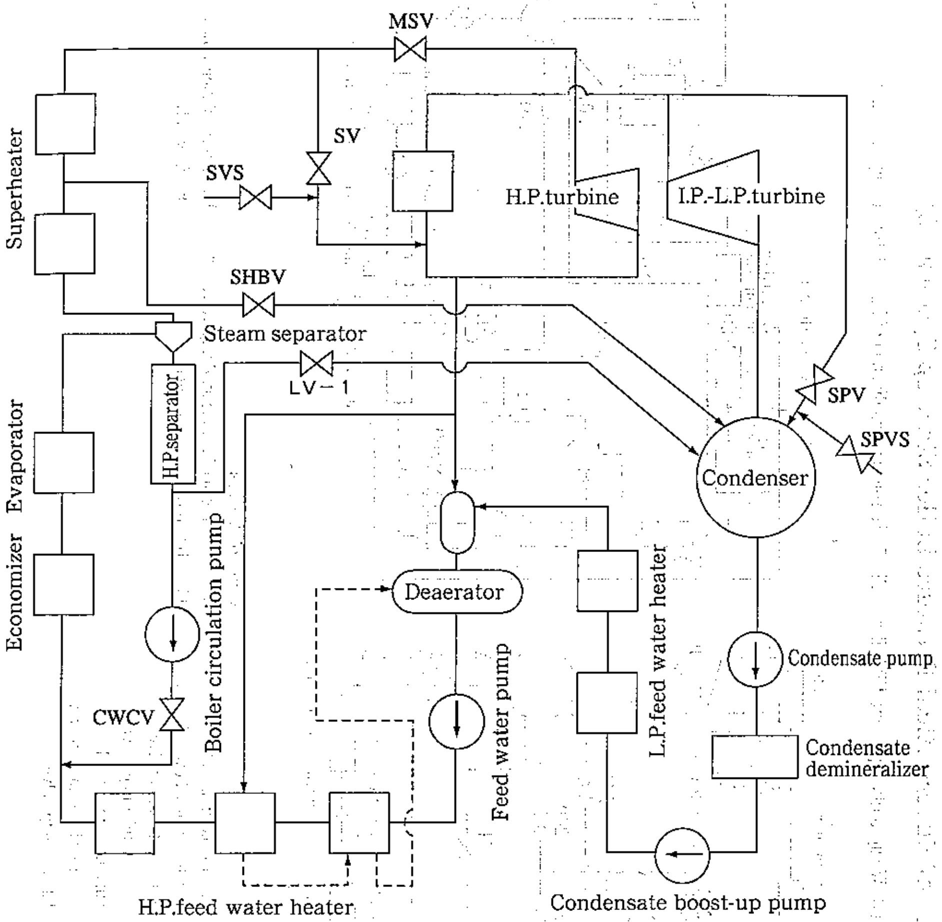


Fig. 1 Start-up system diagram of IHI-FW supercritical pressure once-through boiler

Name of Valves
W: Furnace path pressure control valve
Y: Furnace path outlet valve
V: Superheater isolating valve
P: Flash tank inlet control valve
N: Flash steam-starting valve
A: Flash steam dump control valve
B: Auxiliary steam control valve
C: Flash steam heat recovery control valve
D: Drain dump control valve
I: Main steam pipe drain valve

Examples of Supercritical Pressure Boiler Start-up Systems (2)

Fig. 3 Start-up system of Kawasaki DBW supercritical pressure Benson boiler



Name of Valves
MSV : Main steam stop valve
SV : Start-up control valve
SVS : Spray valve for Start-up control valve
SPV : Spill-over valve
SPVS : Spray valve for Spill-over valve
CWCV: Boiler circulation flow control valve
LV-1 : H.P.separator water level control valve
SHBV : Superheater bypass valve

Examples of Supercritical Pressure Boiler Start-up Systems (3)

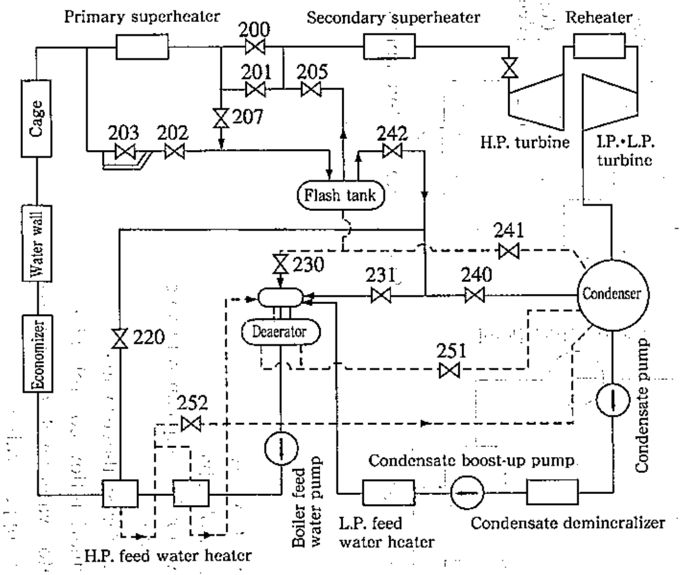


Fig. 4 Start-up system diagram of Babcock-Hitachi-B&W supercritical pressure UP boiler

Name of Valves

202	Primary superheater bypass valve	241	Flash tank drain valve
207	Secondary superheater bypass valve	252	H.P. feed water heater drain valve
201	Superheater pressure reducing valve	200	Superheater stop valve
2201	H.P. feed water heater steam valve	203	Register tube bypass valve
231	Deaerator steam valve	205	Superheater vent valve
240	Flash tank steam dump valve	242	Flash tank steam stop valve
230	Deaerator steam drain valve	251	L.P. clean-up valve

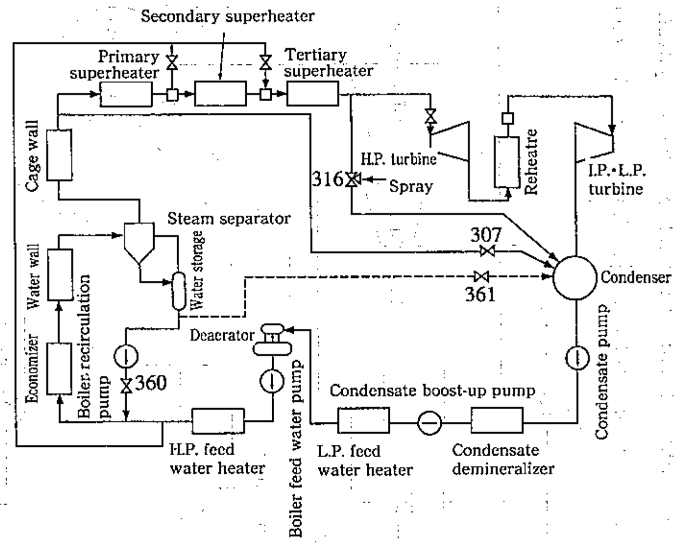


Fig. 5 Start-up system diagram of Babcock-Hitachi supercritical pressure Benson boiler

Name of Valves

307	Superheater inlet steam dump valve	360	Boiler recirculation flow control valve
316	H.P. turbine bypass valve	361	Overflow valve

Examples of Supercritical Pressure Boiler Start-up Systems (4)

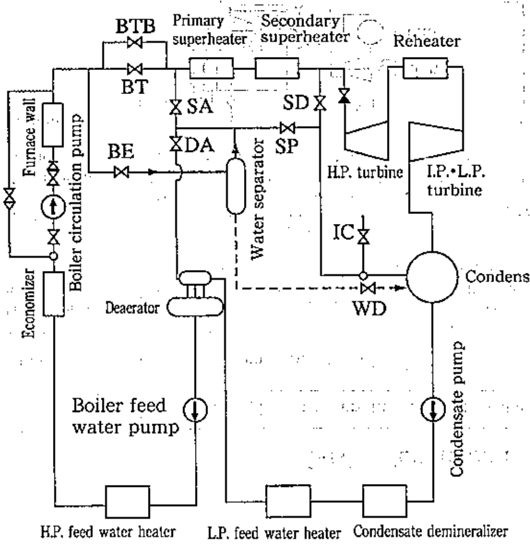


Fig.6 Start-up by-pass system diagram of Mitsubishi-CE combined circulation boilers

Name of Valves

BT : Boiler throttle valve
BTB : Boiler throttle bypass valve
BE : Boiler extraction bypass valve
SA : Steam admission valve
SP : Spill-over valve
WD : Water separator drain valve
DA : Deaerator admission valve
SD : Turbine bypass valve
IC : Spray injection control valve

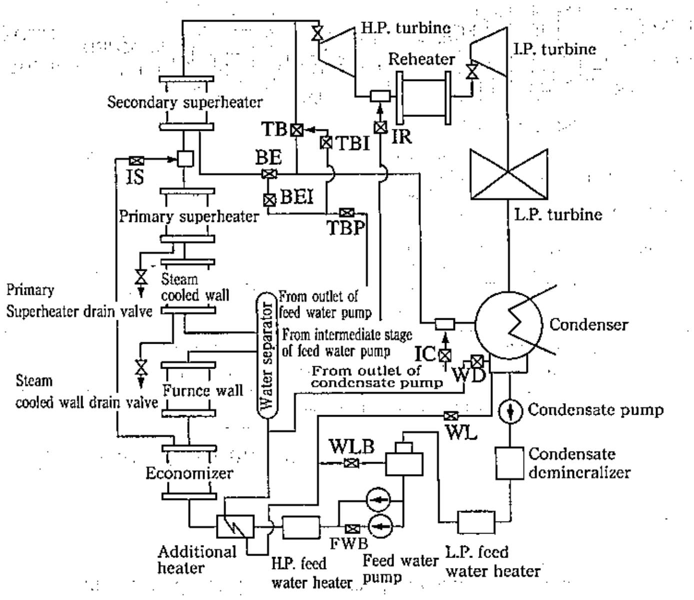


Fig.7 Start-up system diagram of Mitsubishi variable pressure once-through boiler

Name of Valves

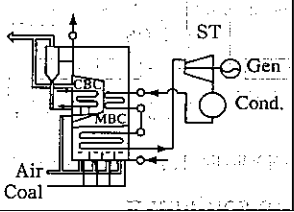
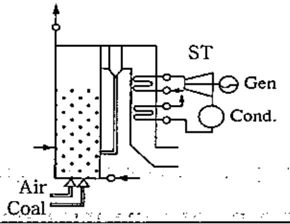
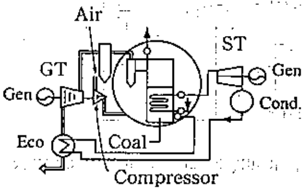
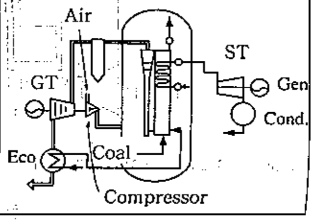
FWB : Feed water control valve
WD : Water separator drain valve
WL : Water separator water level control valve
WLB : Water separator water level bypass control valve
IS : Superheater spray control valve
IR : Reheater spray control valve
BE : Extraction steam control valve for boiler start-up
TB : Turbine bypass control valve
BEI : Extraction steam spray control valve
TBI : Turbine bypass spray control valve
TBP : Turbine bypass spray pressure control valve
IC : Turbine bypass low pressure spray control valve

11-15 Types of Fluidized Bed Combustion Boilers

The fluidized bed combustion boilers are classified into two types: Atmospheric pressure fluidized bed combustion boilers for combustion at the atmospheric pressure, and pressurized fluidized bed combustion boilers for combustion at high pressure. These types are classified as follows:

- Fluidized bed combustion boilers
  - Atmospheric pressure
    - Atmospheric pressure bubbling fluidized bed combustion boilers
    - Atmospheric pressure circulation fluidized bed combustion boilers
  - Pressurized
    - Pressurized bubbling fluidized bed combustion boilers
    - Pressurized circulation fluidized bed combustion boilers

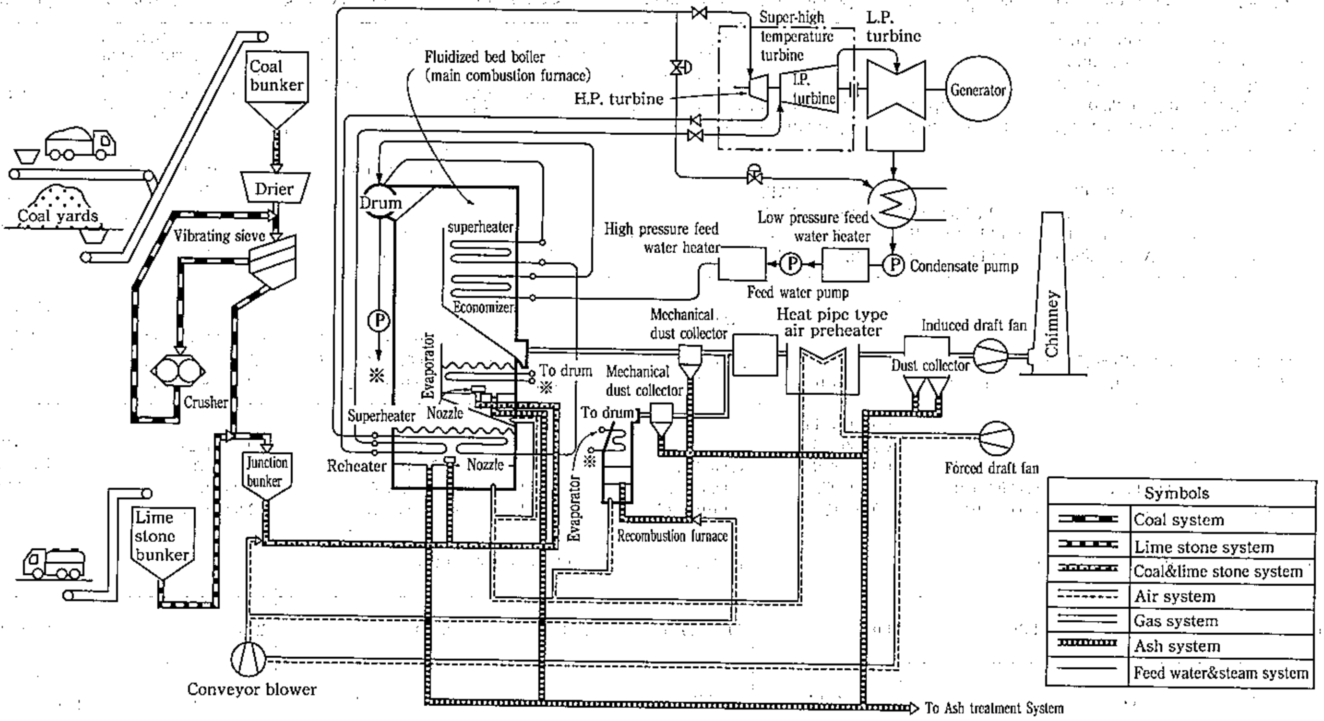
11-16 Features of Various Fluidized Bed Combustion Boilers

Types / Items	Atmospheric pressure fluidized bed combustion boilers (A F B C)		Pressurized fluidized bed combustion boilers (P F B C)	
	Bubbling (A. B F B C)	Circulation (A. C F B C)	Bubbling (P. B F B C) (Combined cycle)	Circulation (P. C F B C) (Combined cycle)
Desulfurization method	Desulfurization in fluidized bed (Desulfurizer: Lime stone)	Desulfurization in furnace (Desulfurizer: Lime stone)	Desulfurization in fluidized bed (Desulfurizer: Lime stone and dolomite)	Desulfurization in furnace (Desulfurizer: Lime stone and dolomite)
Load control method	Fluidized bed temperature control + Celll slumping control (Heating area change control)	Grain circulation control (Thermal-transmission-rate change control)	Fluidized bed height control (Heating area change control)	Grain circulation control (Thermal-transmission-rate change control)
Combustion method	Combustion in fluidized bed (MBC combustion + CBC recombustion)	Floating circulatin combustion in furnace (including in-furnace recirculation combustion)	Combustion in pressurized furnace	Pressurized in furnace plus floating circulation (including in-furnace recirculation combustion)
Heat transmission method	Heat absorption in fluidized bed + Water wall heat absorption + Rear gas duct heat absorption	Water wall heat absorption + Rear gas duct heat absorption	Heat absorption in fluidized bed + Water wall heat absorption	Water wall heat absorption + Furnace heat absorption
System				

11-17 Example of Atmospheric Pressure Fluidized Bed Combustion Boilers

The atmospheric pressure fluidized bed combustion (FBC) boilers are roughly divided into two types: Circulation FBCs, and bubbling FBCs.

The following shows the structure of bubbling FBC.



〔Source: The Thermal and Nuclear Power Vol.38/No.10 (1987/10)〕

For PFBC, refer to the Combined cycle power plants, 22-5 Pressurized fluidized bed combustion boiler (PFBC).

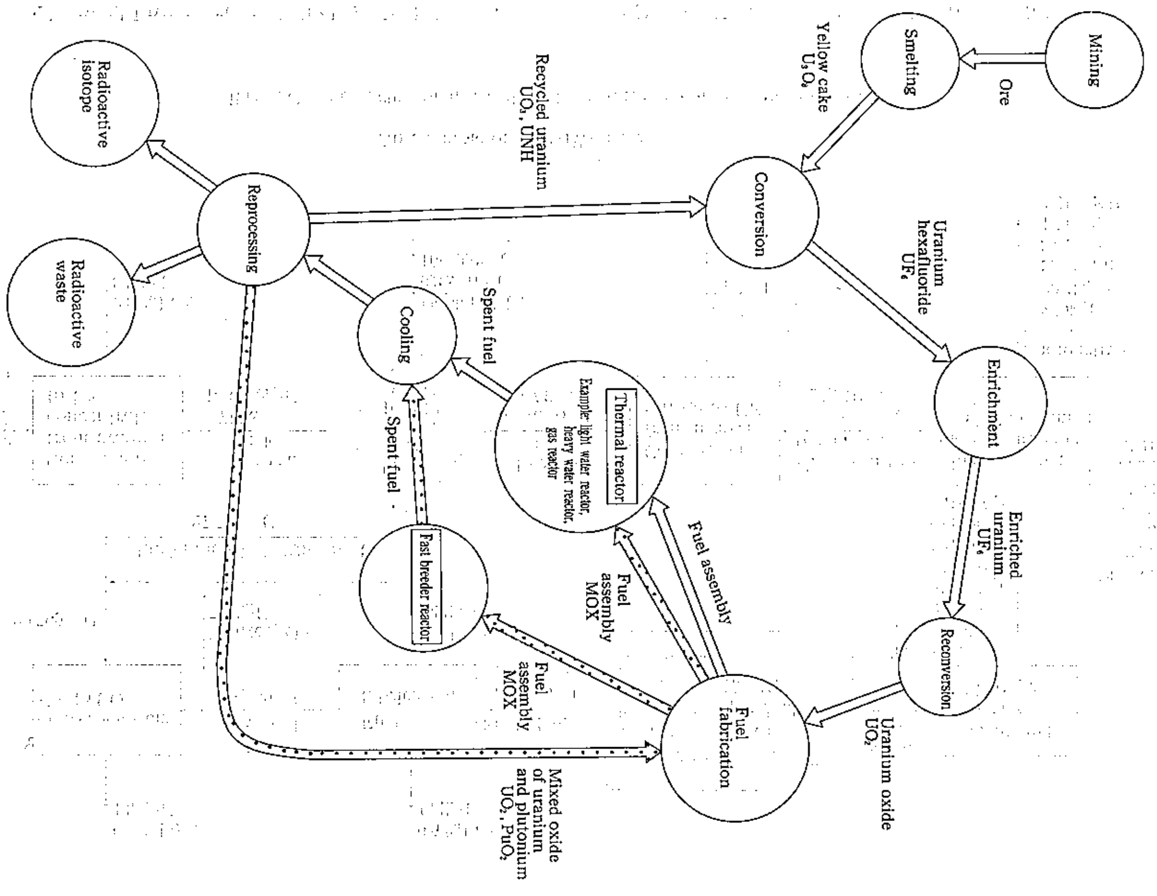
12-1 Major Characteristics of Nuclear Fuels

Nuclear Fuel / Characteristics	UO_2	UC	UN	U (Metal)	PuO_2	PuC	ThO_2	ThC_2
Metallic element density (g/cm³)	9.67	12.89	13.53	19.05±0.02	10.1	13.1	8.79	8.14
Melting point (℃)	2,860	2,315	2,650(2atomN_2)	1,131±1	2,400	1,650	3,200±100	2,655
Thermal conductivity (W/m•K)	10.5(100℃) 6.3(400℃) 3.8(800℃) 2.5(1,400℃)	24.3(200℃) 22.2(400℃) 20.5(700℃)	17.2(400℃) 25.1(1,000℃)	27.2(101℃) 33.9(400℃) 43.5(700℃)	6.7(200℃) 4.6(400℃) 3.3(800℃) 2.9(1,000℃) 2.1(1,600℃)	9.6(200℃) 10.0(300℃) 12.6(400℃)	8.5(200℃) 3.1(1,000℃)	23.9(25℃)
Linear expansion coefficient $\times 10^{-6}$ (1/K)	9.2(27~400℃) 10.8(400~800℃) 12.9(800~1,262℃)	9.5(20~100℃) 13.1(300~400℃) 13.0(900~950℃)	8.6(26~1,000℃)	8.5(300℃) 9.3(400℃) 11.4(500℃) 12.9(600℃)	10.9 (25~1,000℃)	10.8×10^{-6} (20~780℃)	10.2 (25~1,700℃)	8.45 (0~1,000℃)
Radiation damage	Swelling increases linearly with burn-up and the rate of swelling is 0.2 – 0.7% (ΔV/V) (10^{20}fis/cm³).	Low swelling rate even above 50,000 MWd/t. FP gas retension capability is larger than that of UO_2.	Low swelling rate.	High swelling rate.	Cause swelling at burn-up above 50,000 MWd/t.	Low swelling rate even above 50,000MWd/t.	0.46%ΔV/V/ 10^{20}nvt (4.5% UO_2 content)	–
Chemical properties	Stable in atmosphere except fine powder. Stable up to 900℃ in CO_2. Stable up to 300℃ in pressurized water. Compatible with water.	Fine powder oxidizes in atmosphere. Oxidize rapidly at 500℃, 8ata. in CO_2. Compatible with Na.	Fine powder oxidizes in atmosphere. Stable up to 300℃ in case of compacts. Compatible with NaK and boiling water.	Oxidizes in atmosphere at the room temperature. React heavily with boiling water. React with CO_2 above 750℃.	Compatible with water.	Not compatible with water.	Capable to use up to 2,700 ℃ in the air. Compatible with water.	Burn heavily if ignited. Easy to absorb water moisuture and decompose.
Cladding tube used at present or considered to be used in the future.	Zircaloy-2, Zircaloy-4 and SS for light water reactors.	SAP, Nb, Mo, V, SS, and Inconel	Zircaloy, SS, Nb, W	Magnox, SS, Be	Does not react with SS, Cr, Mo, Nb, V, W at the temperature below 1,370℃. React with Zr, W, Ti.	React with many metals. TaC is the only applicable material at the temperature above 1,550℃.	Does not react with SS, Zircaloy, Pylo Carbon, W, Zr, SS or Al.	SS, Zircaloy, Pylo Carbon

Note: Mox fuel contains a little amount of PuO_2 in UO_2 matrix. The crystal structure of PuO_2 is the same fluorspar face-centered cubic lattice as UO_2, and PuO_2 and UO_2 form solid solution state exchanging U atom with Pu atom. Therefore, properties of MOX fuel change from that of uranium to the content of plutonium accordingly.

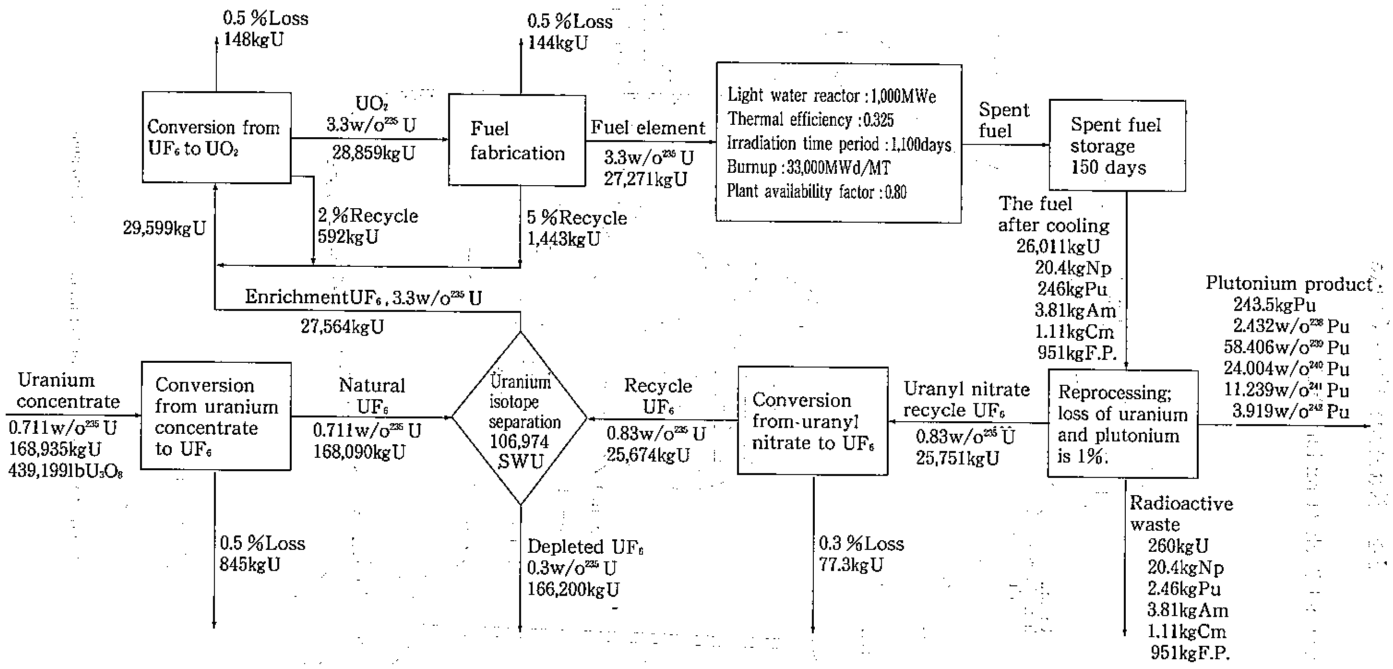
12-2 Nuclear Fuel Cycle

(1) Figure of Nuclear Fuel Cycle (Uranium Fuel)



(Note) MOX: Mixed oxide fuel of uranium and plutonium

(2) Fow Sheet of Fuel Cycle for a Light Water Reactor



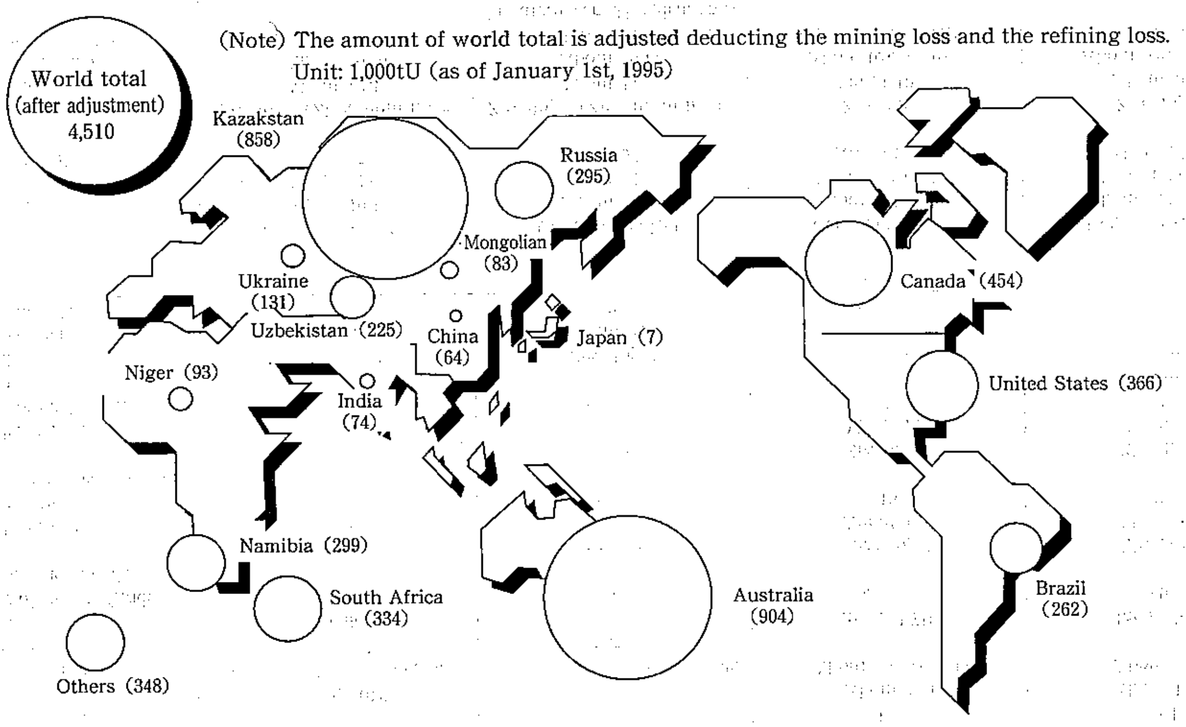
An example of 1000MWe case

Bases: One year, 80% plant availability factor, low enriched uranium fuel

〔Source: Chemical Engineering of Nuclear Fuel Cycle, translated by Ryohei Kiyose (1983), published by *Nikkan Kogyo Shimbun*〕

12-3 Uranium Resources in the World

(Note) The amount of world total is adjusted deducting the mining loss and the refining loss.
Unit: 1,000tU (as of January 1st, 1995)



Source: OECD/NEA/IAEA URANIUM 1995

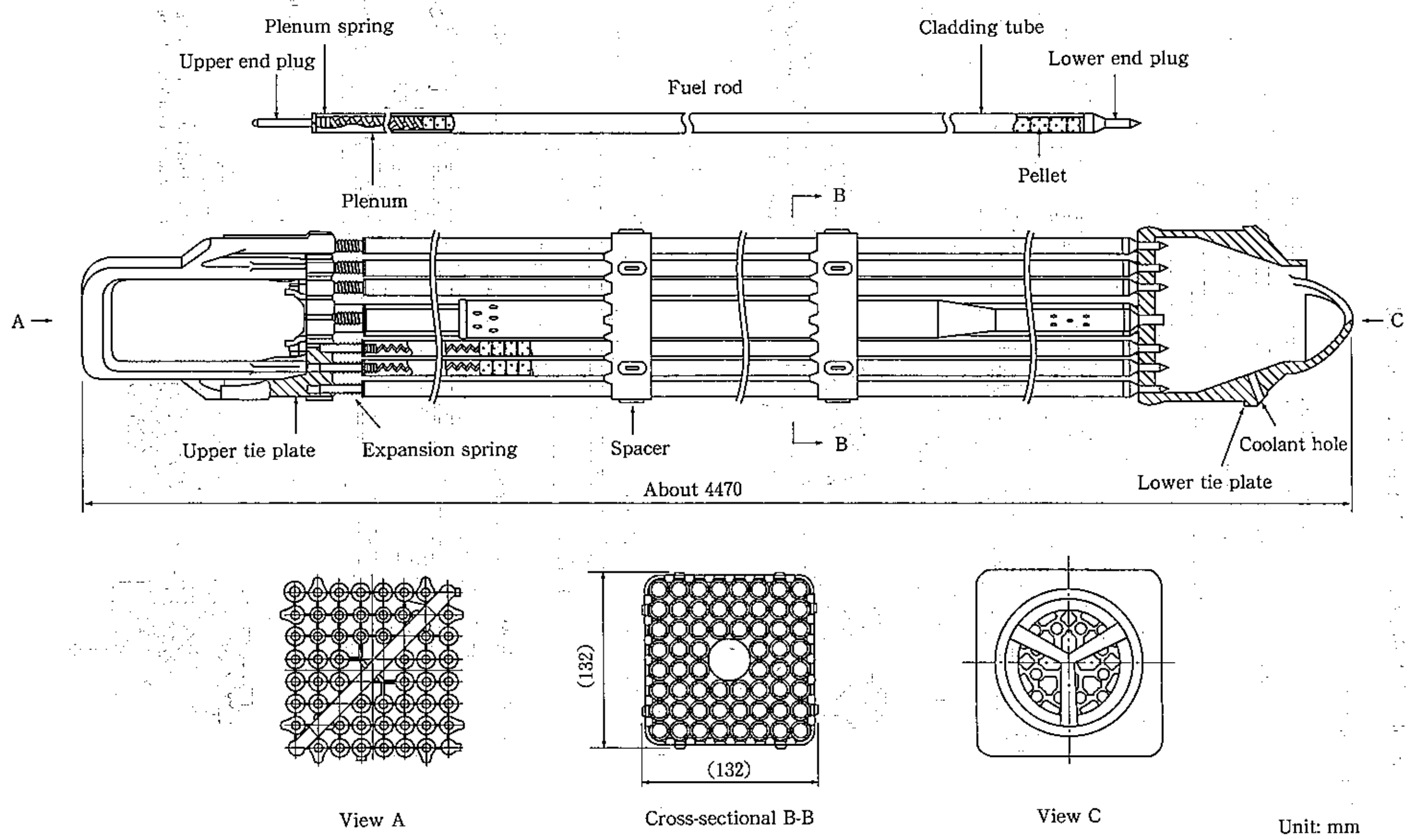
〔Source: Atomic Energy Pocketbook (1998/1999), edited by Japan Atomic Industrial Forum, Inc.〕

12-4 Basic Specifications of Fuel for Boiling Water Reactors and Pressurized Water Reactors (Examples)

	BWR		PWR	
	High burnup 8×8 fuel	9×9 fuel	14×14 fuel	17×17 fuel
1. Fuel Assembly				
Fuel rod array	8 × 8	9 × 9	14×14	17×17
Number of fuel rods (№)	60	74	179	264
Fuel rod pitch (㎜)	About 16.2	About 14.3	About 14.1	About 12.61
Total fuel length (m)	About 4.47 (Including tie plates with grapples)	About 4.47 (Including tie plates with grapples)	About 3.74 or 4.06	About 4.06
Spacer/Grid				
Material	Zircaloy	Zircaloy	Inconel-718	Inconel-718
Number of spacers/grids	7	7	6, 7, 8	9
Control rod guide thimble	——	——		
Material	——	——	Zircaloy-4	Zircaloy-4
Outer diameter (㎜)	——	——	About 13.7	About 12.2
Number of thimbles	——	——	16	24
Guide tubes for in core monitors	——	——		
Material	——	——	Zircaloy-4	Zircaloy-4
Outer diameter (㎜)	——	——	About 10.7	About 12
Number of guide tubes	——	——	1	1
Water rod			——	——
Material	Zircaloy-2	Zircaloy-2	——	——
Outer diameter (㎜)	About 34.0	About 24.9	——	——
Number of rods	1	2	——	——
2. Fuel Rod				
Pellet				
Material	UO_2, UO_2-Gd_2O_3	UO_2, UO_2-Gd_2O_3	UO_2, UO_2-Gd_2O_3	UO_2, UO_2-Gd_2O_3
Diameter (㎜)	About 10.4	About 9.6	About 9.3 or 9.2	About 8.2 or 8.1
Length (㎜)	About 1.0	About 1.0	About 1.1 or 1.0	About 1.0 or 0.9
Density (%TD)	About 97	About 97	About 95	About 95
Cladding tube				
Material	Zircaloy-2 (Zirconium liner)	Zircaloy-2 (Zirconium liner)	Zircaloy-4	Zircaloy-4
Outer diameter (㎜)	About 12.3	About 11.2	About 10.7	About 9.50
Wall thickness (㎜)	About 0.86	About 0.71	About 0.62 or 0.66	About 0.57 or 0.64
Effective fuel length (m)	About 3.71	About3.71 (Standard fuel rod) About2.16(Partial length fuel rod)	About 3.05 or 3.66	About 3.66
Pellet-cladding gap (㎜)	About 0.20	About 0.20	About 0.19	About 0.17
Helium pressure (MPa [abs])	About 0.5	About 1.0	*Helium pressurization*	*Helium pressurization*

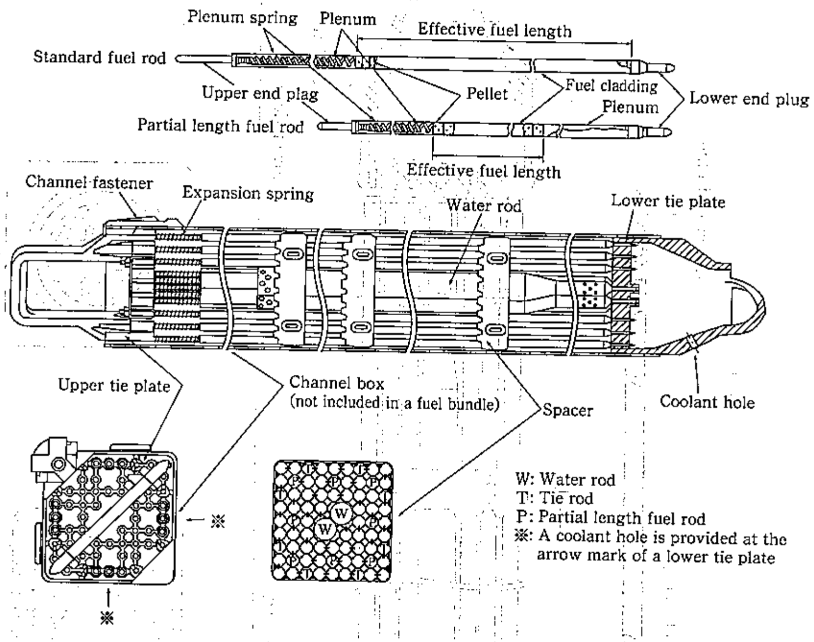
12-5 LWR Fuel Assembly Structural Drawings

(1) Example of Boiling Water Reactor Fuel Assembly (8×8 type)



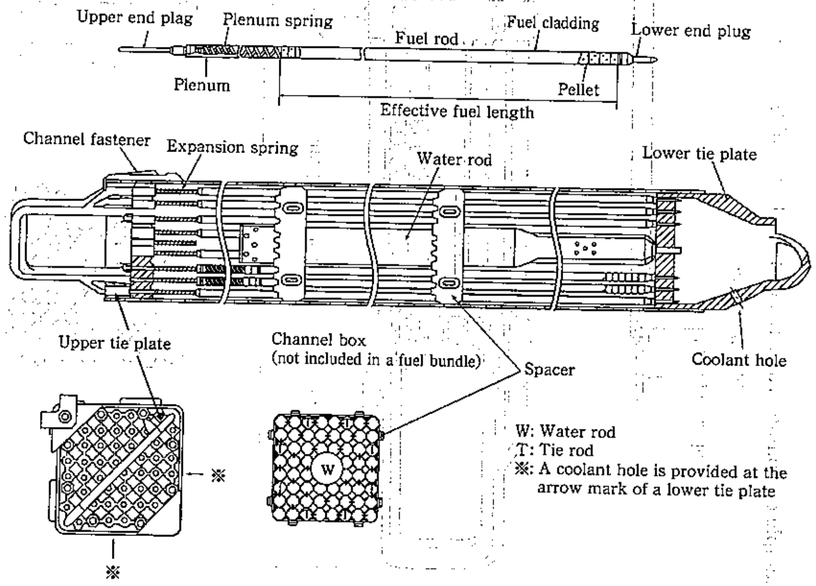
(2) Example of Boiling Water Reactor Fuel Assembly

(9×9 fuel, A-type)



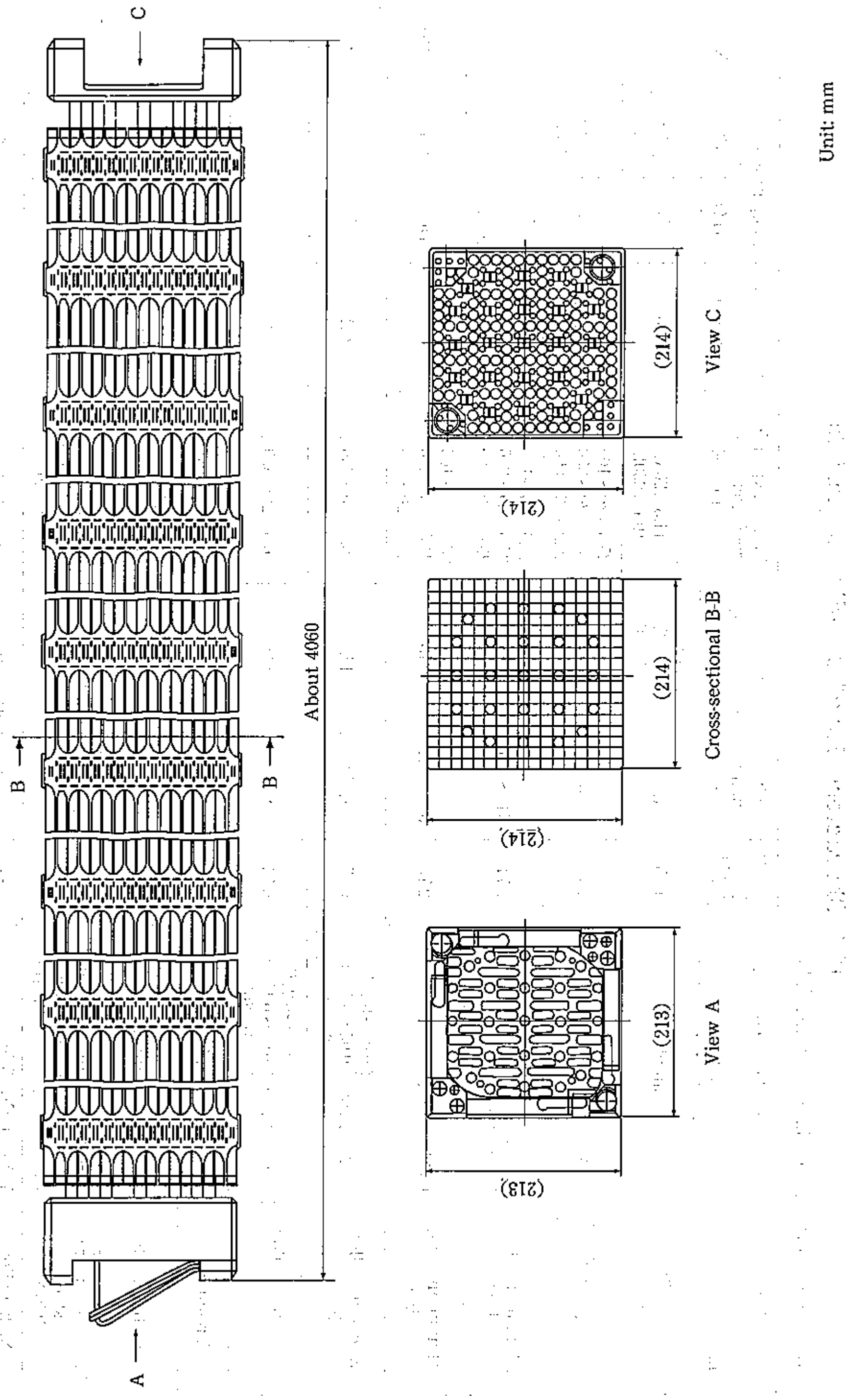
W: Water rod
T: Tie rod
P: Partial length fuel rod
※: A coolant hole is provided at the arrow mark of a lower tie plate

(9×9 fuel, B-type)



W: Water rod
T: Tie rod
※: A coolant hole is provided at the arrow mark of a lower tie plate

(3) Example of Pressurized Water Reactor Fuel Assembly (17×17)



12-6 Characteristics of Cladding Materials

Major characteristics of cladding materials

Characteristics / Materials	Chemical composition (Wt%)	Density (g/cm³) (Room temp.)	Melting point (℃)	Thermal conductivity (W/m·K)	Linear expansion coefficient (×10⁻⁶/K)	Cross section of thermal neutron absorption (barn)	Compatibility with coolant		
							H_2O	CO_2	Na
Beryllium Be	Simplex	1.85	1,283	167 (100℃) 130 (300℃) 92 (700℃)	11.3 (20℃) 19.1 (800k)	0.009	○	○ (equal or less than 600℃)	○
Magnesium alloy A−12	1.0Aℓ, 0.01Be	1.74	650	157	25.8 (20~100℃) 28.2 (20~300℃) 29.9 (20~500℃)	0.059±0.0042	×	○ (400~500℃)	×
Aluminium alloy 1,100	99%Aℓ Si+Fe=1	2.71	643~657	218	23.5 (20~100℃) 24.6 (20~200℃) 25.6 (20~300℃)	0.23	○ (100~300℃)	○	×
Aluminium alloy 6,063	0.7Mg, 0.4Si	2.70	616~651	213	23.4 (20~100℃) 24.5 (20~200℃) 25.5 (20~300℃)	0.23	Ditto	Ditto	Ditto
Zirconium alloy Zr−2	1.2~1.7Sn { 0.07~0.20Fe 0.05~0.15Cr 0.03~0.08Ni	6.55	1,852	14.6	6.5 (20~350℃)	0.21	○	×	○
Zirconium alloy Zr−4	1.2~1.7Sn { 0.18~0.24Fe 0.07~0.13Cr ≦0.007Ni	6.55	1,852	14.6	6.5 (20~350℃)	0.21	○	×	○
Vanadium V	Simplex	5.87	1,917	29	8.4 (20℃) 10.9 (800k)	5.04	–	–	○
Niobium Nb	Simplex	8.57	2,468	55.3	7.2 (20~100℃) 7.4 (20~200℃) 7.5 (20~300℃)	1.1	○	○	○
Austenitic stainless steel SUS304	18~20Cr, 8~10.5Ni, equal or less than 2Mn, equal or less than 1Si, equal or less than 0.08C	8.03	1,399~1,454	16.3 (100℃) 18.8 (300℃)	14.7 (20℃) 17.5 (500k) 20.2 (800k)	3	○	○	○
Nickel alloy Inconel 600	72Ni, 15Cr, 8Fe 0.5Cu	8.51	1,410	15.1 (100℃)	11.5 (0~100℃)	4.03	○	○	–

Reference: Metal's Handbook, edited by The Japan Institute of Metals (1990), Rika Nenpyo (Chronological Scientific Tables) (1999), edited by National Astronomical Observatory and Metal's Data Book, (1974), edited by The Japan Institute of Metals, published by Maruzen Co., Ltd. etc.

13-1 Outline of Main Types of Nuclear Power Reactors

(1) Types of Nuclear Power Reactors

There are various types in nuclear power reactors by the combination of the shapes and the kind of the assembly elements of the reactor such as the fuel, the moderator, and the coolant. The followings are typical types of nuclear power reactors;

(a) Graphite moderated, carbon dioxide gas cooled reactor (called Calder Hall type or Magnox reactor)
(b) Light water moderated and cooled pressurized water reactor (PWR: Pressurized water reactor)
(c) Light water moderated and cooled boiling water reactor (BWR: Boiling water reactor)
(d) Advanced graphite moderated, carbon dioxide gas cooled reactor (AGR: Advanced gas cooled reactor)
(e) Graphite moderated, helium cooled reactor (HTGR: High temperature gas cooled reactor)
(f) Heavy water moderated (light water or heavy water cooled) reactor (HWR: Heavy water reactor)
(g) Liquid metal cooled fast breeder reactor (LMFBR: Liquid metal cooled fast breeder reactor)
(h) Light water reactor of old USSR type (RBMK-Graphite moderated, light water cooled, channel type and VVER-Pressurized light water reactor)

(2) Outline of Main Reactor Types

(a) Calder Hall Type

(i) General Description

The prototype of this reactor was developed in England and France. The main assemblies of the reactor consist of piled graphite blocks, which function as the moderator and the reflector.

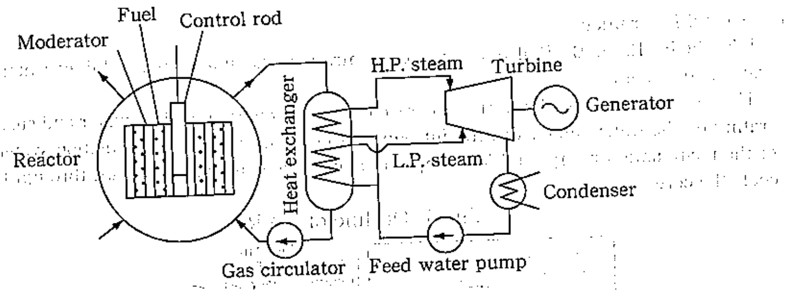
The fuel is a metal rod of natural uranium coated with Magnox (magnesium alloy) and is inserted into the multiple hole (vertical or horizontal) dug in the moderator.

The reactor core is housed in a spherical or cylindrical steel containment.

Heat generated in the reactor core is transferred to pressurized carbon dioxide gas flowing in the groove of the fuels.

The carbon dioxide gas is circulated between the reactor and the tube side of the heat exchanger by the gas compressor.

Fig. 1 Outline of Calder Hall Reactor



(ii) Features

The reactor core consists of the fuel assemblies with metal rods of natural uranium and the graphite blocks of the moderator, so that its size is large. The cost of the fuel is low, while the construction cost is high.

Carbon dioxide gas is used as the primary coolant, so that large heat exchanger is required. The drive power for the circulator is also large.

As the reactor core is the structure of piled blocks, the special consideration is required to meet aseismic requirement. The secondary steam (turbine plant side) is controlled by the double pressure method to give the optimum condition to the relation of the difference between the temperature at inlet of the heat exchanger and that at outlet, and the thermal efficiency of the turbine. The refueling can be carried out during power operation.

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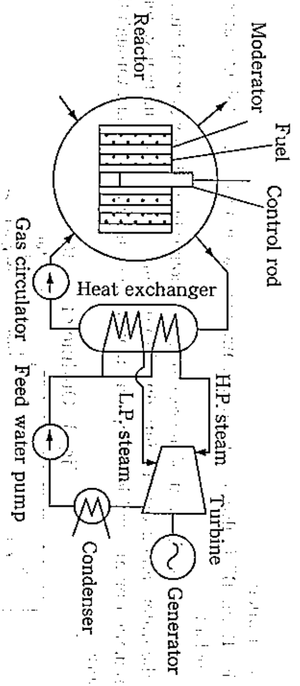
The fuel is a metal rod of natural uranium coated with Magnox (magnesium alloy) and is inserted into the multiple hole (vertical or horizontal) dug in the moderator.

The reactor core is housed in a spherical or cylindrical steel containment.

Heat generated in the reactor core is transferred to pressurized carbon dioxide gas flowing in the groove of the fuels.

The carbon dioxide gas is circulated between the reactor and the tube side of the heat exchanger by the gas compressor.

Fig. 1 Outline of Calder Hall Reactor



(ii) Features

The reactor core consists of the fuel assemblies with metal rods of natural uranium and the graphite blocks of the moderator, so that its size is large. The cost of the fuel is low, while the construction cost is high.

Carbon dioxide gas is used as the primary coolant, so that large heat exchanger is required. The drive power for the circulator is also large.

As the reactor core is the structure of piled blocks, the special consideration is required to meet aseismic requirement. The secondary steam (turbine plant side) is controlled by the double pressure method to give the optimum condition to the relation of the difference between the temperature at inlet of the heat exchanger and that at outlet, and the thermal efficiency of the turbine. The refueling can be carried out during power operation.

(b) PWR

(i) General Description

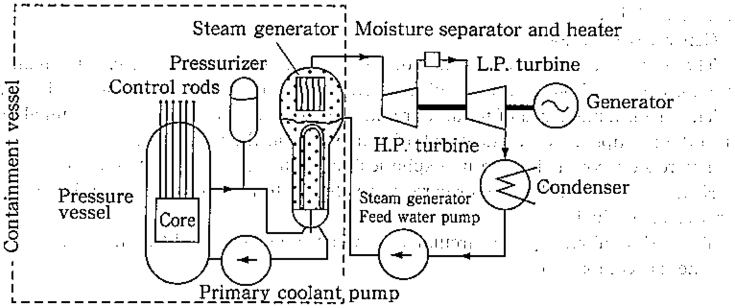
PWR is one type of light water moderated and cooled reactor, which uses low-enriched uranium dioxide sintering pellets as the fuel.

Light water (the primary coolant) heated in the reactor core is circulated between the reactor and the steam generator by the primary coolant pump. High pressure and temperature steam to drive the turbine is generated by exchanging the heat between the primary coolant and the secondary coolant (light water) in the steam generator.

(ii) Features

Since the turbine is driven by the clean steam generated in the secondary side of the steam generator, the turbine and related equipments are free from radioactive contamination. Relatively slow reactivity fluctuation by fuel burnup is controlled by adjusting the concentration of boron in the primary coolant. In this operation, distortion of the power distribution is very small and the operation is easy, because of all control rods are withdrawn fully. The water quality is well controlled because of the primary coolant system is a closed loop.

Fig. 2 Outline of PWR



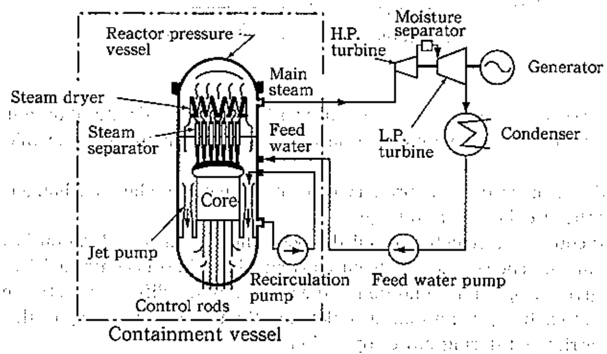
(c) BWR

(i) General Description

Like the PWR, the BWR also uses low-concentration uranium as fuel and light water as the moderator and coolant.

The steam is generated by heat of the reactor core (cooling by boiling water and steam, and moderating by the water) and is directly introduced to the turbine. The recirculation system consisting of the recirculation pumps and jet pumps circulates large amount of coolant through the core and cools the core.

Fig. 3. Outline of BWR



(ii) Features

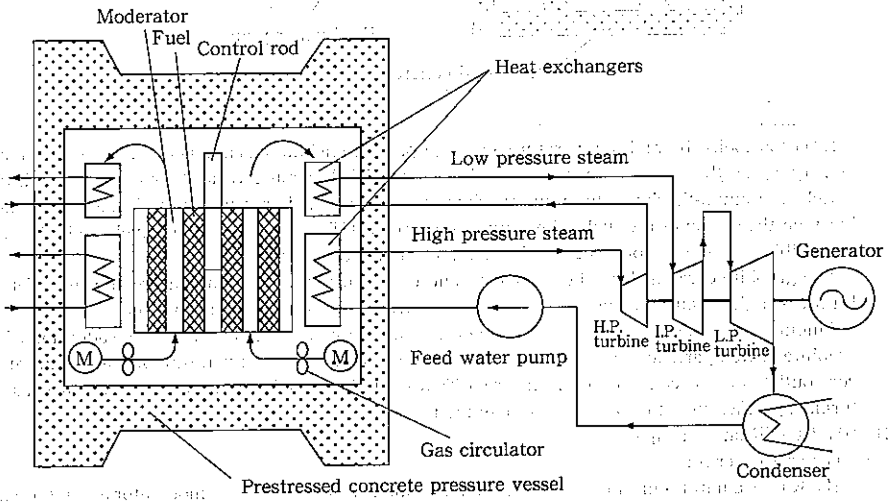
The power density of BWR is approximately limited to half of PWR in accordance with the relation of boiling phenomena and nuclear physics, because the steam is generated in the core and is usually existed in the core. The steam generator is not necessary to generate steam, but the steam to drive the turbine is slightly radioactive. The control of the reactor power is normally performed by the variation of the recirculation flow rate.

(d) AGR

(i) General Description

AGR had been developed in England as an advanced development of the Magnox reactor and their related facilities are almost similar to those in the Magnox reactor. The primary system such as the heat exchanger and the gas circulator is enclosed in the prestressed concrete pressure vessel with the reactor. The primary coolant flows upward in the fuel channels and next flows downward through the heat exchanger. The low enriched uranium is used as the fuel and the material of the fuel cladding is stainless steel.

Fig. 4 Outline of AGR



(ii) Features

AGR could use the newly high efficient steam turbine if the temperature of the carbon dioxide gas would be raised higher and the steam condition would be improved. The core size is large because of the low power density. There is less radioactive waste. Refueling can be carried out during power operation.

(e) HTGR

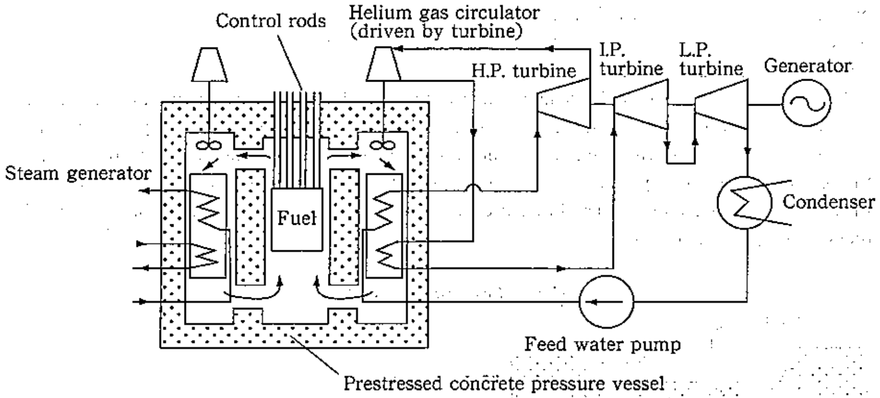
(i) General Description

HTGR had been independently developed in US, England and Germany (West Germany) simultaneously. This reactor is graphite moderated, helium gas cooled reactor using graphite coated high-enriched uranium-thorium as the particle fuel.

There are two types in the structure to enclose the fuel core, the control rod and the primary coolant system such as the heat exchanger and the helium circulator. The one is the integrated structure enclosed in a prestressed concrete pressure vessel and the other is a small modular type using a steel pressure vessel.

There are two types in the shape of the fuel element in HTGR: the one is the prism type (hexagonal graphite block) developed in England and USA, the other is the pebble bed type developed in Germany (West Germany).

Fig. 5 Outline of HTGR



(ii) Features

HTGR is cooled by high temperature and high pressure helium gas and is possible to have power density higher than that of other gas cooled reactors. HTGR can use various combinations of highly enriched uranium-thorium, plutonium-thorium and low enriched uranium as the fuel and has a flexibility on the option of the fuel. The conversion ratio of HTGR can be comparatively so high that it is possible to make use of resources for the nuclear fuel efficiently.

The graphite core has large heat capacity and can withstand high temperature and the safety of HTGR is high because of the adoption of the prestressed concrete pressure vessel.

Amount of radioactive waste from the plant is comparatively small because of the adoption of the graphite coated particle fuel and the helium of the coolant. If the temperature of the coolant at the core outlet could become higher in future, HTGR could be used for multiple purposes such as gas turbine, gasification of coal and steel manufacture.

(f) HWR (ATR only in Japan)

(i) General Description

HWR uses a natural uranium as the fuel mainly and heavy water as the moderator and light water (SGHWR-England) and heavy water (CANDU-Canada) as the coolant. The advanced thermal reactor (ATR) developed by Japan Nuclear Cycle Development Institute is planned to use a mixed oxide fuel of natural uranium and plutonium (MOX) as the fuel and heavy water as the moderator and light water as the coolant.

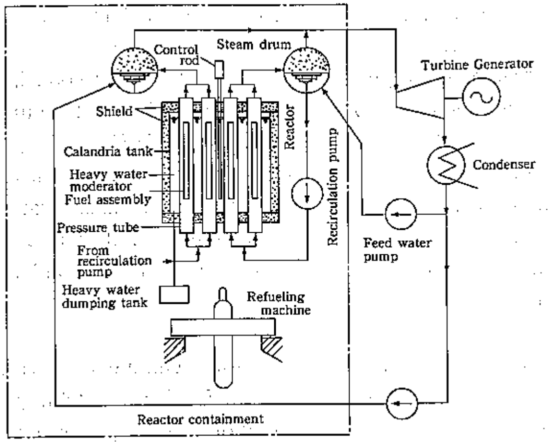
The core assembly of ATR consists of the calandria tank and multiple pressure tubes made of zirconium alloy and penetrates the calandria tank at both end and enclose a fuel assembly per a tube. The coolant circulates in the pressure tube and the steam is generated.

The control rods of HWR is inserted into the heavy water with low temperature and atmosphere in the calandria tank from above and the heavy water dumping function which reduces the level of the heavy water as the moderator rapidly at an emergency and keeps the reactor subcritical is provided as the back up device.

(ii) Features

In the design of ATR, neutrons generated by fission are mainly moderated to sufficient low energy level in the heavy water so that neutrons has less effect of resonance absorption of plutonium. As the result, both uranium and plutonium are used evenly on the nuclear fission. The refueling is performed from the bottom of the reactor and the facility can make refueling during plant operation.

Fig. 6 Outline of HWR



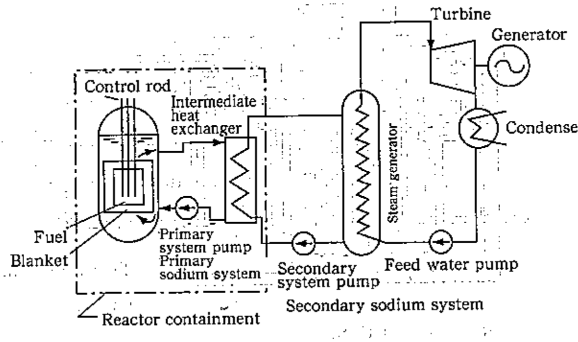
(g) LMFBR

(i) General Description

LMFBR uses high-enriched uranium or plutonium as the fuel, and the core is surrounded by the blanket loading natural uranium and liquid metal sodium is used as the coolant.

Heat generated in the core is removed from the core by liquid metal sodium circulating through the core and is transferred to the secondary sodium system at the intermediate heat exchanger. Superheated steam is generated at the steam generator in the secondary sodium system and drives the turbine.

Fig. 7 LMFBR



(ii) Features

Nuclear fission is carried out by fast neutron so that a moderator is not necessary in LMFBR. LMFBR can breed the plutonium of the nuclear fissile material. This means that it can breed plutonium (new fuel) more than the fuel (enriched uranium or plutonium) consumed. The power density of the core is so high that the core size becomes compact. The design of the core and the instruments and control system is crucial to the safety because of the large amount of high-enriched uranium or plutonium.

(h) LWR of old USSR (Russia)

1) Graphite Moderated, Light Water Cooled, Channel Type Reactor (RBMK)

(i) General Description

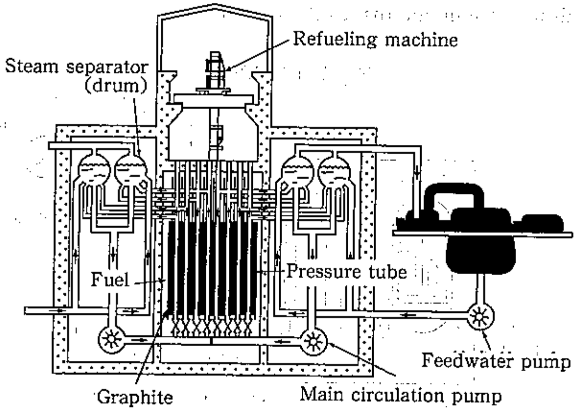
RBMK reactor is graphite moderated, light water cooled, channel type, boiling water reactor which uses approx. low- enriched (^{235}U of 2%) uranium oxide as the fuel and is the reactor developed originally by old USSR. The light water of the coolant is supplied into the fuel channels through the header by the circulation pump and is heated and is evaporated and flows up into the steam separator. After steam separating, dry steam is introduced into the turbine and electric power is generated. The steam exhausted from the turbine is condensed in the condenser and is returned to the steam separator.

(ii) Features

The one of characteristics of the reactor of channel type which does not use a large steel pressure vessel is not to require the fabrication technique of the large and precise plant. The refueling can be carried out during power operation by the refueling machine which is installed at the top of the graphite blocks.

The void reactivity coefficient of the various reactivities for RBMK is so large positive that RBMK has a tendency to be unstable at a low power. And the containment vessel which has a critical function to prevent radioactive materials from releasing to the environment is not provided.

Fig. 8 Outline of RBMK



* Resources of USSR

〔Source: Nuclear Handbook, editorially supervised by Asada, et al, published by Ohmsha Ltd. (1989)〕

2) Pressurized Light Water Reactor (VVER)

(i) General Description

USSR pressurized light water reactor is called VVER and there are two types such as VVER-440 with 6 loops and VVER-1000 with 4 loops. The primary loops consists of 6 loops and each loop consists of the main primary circulation pump, the steam generator, valves and austenitic pipe with inner diameter 50cm. The secondary system consists of the steam generator of horizon type, the turbine-generator, the feedwater heater, pump, valves and piping. The containment vessel was not provided in the early plant.

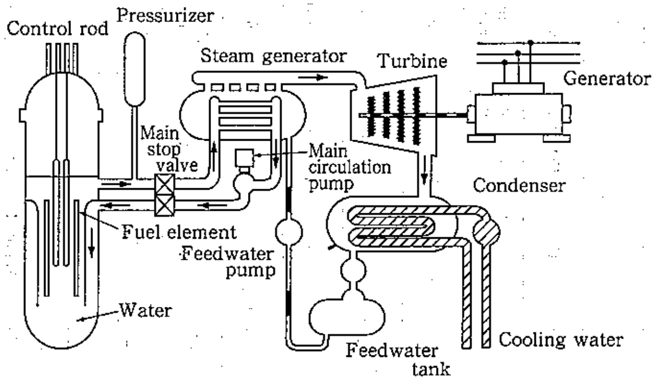
(ii) Features

A heat exchanger of a horizontal type was used as the steam generator in order to reduce potential corrosion problems of the heat transfer tube. The fuel assembly encloses 126 fuel rods in the hexagonal outer box and the pipe arranged in the center of the box is the support structure of the spacer of the fuel elements. The length of active fuel is short and 2.5 m.

The pressure vessel is provided with 12 nozzles for the inlet／the outlet of the coolant and these nozzles are located at two columns. 4 nozzles for the emergency core cooling are also provided. The pressure vessel is divided into two parts, upper shell and lower shell and transferred to the site by the railroad.

The containment vessel essential to the safety is not provided in the standard plant of VVER-440. Therefore, Lovissa nuclear power station in Finland changed to install the containment vessel of the ice condenser type additionally and enhances the confinement function for radioactive materials.

Fig. 9 Outline of VVER



* Pamphlet of Loviisa (Finland)

〔Source: Nuclear Handbook, editorially supervised by Asada, et al, published by Ohmsha Ltd. (1989)〕

13-2 Specifications for Various Types of Reactors

Parameters / Reactor type		PWR (Standard type)	BWR (Standard type)	HWR: Heavy water cooling type	HWR: Advanced thermal reactor	Mognox reactor	AGR	HTGR	LMFBR	LWR of old USSR: RBMK (graphite moderator/light water cooling channel)	LWR of old USSR: VVER (PWR)
Unit output, gross	(MWe)	1,180	1,100	788	165	166	660	342	250	1,000	1,000
Fuel	Type	UO_2	UO_2	UO_2	UO_2-PuO_2	Uranium metal	UO_2	UO_2-ThC_2	UO_2-PuO_2	UO_2	UO_2
	Enrichment (%)	2 ~ 3	2 ~ 3	Natural uranium	U1.5/Natural uranium Pu0.67	Natural uranium	2.1~2.6	93	Pu enrichment Inside: 19.2 Outside: 27.1	Approx.2	3.3~4.4
Moderator	Material	Light water	Light water	Heavy water	Heavy water	Graphite	Graphite	Graphite	None	Graphite	Light water
Coolant	Type	Pressurized light water	Boiling light water	Pressurized heavy water	Boiling light water	Pressurized carbon dioxide	Pressurized carbon dioxide	Pressurized helium	Liquid sodium	Light water	Pressurized light water
	Pressure (MPa[gage])	15.4	6.93	11	6.67	1.41	4.15	4.83	0	6.86	15.7
	Temperature at inlet/outlet (℃)	289/325	216/286	261/299	277/284	207/386	317/654	404/777	400/560	270/284	290/322
Steam condition (at turbine inlet)	Pressure super-heat/reheat (MPa[gage])	Approx.5.79	6.55	4.22	6.23	H.P. 4.44 L.P. 1.64	15.9/3.82	16.5/3.92	16.0/3.28	6.37	5.88
	Temperature, superheater /reheater (℃)	Approx.274	282	253	279	H.P. 355 L.P. 357	538/538	538/538	510/510	280	274.3
Plant efficiency	(%)	34.5	33	31.3	29.6	28.3	43.2	40.7	44	31.9	33.3
Nuclear characteristics	Power density (kWt/l)	100	50	Approx.11	Approx.12	Approx.1.0	Approx.2.8	6.3	406	Approx.4	108.0
	Burnup(MWD/t)	27,000 ~33,000	27,000 ~39,500	9,600	17,000	3,000	18,000	100,000	50,000 ~100,000	18,500	40,000
Power plant (examples)				Bruce (Canada)	Fugen (Japan)	Tokai-1 (Japan)	Hunter Stone B (U.K.)	Fort St. Vrain (USA)	Phoenix (France)	Chernobyl (Ukraine)	Balakovo (Russia)

13-3 Safety Design of Nuclear Reactor

(1) Fundamental Concept of Safety Design

The fundamental concept of safety design for the nuclear reactor is the protection of the public and the workers in the facility from radiation exposure and the concept of defense in depth is taken in the design.

The bases of concept of defense in depth are: First is to prevent the occurrence of abnormal incidents. Second is to prevent the abnormal incidents from developing to the accidents. Third is to prevent the radioactive materials from releasing to the environment outside the plant, if developed into the accidents.

(a) Prevention of Occurrence of Abnormal Incidents (Safety Measures of Level 1)

For countermeasure to prevent occurrence of abnormal incidents, these equipments are designed to be able to withstand the temperature and load applied to them during operation. For the facilities which erroneous operation and malfunction affect crucially the safety of the power plant, equipments and materials with high performance and high quality are used and the concept of fail safe system and interlock system are also taken in the design.

A fail safe system means the concept that the system is designed to become stable to ensure the safety of the plant, even if the a failure in a part of the system occurs.For instance, when the electrical power for the control rod drive device is lost for some reason, it is designed for the control rod to be automatically inserted into the core by gravity or the hydraulic system and for the reactor to be shut down safely. An interlock system means the system to prevent the occurrence of abnormal incidents by human error. For instance, it is designed for the control rod not to be withdrawn, even if an operator try to withdraw a control rod mistakenly.

Except the above, equipments essential to safety is designed and fabricated under the complete program of quality assurance. The power station is forced to shut down the reactor and to disassemble and inspect these components once annually by law. If the performances of these components can or may not meet the criteria determined by the law, the proper measures such repairs is taken immediately.

(b) Prevention of Development into Accident (Safety Measures of Level 2)

The countermeasures to prevent abnormal incidents from developing to accidents are to detect abnormal condition early and to take the proper measures such as a plant shutdown before abnormal incidents does not develop to accidents, even if abnormal incidents occurs.

For example, when a pin hole occurs in the heat transfer tube of the steam generator during power operation and the primary coolant leaks into the secondary cooling system, the automatic monitoring system to be able to detect some leakage, which may be very small, is provided in PWR.

There are the devices to automatically insert the control rod and shut down the reactor, when detecting the abnormal or emergency condition which the reactor pressure rapidly increases for some reason.

(c) Prevention of Radioactive Materials Release to Environment (Safety Measures of Level 3)

Assuming the occurrence of accidents in spite of above countermeasures, other countermeasures are taken to prevent radioactive materials from releasing into the environment.

For instance, the emergency core cooling system (ECCS) and the reactor containment vessel are provided to mitigate the influence of the loss of accident coolant (LOCA), assuming the guillotine break of the piping of the primary coolant system in the Japanese nuclear power station. These facilities are designed and fabricated with sufficient margin of performance and mechanical strength and these functions of these facilities are kept to be performed by careful inspection and maintenance after starting the commercial operation.

Concept of Defense in Depth

Occurrence of incidents

Prevention of abnormal incidents
(Safety measures of level 1)

- Design with suitable margin
- Perfect quality assurance
- Fail-safe system
- Interlock system, etc.

Prevention of development of abnormal incidents
Prevention of development to accidents
(Safety measures of level 2)

- Detector to find incidents early
- Activation of safety protection system at abnormal incidents etc.

Prevention of radioactive materials release
(Safety measures of level 3)

- ECCS (Emergency core cooling system)
- Reactor containment vessel, etc.

〔Source: White Paper on Nuclear Safety in 1991, edited by Japan Atomic Energy Safety Commission〕

(2) Confinement of Radioactive Materials

In general, a nuclear reactor plant is providing with multi barriers to prevent radioactive materials produced in the reactor from releasing to the environment.

First barrier: Fuel pellet	The pellets of uranium dioxide (UO_2) being the fuel element of a light water reactor has a superior retentive capability of fission products (FP) and most of FP produced in the pellets is confined in the pellets.
Second barrier: Fuel cladding	The fuel cladding enclosing the fuel pellets is the barrier to confine FP released from the fuel pellets.
Third barrier: Reactor coolant pressure boundary	The reactor coolant pressure boundary is the piping and the equipments which is filled with the reactor coolant and which is in the same pressure as the reactor. This boundary forms the pressure barrier during normal operation and under severe condition at transients and accidents and also is the barrier of FP release next to the fuel cladding.
Fourth barrier: Containment vessel boundary	The containment vessel boundary is the pressure barrier after loss of coolant accident. This boundary consists of the containment vessel and the piping penetrating the containment vessel which is designed to form a final barrier against releasing of radioactive materials in principle.
Fifth barrier: Reactor building	The reactor building prevents FP from releasing to the environment outside the plant.

〔The reactor pressure boundary and the containment vessel boundary for a light water reactor are defined in the electric technology guide book, JEAG 4602-1986, published by the Japan Electric Association〕

The following drawing shows the concept of confinement of radioactive materials for PWR.

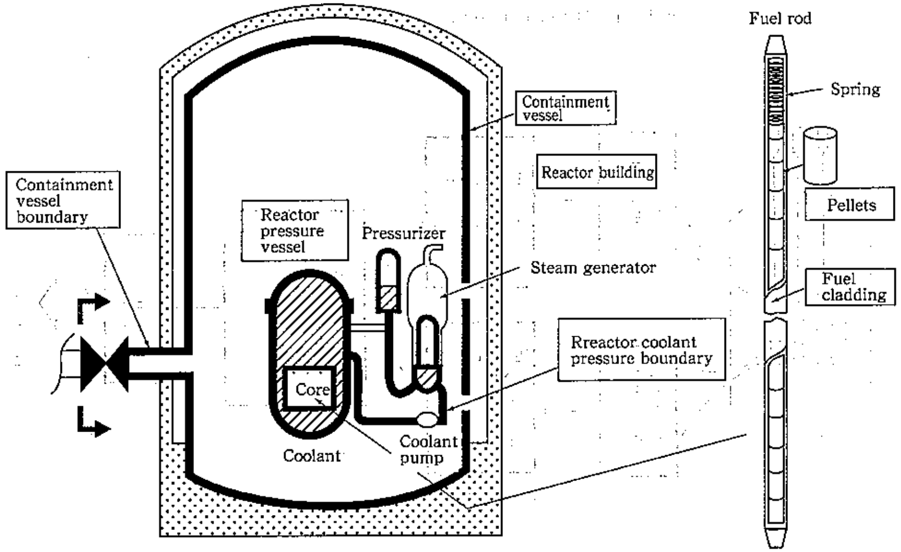
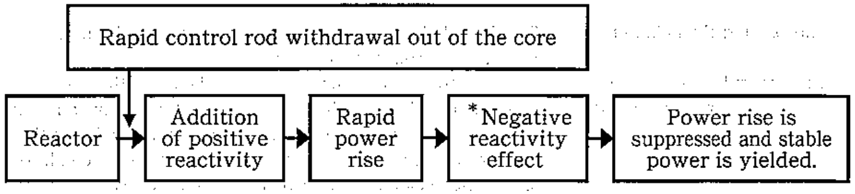


Fig. 1 Conceptual Drawing of Confinement of Radioactive Materials (for PWR)

(3) Self Control Capability of a Reactor

A light water reactor has inherent self-control capability by feedback of negative reactivity against power increase. As shown in the following drawing, a reactor has the capability of self control limiting the increase of the reactor power, if the control rod is rapidly withdrawn out of the core and the positive reactivity is rapidly added.



* Negative reactivity effect : There are abnormal withdrawal, projection and drop of the control rods as the examples of the incidents of rapid addition of positive reactivity in a light water reactor. When the reactor power increases by these incidents, the temperature of the fuel rises and a resonance absorption of neutron by uranium increases. As the result, Doppler's effect which decrease the reactivity occurs. As the temperature of the moderator also rises, it's density lowers or the moderating rate of neutron is reduced by the effect of the void generated by boiling. It is called negative reactivity effect or self-control capability that when the power increases, the reactivity is naturally reduced.

〔Source: Nuclear Power Generation hand Book (1982) edited by the Nuclear Power generation Section in the Public-service Undertaking Dept., Agency of Natural Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-Sha〕

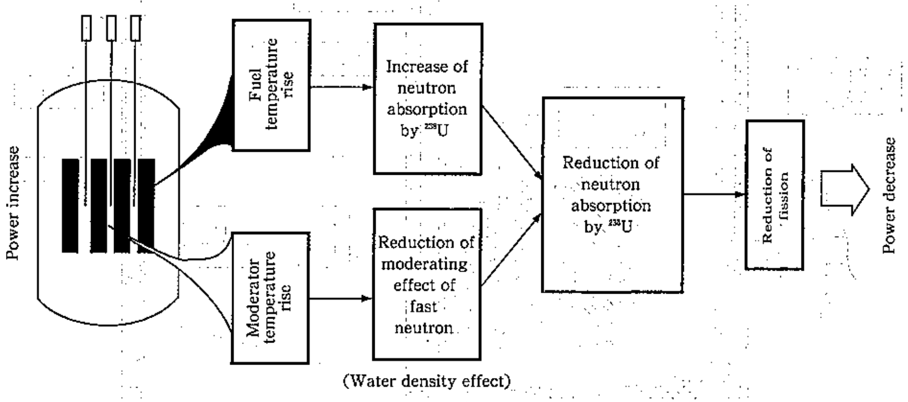


Fig. 2 Self-Control Capability

(4) Emergency Core Cooling System (ECCS) for LWR

Emergency core cooling system (ECCS) which is one of the engineered safety facilities injects the cooling water (boric acid for PWR) into the reactor at loss accident of the primary coolant to prevent the fuel from deteriorating by excessive heating and from reacting the cladding (zirconium) with water. The containment spray system sprays the cooling water into the containment vessel and decreases the internal pressure and takes in the floating iodine in the gas not to release from the containment. Strictly speaking, the containment spray system is not included in the ECCS.

The pumps and piping in the ECCS is designed with multiplicity and diversity. The drive power for these pumps can be supplied from the emergency power system. Therefore, the ECCS can perform their functions and ensure the safety of the reactor at all assumed accidents.

The ECCS is designed to be tested their functions periodically during plant operation.

(a) ECCS for BWR

The ECCS network for BWR 5 type is shown in **Fig. 3**. The purpose and the function of the ECCS are following.

1) Low Pressure Core Spray System

The low pressure core spray system has a function to spray the cooling water above the core in conjunction with the low pressure injection system and the high pressure core spray system at large break accidents. At small/medium break accidents in which the reactor pressure does not decrease rapidly, first, the automatic depressurization system forces the reactor to depressurize and after that the low pressure core spray system can inject the cooling water into the reactor. The low pressure core spray system sprays the suppression pool water above the fuel assemblies through the spray nozzle of the spray headers attached the upper shroud and cools the fuel.

2) Low Pressure Core Injection system

The low pressure core injection system is one of some operation modes of the residual heat removal system. The low pressure core injection system has a function to cool the fuel in conjunction with the low pressure core spray system and the high pressure core spray system at large break accidents. At small/medium break accidents, the low pressure core injection system also has the function to cool the fuel in conjunction with the automatic depressurization system. The low pressure core injection system can directly inject the suppression pool water inside the core shroud and cool the fuel by flooding the fuel to the height of two third at the break of the piping of the recirculation system.

3) High Pressure Core Spray System

The high pressure core spray system has a function to inject the cooling water into the reactor over all pressure range at assumed accident of piping break. At large break accidents, the high pressure core spray system cools the fuel in conjunction with the low pressure core spray system and the low pressure injection system and at small/medium break, has the function to cool the fuel only. The high pressure core spray system sprays the cooling water above the fuel assemblies through the spray nozzle of the spray headers attached the upper shroud and cools the fuel.

4) Automatic Depressurization System

The automatic depressurization system has the function to cool the fuel in conjunction with the low pressure core spray system and the low pressure injection system when the high pressure core spray system does not function at small/medium break accidents.

5) Residual Heat Removal system

The residual heat removal system has five operation modes which are independent functionally. Two other modes are described here.

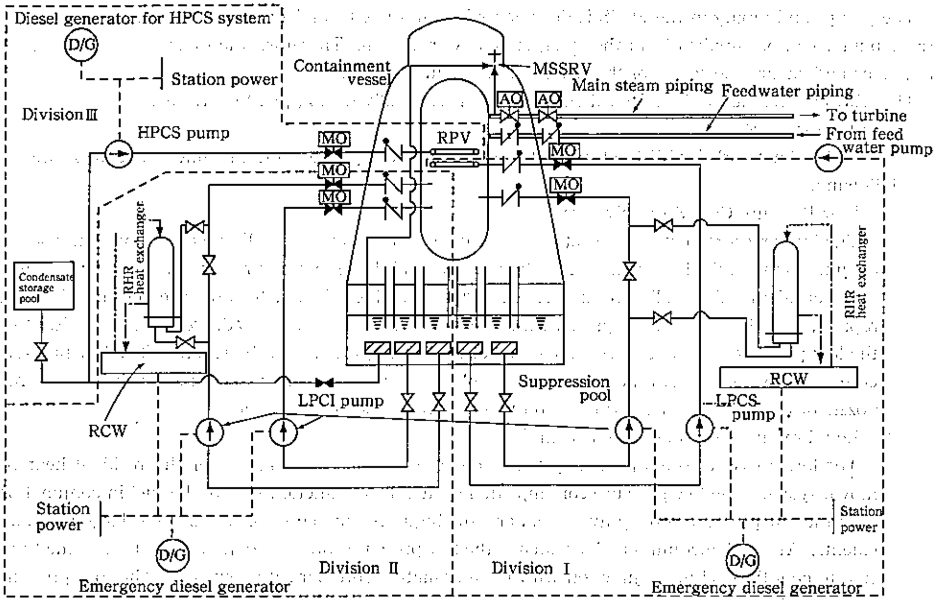
(i) Suppression pool water cooling system

When the temperature of the suppression pool water is increased, the suppression water cooling system takes in the suppression water and cools it by the heat exchanger and return it to the suppression pool.

(ii) Containment Spray Cooling System

At loss accident of the primary coolant, the containment spray cooling system sprays the suppression pool water into the containment vessel to condense a steam and decrease the inner pressure of the containment vessel.

Fig. 3 Network of ECCS (BWR 5 type, 1100MWe class)



RCW: Reactor building closed cooling water system
RPV: Reactor pressure vessel
MSSRV: Main steam safety relief valve
HPCS: High pressure core cooling system
LPCS: Low pressure core cooling system
RHR: Residual heat removal system

(b) ECCS for PWR

The ECCS network for PWR type is shown in **Fig. 4**. The purpose and the function of the ECCS are following.

1) Accumulator Injection System

At loss accident of the primary coolant, the accumulator injection system injects the water with boric acid into the reactor with the reactor pressure decreasing and keeps the reactor subcritial and prevents the fuel from melting due to delay of the water injection by the high and low pressure injection system.

2) Safety Injection System

(i) High Pressure Injection System

At loss accident of the primary coolant, the high pressure injection system injects the water with boric acid stored in the refueling water storage tank into the reactor vessel through the piping of the primary coolant and ensures to cool the fuel and to keep the core subcritical. The charging pump connected the primary coolant loop can increase the amount of the injection water.

(ii) Low Pressure Injection System

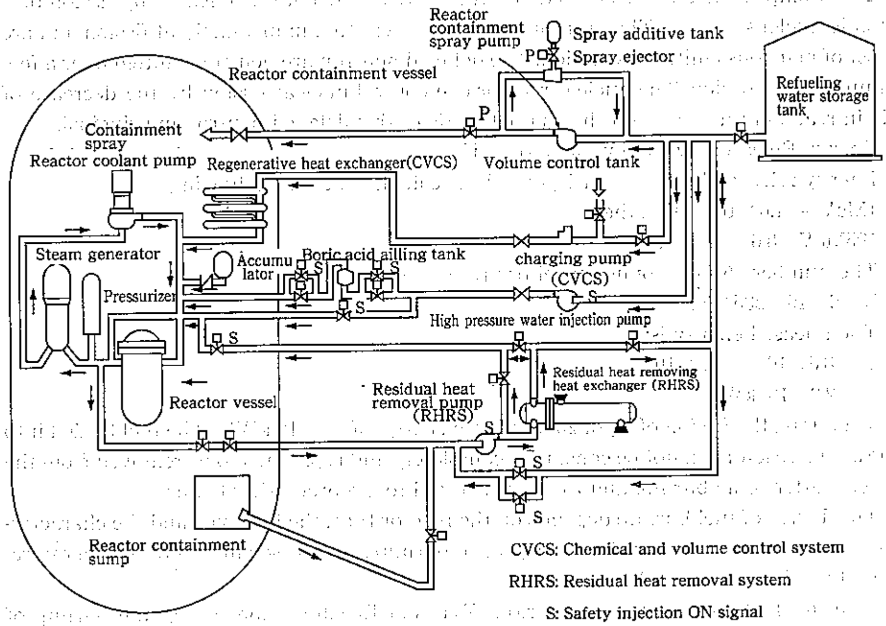
At loss accident of the primary coolant, the low pressure injection system injects the water with boric acid stored in the refueling water storage tank into the reactor vessel through the piping of the primary coolant and ensures to cool the fuel and to keep the core subcritical. After all water with boric acid stored in the refueling water storage tank being injected, the water in the sump installed at the bottom of the containment vessel is taken by the residual heat removal pumps and is cooled by the residual heat removal heat exchanger and is injected into the reactor vessel. Therefore, the necessary water source is ensured continuously.

The high pressure injection system can also inject the sump water into the reactor vessel through the bypass line from the outlet of the RHR heat exchanger. The RHR system can be used to remove decay heat during the reactor shutdown and is in standby during normal operation as the low pressure injection system. Both functions are not required at the same time and there is no problem on safety.

(iii) Containment Spray System

At loss accident of the primary coolant, the containment spray system injects the water with boric acid stored in the refueling water storage tank into the containment vessel and decrease the inner pressure rapidly. At the same time, the chemical additive in the tank is added into the water with boric acid and removes iodine in the gas of the containment vessel. After all water with boric acid stored in the refueling water storage tank being injected, the water in the sump installed at the bottom of the containment vessel is taken by the containment spray pumps and is injected into the containment vessel again.

Fig. 4 Network of ECCS for PWR (1100MWe class)



CVCS: Chemical and volume control system
RHRS: Residual heat removal system
S: Safety injection ON signal
P: Containment spray pump ON signal

13-4 Physics of Nuclear Reactor

(1) Nuclear Fission Reaction

(a) Reaction Equation

$$^{235}_{92}U+^{1}_{0}n \longrightarrow ^{x}_{a}A+^{y}_{b}B+(2\sim3)^{1}_{0}n+(\text{energy})$$

As the result of the nucleus fission of ^{235}U, 2 fission products, a few neutrons are produced and some energy is released. The nuclear reactor makes use of this released energy.

(b) Total Usable Energy per Fission of an Atomic Nucleus

In units of MeV

Energy type	^{233}U	^{235}U	^{239}Pu
Kinetic energy of fission fragment	163	168	172
Total energy of gamma ray	14	14	14
Total energy of fission neutron	5	5	5.8
Total energy of beta ray	8	8	8
Total	190	195	200
Number of prompt fission neutrons	2.51	2.47	2.91
Ratio of delayed neutrons	0.0026	0.0064	0.0021

2.47 prompt neutrons are emitted and the energy of 195MeV is released by fission of a atomic nucleus of ^{235}U. The prompt neutrons are emitted immediately at fission and are most of neutrons emitted by fission. The delayed neutron are neutron emitted over a few minutes after fission. The nuclear reactor can control nuclear fission by the decrease of chain reaction rate based on the characteristic of this delayed neutron in principal.

(c) Energy Released by Fission of 1g of ^{235}U

Energy released by fission of 1g of ^{235}U is calculated as the following.

$1\text{MeV} = 1.6\times10^{-13}\,\text{W}\cdot\text{s}$, then:

$195\text{MeV}=8.6\times10^{-18}\,\text{kWh}$

The number (N) of atomic nuclei per 1g of ^{235}U:

$N=6\times10^{23}/235\fallingdotseq2.5\times10^{21}$

The released energy is:

$W=8.6\times10^{-18}\times2.5\times10^{21}$

$\quad=2.2\times10^{4}\,\text{kWh}$

Therefore, the fission of 1g of 235U release energy of 2.2×10^{4}kWh. The fuel loaded into the actual reactor can not be consumed completely and is planned to be removed from the reactor after some burnup and to be transferred to a reprocessing factory.

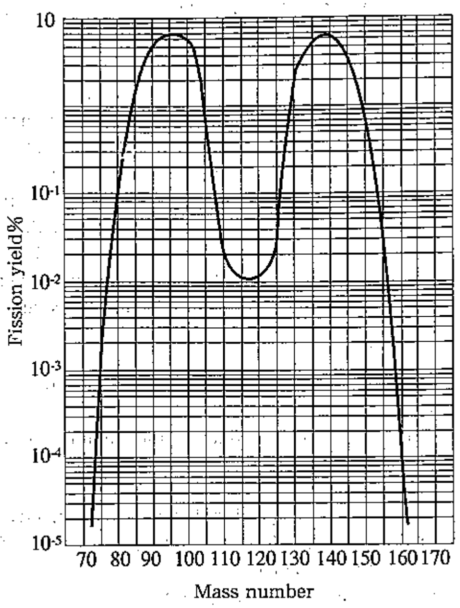
The degree of fuel burnup depends on the reactor type, the fuel type and the characteristics of the reactor. Generally, the degree of burnup is expressed in unit of the energy released per 1ton of the fuel (MWD/t).

Refer to "13-2 Specifications of Various Types of Reactors" concerning the burnup of various reactors.

(2) Fission Products and Their Decay Heat

(a) Fission Yield (%) of ^{235}U

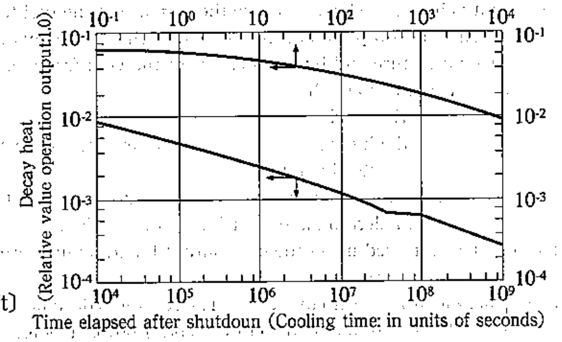
The range of the mass number of the fission products A and B is from 72 to 161. The range of atomic number is from 30 of Zn to 66 of Dy. The right drawing shows the fission yields of the fission products of ^{235}U.



(b) Major Fission Products

Near mass number of 95		Near mass number of 139	
Products	Half time	Products	Half time
$^{83}_{35}Br$	2.3 hours	$^{132}_{52}Te$	77.7 hours
$^{85}_{36}Kr$	10.8 years	$^{133}_{53}I$	20.3 hours
$^{91}_{38}Sr$	9.67 hours	$^{137}_{55}Cs$	30.0 years
$^{91}_{39}Y$	58.8 days	$^{130}_{56}Ba$	84 minutes
$^{95}_{40}Zr$	65.5 days	$^{153}_{62}Sm$	47.1 hours

(c) Decay Heat Curves of Fission Products (infinite irradiation)



〔Source: ANS-5.1, Oct, 1971-Draft〕

(3) Breeding Reaction Equation

$$^{238}U+^{1}_{0}n\rightarrow{}^{239}U\xrightarrow[(23.5\text{minutes})]{\beta}{}^{239}Np\xrightarrow[(2.35\text{days})]{\beta}{}^{239}Pu$$

$$^{232}Th+^{1}_{0}n\rightarrow{}^{233}Th\xrightarrow[(22.2\text{minutes})]{\beta}{}^{233}Pa\xrightarrow[(27\text{days})]{\beta}{}^{233}U$$

Note: The values enclosed in parentheses means half life.

The materials as ^{238}U or ^{232}Th do not undergo nuclear fission, but after these materials absorbed neutron and undergo twice β decay, these become converted to fissile materials of ^{239}Pu or ^{233}U.

A breeder reactor makes use of such a reaction and produce fissile material (such as ^{239}Pu or ^{233}U) greater than be consumed. But, in the conventional reactors (such as a thermal reactor), the amount of fissile material converted is less than be consumed.

13-5 Reactivity Change and Operation of Nuclear Reactor

(1) Effective Multiplication Factor

The nuclear reactor consists of the nuclear fuel, the moderator to decrease the energy of the neutron emitted by fission, and the neutron reflector surrounding the core. The control rod to be neutron absorption material is inserted or withdrawn to control the operation of the reactor.

It is assumed that the neutrons of N_1 are absorbed into the fuel. Most of the absorbed neutrons are absorbed into the fissile materials and a few prompt neutrons are emitted per fission. These neutron flux collide with the moderator and become the thermal neutron and diffuse in the core.

In this process, some of the neutrons are absorbed into the moderator or leak out of the core. The remaining neutrons N_2 is absorbed in the fuel as next thermal neutrons. The effective multiplication factor is defined as the ratio of these neutrons (N_1 and N_2).

$$K_{eff} = \frac{N_2}{N_1}$$

The condition, Keff equals 1, is called the critical condition and the chain reaction continues at $K_{eff} \geqq 1$.

The reactivity is defined as the amount of deviation from the critical condition.

$$\rho = \frac{K_{eff} - 1}{K_{eff}}$$

The core is designed with some excess reactivity to be $\rho > 0$. Therefore, the reactor is normally operated keeping $\rho = 0$ by controlling the position of the control rod.

(2) Reactivity Change

(a) Reactivity Change by Power

As the power of the reactor increases, the temperature of various parts of the core also increases and the reactivity changes. This is because the increase of the fuel temperature causes the changes of the degree of neutron absorption and the reactivity changes (generally decrease) by the increase of the moderator temperature and by the increase of the void fraction. Designating the initial reactivity by ρ_{ex}, reactivity is defined as follows,

$$\rho = \rho_{ex} + K_f t_f + K_m t_m + K_v v + \cdots\cdots$$

t_f, t_m, v: the increases of fuel temperature, moderator temperature, and void fraction from the steady state values

K_f, K_m, K_v: Doppler's coefficient (temperature coefficient of fuel), temperature coefficient of moderator, and void fraction coefficient

This can be expressed using the core output P and its increase ΔP as below.

$$\rho = \rho_{ex} + K_p\ (\Delta p/p)$$

The K_p is called the power coefficient. The reactor is designed for K_p to be negative. The outline values such as the reactivity coefficient of typical power reactors are shown in the next table.

	K_f (10^{-5}/℃)	K_m (10^{-4}/℃)	K_v (10^{-4}/%)	K_p ($10^{-3}/\Delta p/p$)	Excess reactivity (10^{-2})	Reactivity of control rod (10^{-2})
PWR	−2.3∼−5.6	0∼−7.8	+6∼−25	−25	+14	+7+20*
BWR	−1.5	−	−8	−45	+14	+18
HWR	−1.6	+2	∼0	−8.5	−	−

* Reactivity by chemical shim

[Source: Mechanical Engineers' Handbook, edited by the Japan Society of Mechanical Engineers, Part B6 (1986),135]

(b) Reactivity Change by Buildup of Fission Products

Some of the fission products have large absorption cross section and high fission yields. These materials cause negative reactivity effect. The important nuclides of these products in operation are Xe-135 and Sm-149. Xe-135 which is dependent on the power, is particularly important, because of Sm-149 is not dependent on the power.

The concentration of Xe-135 reaches to a equilibrium state after the reactor has been operated long time at a constant power. If the reactor is shut down after this long period operation, the concentration of Xe-135 become greater than the equilibrium value 8∼9 hours after shutdown by the decay of I-135 being the parents nuclide of Xe-135 and then decreases after that. Therefore, when restarting the reactor in a few hours after shutdown, the reactivity of the core has been decreased by the negative reactivity effect of Xe-135.

(c) Reactivity Change by Fuel Burnup

Burnup of the fuel brings the following phenomena.

1) Consumption of ^{235}U (decrease of reactivity)
2) Production of Pu, etc. (reactivity increase by buildup of fissile ^{239}Pu and ^{241}Pu)
3) Buildup of fission products (F.P.) (decrease of reactivity)
4) Decrease of burnable poison (increase of reactivity)

The reactivity of the core decreases in accordance with burnup as the summation of these four effects.

(3) Control of Operation

(a) Reactivity Control by Control Rod

The reactivity control by the control rod is used to control large reactivity and performs the following function.

1) To keep $K_{eff} < 1$ with margin sufficient to compensate all excess reactivity during reactor shutdown.
2) To shut down the reactor by inserting all control rods into the reactor in the short time at the upset condition
3) To control the reactivity at big power fluctuation
4) To compensate the decrease of reactivity by burnup
5) To adjust the power distribution in the core as uniform as possible

(b) Reactivity Control by Control of the Recirculation Flow

If the recirculation flow rate is increased at the steady state operation with a constant power and a constant recirculation flow, the reactor power will be increased by being added the positive reactivity of the void effect because of the reduction of the void fraction. If the recirculation flow rate is decreased, the power will be decreased by the reverse effect (the increase of the void fraction and the negative reactivity).

BWR can control the power range from 60% of the rated to 100% by the control of the recirculation flow rate without moving the control rod. Therefore, this control way is used to respond the power control at load fluctuation, etc in BWR. This control way is easier than moving the control rod and limit the change of the power distribution small and has a merit of a small impact to the fuel.

(c) Reactivity Control by Concentration of Boric Acid

The boric acid is a material having large neutron absorbing effect and it's concentration change can be used to control the reactivity of the nuclear core. In PWR, a boric acid is dissolved into the primary coolant and the reactivity of the core is controlled adjusting the concentration of the boric acid in the primary coolant. The adjustment of the concentration of boric acid is done by adding the purified water (the dilution of the boron concentration) or by adding the boric acid of the high concentration (the addition of the boron).

This control way is used to control the following slow reactivity fluctuation.

1) Reactivity change by the temperature change of the primary coolant from cold condition to hot condition
2) Reactivity change by the concentration change of Xe and Sm
3) Reactivity change by the fuel burnup

For instance, when compensating the reactivity change resulting from the burnup by the adjustment of the boron concentration, the concentration of the boron is decreased corresponding to the reduction of the reactivity.

13-6 Coolants

Coolants \ Properties	Density (kg/m³)	Melting point (℃)	Boiling point at 1 atm (℃)	Specific heat (kJ/kgK)	Thermal conductivity (W/mK)	Absorption cross section (b∗)
Light water (6.93MPa [gage]288℃)	736	0	100	5.40	0.565	0.66
H_2O (15.5MPa [gage]307℃)	712			5.65	0.544	
Saturated steam H_2O	46.2 (300℃)	—	—	5.99 (300℃)	0.0615 (300℃)	0.66
Heavy water D_2O	795 (316℃)	3.8	101	7.03 (316℃)	0.490 (316℃)	0.0011
Helium He (1.03MPa [abs])	0.093 (316℃)	—	—	5.228 (316℃)	0.155	0.0070
Sodium Na	831 (500℃)	97.8	883	1.2621 (500℃)	67 (500℃)	0.525
Carbon dioxide CO_2	1.976 (0℃,1atm)	—	—	0.850 (20℃)	1.51×10^{-2} (20℃)	0.0041

∗1b (barns) $=10^{-28}$m²

13-7 Moderators

Property Comparison of Main Moderator Materials

Properties	Light water	Heavy water 99.75 (%) D_2O	Beryllium	Beryllium oxide	Graphite
Atomic weight or molecular weight	18.0	20.0	9.01	25.0	12.0
Density [kg/m³]	1.00×10^3	1.10×10^3	1.84×10^3	2.80×10^3	1.62×10^3
N [cm⁻³]	3.3×10^{22}	3.3×10^{22}	1.2×10^{23}	6.7×10^{22}	8.1×10^{22}
Scattering cross section (Epithermal neutrons) [b]	49	10.5	6.0	9.8	4.8
Absorption cross section (Thermal neutrons) [b]	0.66	0.0026	0.009	0.0092	0.0045
Macroscopic scattering cross section Σ_s(Epithermal neutrons) [cm⁻¹]	1.64	0.35	0.74	0.66	0.39
Macroscopic absorption cross section Σ_a(Thermal neutrons) [cm⁻¹]	0.022	0.000085	0.0011	0.00062	0.00037
Average logarithmic attenuation factor of energy produced in one-time collision ξ	0.93	0.51	0.206	0.17	0.158
Moderating power $\xi\Sigma s$ [cm⁻¹]	1.5	0.18	0.16	0.11	0.063
Moderating ratio $\xi\Sigma s/\Sigma a$	70	2,100	150	180	170
Diffusion Constant [cm]	0.18	0.85	0.61	0.56	0.92
Diffusion length [cm]	2.88	100	23.6	30	50
Fermi age [cm²]	33	120	98	110	350
Travel [cm]	6.4	101	26	32	54

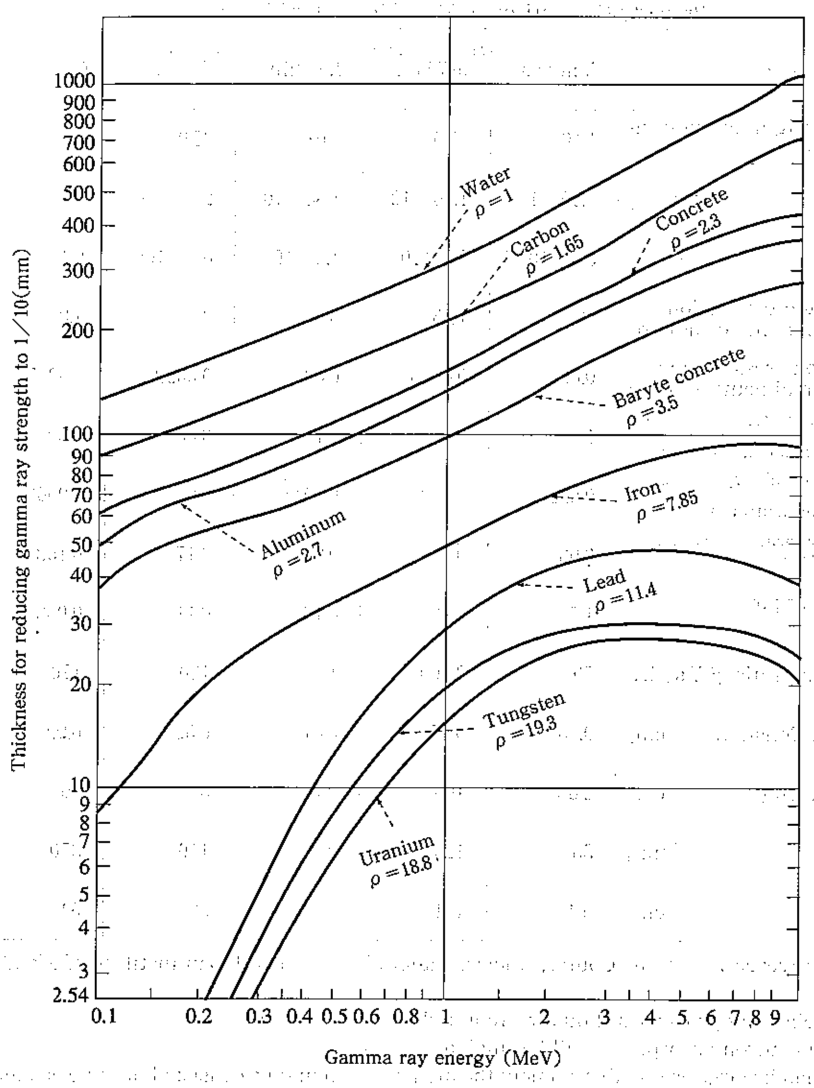
〔Source: New Metallic Course, Nuclear Material(1962), The Japan Institute of Metals 〕

(1) The following properties should be required as the moderator.
- (a) The neutron absorption shall be small as possible.
- (b) ξ shall be large as possible, namely the moderator should be consisted of some elements with small atomic weight.
- (c) Moderating power and moderating ratio shall be large as possible.

(2) Function of the reflector

The function of the reflector is to return neutrons, which are produced by fission in a reactor, into a reactor by scattering in order to prevents them from leaking out of a reactor and to enhance neutrons economics. The properties of reflector is required as same as moderator so that the material of a moderator is also used as a reflector in a thermal reactor.

13-8 Shielding Materials



(Note) 1. These curves show the thickness required to reduce the strength of gamma rays to 1/10, which is called 1/10 value layer. These values are based on the assumption that gamma rays is irradiating in linear flux.
2. "ρ" in this figure means specific gravity of each material.
3. Half thickness is obtained by multiplying the value shown in this diagram by $\log_{10}2=0.3010$

〔Source: Nuclear Power Generation Hand book (1982 Edition) edited by the Nuclear Power Generation Section in the Public -Service Undertaking Dept., Agency of Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-Sha〕

13-9 Materials for Neutron Absorption

Properties of Potential Materials for Neutron Absorption

Element	Atomic number	Density		Melting point (℃)	Isotope with large thermal neutron absorption cross section	Natural abundance of isotope in the left column (%)	Thermal neutron absorption cross section 〔b〕	Mecroscopic thermal neutron absorption cross section 〔cm^{-1}〕	Neutron absorbing reaction
		g/cc	10^{22}/cc						
Boron	5	2.3	14.0	2,300	Natural 10	(100) 20	750 3,800	97.0	n • α
Silver	47	10.5	5.9	960	Natural 107 109	(100) 51.35 48.65	63 31 87	3.7	n • γ
Cadmium	48	8.6	4.6	321	Natural 113	(100) 12.26	2,450 20,000	113.6	n • γ
Indium	49	7.3	3.8	156	Natural 113 115	(100) 4.23 95.77	196 58 207	7.5	n • γ
Gadrium	64	7.9	3.1	1,350	Natural 155 157	(100) 14.73 15.68	46,000 60,000 240,000	1400	n • γ
Hafnium	72	13.09	4.4	2,222	Natural 176 177 178 179 180	(100) 5.15 18.39 27.08 13.78 35.44	105 15 380 75 65 14	4.6	n • γ
Tantalum	73	16.65	5.5	2,996	181	100	21.3	1.18	n • γ

＊1b (barn) $=10^{-28}m^2$

Comparison of Main Neutron Absorbing Materials

Material	Contents of major neutron poisons	Relative absorbing value with respect to hafnium
Stainless steel with boron	3.0w/o^{10}B	1.13
〃 〃	2.0w/o^{10}B	1.08
Hafnium	—	1.00
Silver-indium-cadmium alloy	80w/oAg, 15w/oIn, 5w/oCd	1.03
Silver-cadmium alloy	70w/oAg, 30w/oCd	0.92
Silver	—	0.88
Cadmium	—	0.88
Tantalum	—	0.71
Zircaloy 2 (Reference)	—	0.049

〔Source: Special Metal Materials by Ryouseki Mishima, Corona Publishing Co. Ltd. (1971)〕

13-10 Main Materials of Reactor

Major Materials of BWR and PWR

Item		Material	Remarks
Reactor pressure vessel	Body	Low alloy steel $\left(\frac{3}{4}\mathrm{Ni}-\frac{1}{2}\mathrm{Mo}-\mathrm{Cr}-\mathrm{V}\text{ or }\mathrm{Mn}-\frac{1}{2}\mathrm{Mo}-\frac{1}{2}\mathrm{Ni}\right)$	SFVQ1A or SQV2A
	Nozzle	Low alloy steel $\left(\frac{3}{4}\mathrm{Ni}-\frac{1}{2}\mathrm{Mo}-\mathrm{Cr}-\mathrm{V}\right)$	SFVQ1A
	Bolt	Alloy steel rod $\left(2\,\mathrm{Ni}-\frac{3}{4}\mathrm{Cr}-\frac{1}{3}\mathrm{Mo}\right)$	SNB24
Core internals		18Cr-8Ni, 18Cr-12Ni-2.5Mo, 72Ni-14Cr-6Fe	SUS304, 316 NCF600

13-11 Outline of BWR

(1) Specification of Main Parameters for BWR Standard Plant

Item	Sub-item	Specifications				
		Main parameters	500MWclass	800MWclass	1100MWclass	1350MWclass
Core & Fuel	Core	Core thermal output (MWt)	1.593	2,436	3,293	3,926
		Core flow (t/h)	23×10^3	36×10^3	48×10^3	52×10^3
		Steam pressure (MPa[gage])	6.93	6.93	6.93	7.07
		Steam temperature (℃)	286	286	286	287
		Number of coolant recirculation loops	2	2	2	—
	Fuel	Number of fuel assemblies	368	560	764	872
		Fuel rod array	8lines×8rows 9lines×9rows	8lines×8rows 9lines×9rows	8lines×8rows 9lines×9rows	8lines×8rows 9lines×9rows
Reactor	Reactor pressure vessel	Vessel I.D. (m)	4.7	5.6	6.4	7.1
		Vessel height (m)	21	22	22	21
		Maximum operating pressure (MPa[gage])	8.62	8.62	8.62	8.62
		Maximum operating temperature (℃)	302	302	302	302
	Steam separator	Number	108	163	225	349
	Steam dryer	Number of units	1	1	1	1
	Jet pump	Number	16	20	20	10 (Internal pump)
Reactivity control system	Control rod	Number	89	137	185	205
	Control rod drive system	Number of CRD	89	137	185	205
ECCS	L.P. core spray system	System flow (t/h)	744	1,050	1,440	—
		Number of pumps	2	1	1	—
	L.P. core injection system	System flow (t/h)	1,100	1,140	1,690	950
		Number of pumps	4	3	3	3
	H.P. core spray system	System flow (t/h)	681	320～1,050	350～1,580	180～730
		Number of pumps	1	1	1	2
	Automatic depressurization system	Number of valves	4	6	7	8
		Valve capacity (t/h) Maximum operating pressure (MPa[gage])	375 (Reactor pressure 7.78MPa [gage])	375 (Reactor pressure 7.78MPa [gage])	375 (Reactor pressure 7.78MPa [gage])	380 (Reactor pressure 7.92MPa [gage])
Reactor containment	Reactor containment	Type	MARK－I	Improved MARK-I	Improved MARK-I and Improved MARK-II	Reinforced concrete integrated with building
	Containment spray system	Number of systems	2	2	2	2

(2) Assembly of the Reactor and Core Internals for BWR

The principal reactor for BWR consists of the reactor pressure vessel (RPV), the core internals, the fuel, the control rods, and its drive system.

The RPV contains and supports the core fuel, and also contains the jet pumps. In the RPV, the flow path necessary for the coolant to flow through the core fuel, the flow path necessary for steam - water mixture out of the core to flow and the flow path for water and steam separated by the steam separator to flow are formed by some of reactor core internals.

The core fuel is enclosed inside the core shroud which isolates the upward flow of the coolant in the core and the downward flow of the coolant in the annulus between the RPV wall and the core shroud. All fuel assemblies in the core are respectively mounted on the fuel support mounted on the control rod guide tube.

Each control rod guide tube supports the weight of 4 fuel assemblies with one fuel support and is supported by the CRD housing penetrating the wall of the RPV bottom. The core support plate has the function to horizontally position the control rod guide tube at the top end. The top guide attached to the inside wall of the upper portion of the core shroud also has the function to support the top of the fuel assemblies horizontally.

One control rod is arranged among 4 fuel assemblies and is inserted into the core from the bottom of the core. The control rod is connected to the control rod drive (CRD) by the coupling device and the CRD is encased in the CRD housing which is welded to the RPV lower head and is fixed to the flange of the bottom of the housing.

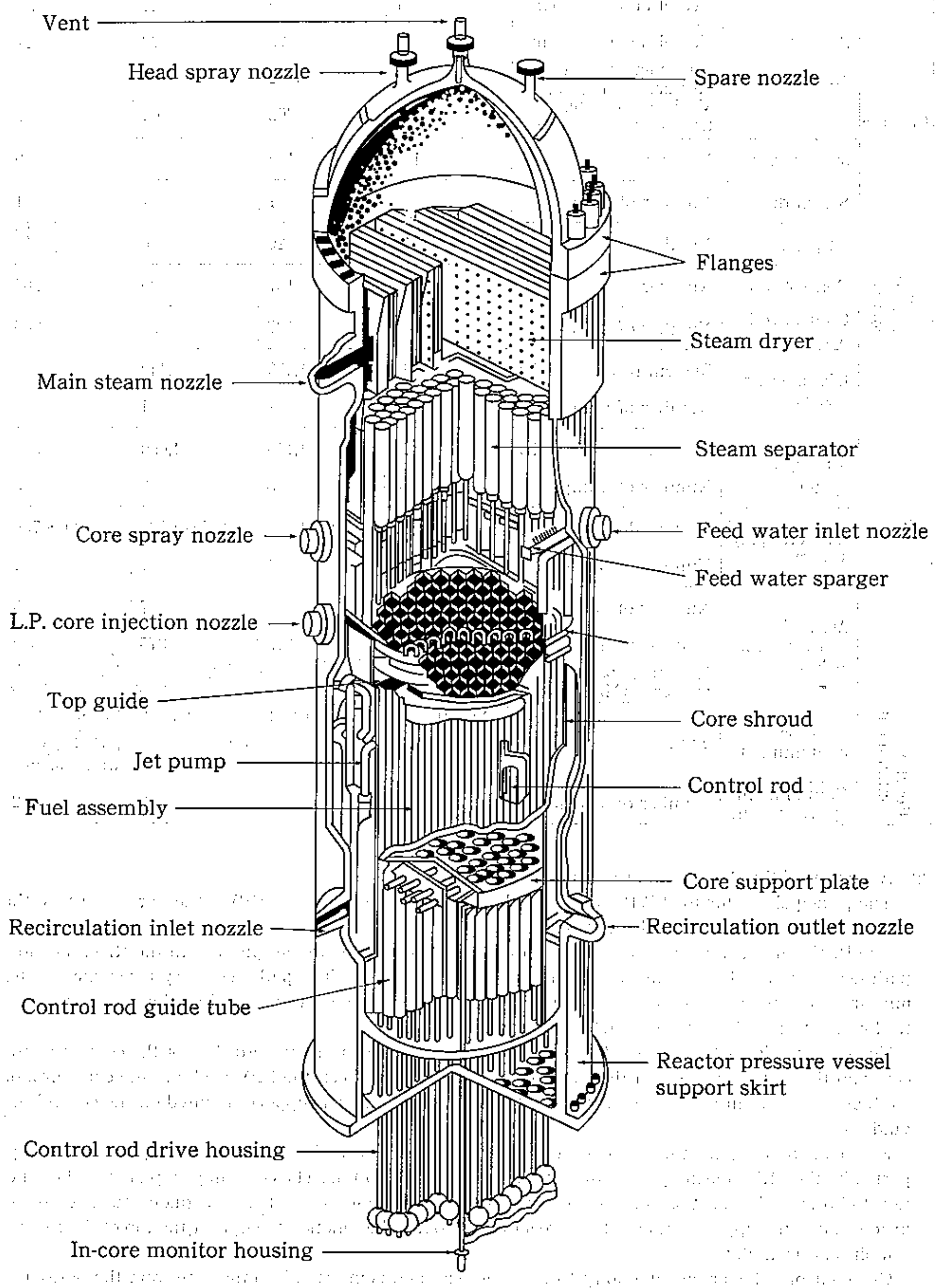


Fig. 1 Assembly of RPV and Reactor Core Internals for BWR

(3) Control Rod and Control Rod Drive for BWR

The control rod has the crucified blade to move up and down in gap formed by four fuel assemblies. The neutron absorber of the control rod is boron carbide and/or hafnium. There are a few types of the control rod assembly which uses boron carbide, hafnium and a combination of boron carbide and hafnium (Refer to the following drawing about the control rod with boron carbide).

The velocity limiter with a umbrella shape is attached to the lower end of the control rod to limit the addition rate of the positive reactivity at the control rod drop accident.

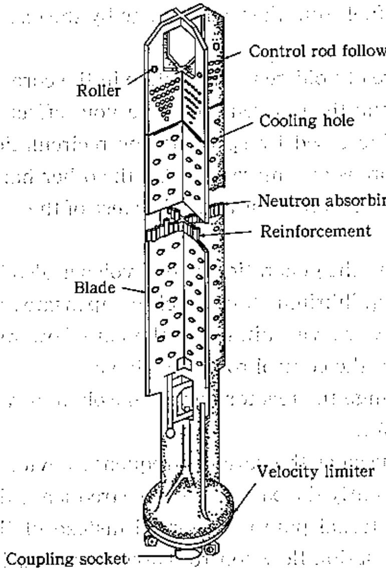


Fig. 2 Assembly of the Control Rod for BWR

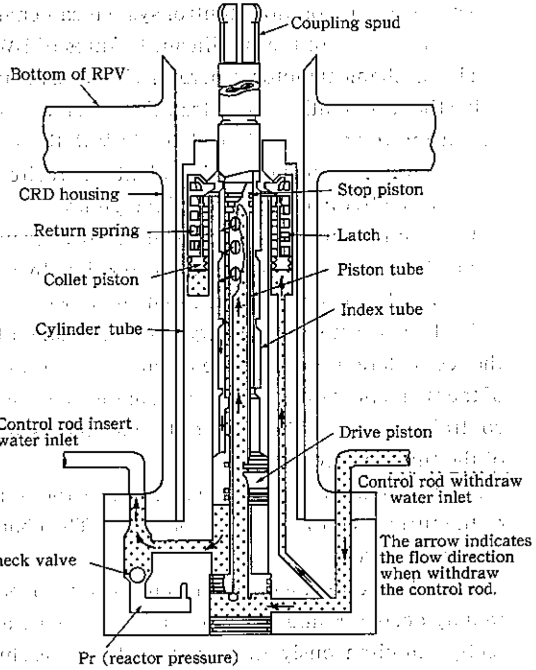


Fig. 3 Sectional Drawing of CRD for BWR

[Source : Nuclear Power generation Hand book(1991) edited by the Nuclear Power Generation Section in the Public Service Undertaking Dept., Agency of Natural Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-sha]

(4) Power Control for BWR

The reactor power is controlled by either of the following two methods :

(a) Changing the position of the control rods

(b) Changing the reactor core flow-rate

The method of (a) is to control the reactor power by changing the core reactivity by changing the position of the control rods manually from the main control room. The rod block monitor system is provided to protect the fuel from thermal damage by the excess withdrawal of the control rods.

The method of (b) is to make use of the change of void generation state in the core resulting from the variation of the core flow rate and the inherent negative void effect of BWR. For example, when the core flow rate is increased by speeding the recirculation pump up, the sweeping rate of void out of the core is also increased. On the other hand, the void ratio in the core decreases and the positive reactivity is added because of the generation rate of void does not change.

By this effect, the reactor power is increased and the generation rate of voids is also increased and the reactor power reaches to some equilibrium state which compensates an excess reactivity added temporally. The new power level suitable to the core flow rate can be achieved without changing the position of the control rods like above.

This recirculation flow control system can change the reactor power sharply and rapidly. This is one of the significant features of BWR.

The mechanical motor-generator (M/G) set is used as the variable frequency device to drive the recirculation pump traditionally, but recently the passive variable frequency device using thyristor is adopted. In ABWR, the internal pump is adopted instead of the recirculation pump and in other plant, the recirculation flow control valve was used instead of the frequency control of the pump.

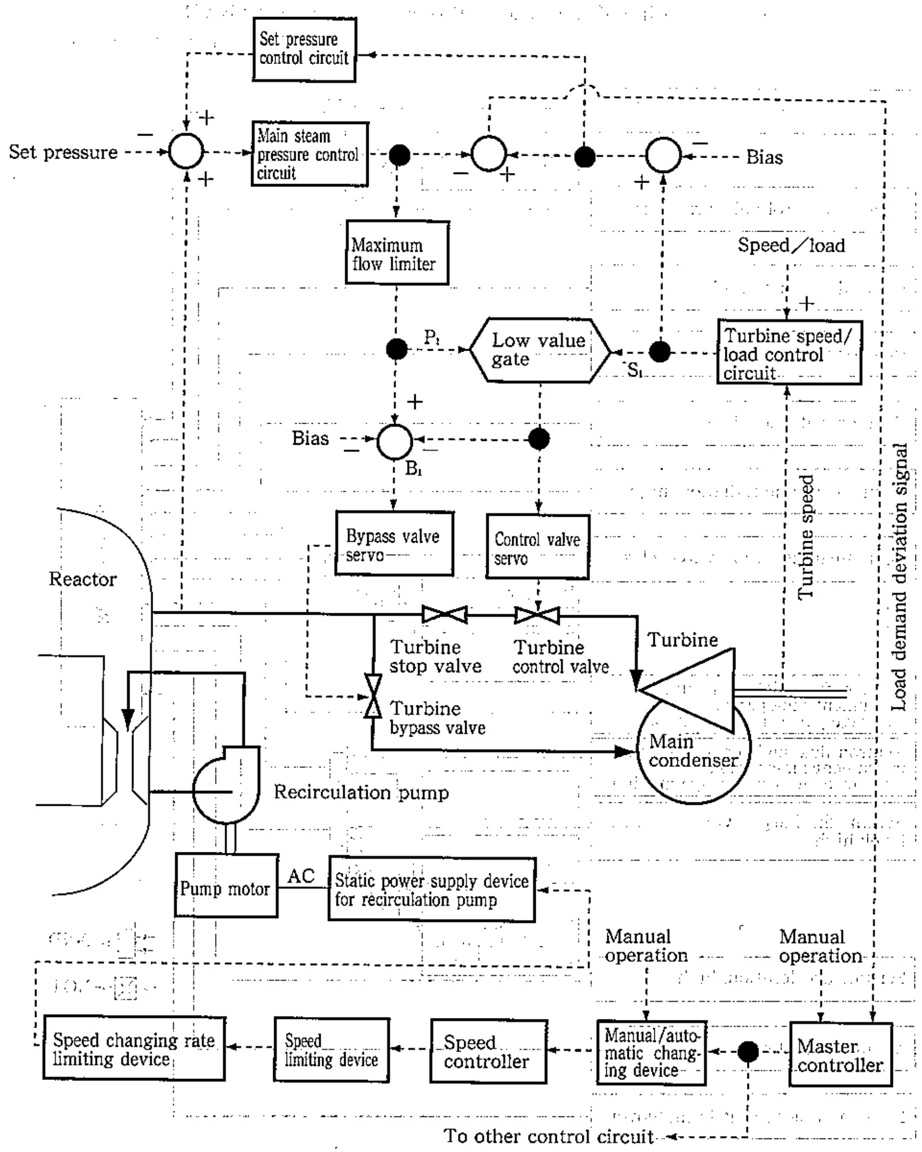
The main steam pressure constant control system is adopted as the control method of the turbine output. This method is possible by setting the input signal S1 to low value gate by 10% greater than the input signal P1.

As the load set signal changes, the subsequent load demand deviation signal changes the recirculation flow and the reactor power is also changed. In accordance with change of the steam flow rate, the signal from the main steam pressure control circuit changes the control valve opening and keeps the steam pressure constant and then the steam flow rate of the turbine is controlled.

In order to improve the initial response, the function to temporally adjust the opening of the turbine control valve is provided. The changing rate of the turbine output is approximately 30% /min.

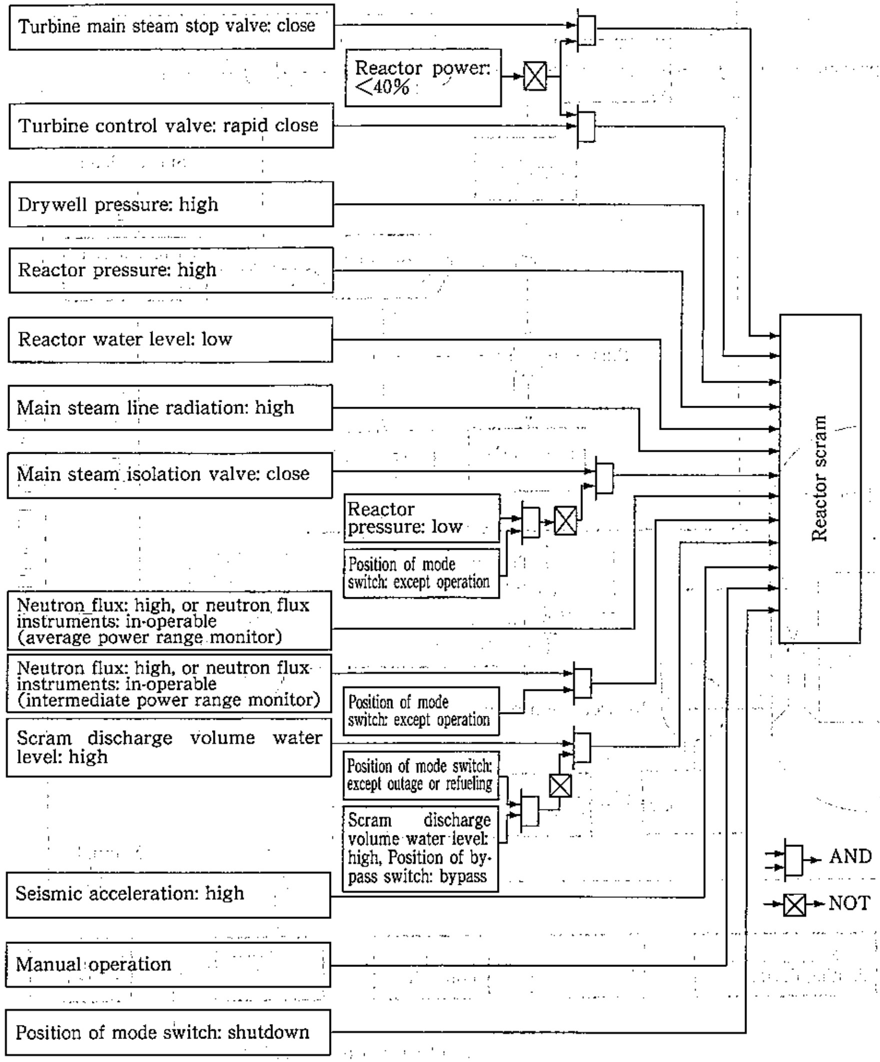
At load rejection incident, the output signal from the turbine speed/load control circuit rapidly decreases and passes the low value gate and make the control valve throttle directly. Simultaneously, the signal of B1 becomes high and opens the turbine bypass valve.

Fig. 4 Power Control Circuit Diagram for BWR Plant (1100MWe class)



(5) Reactor Protection System for BWR

Fig. 5 Outline of the Reactor Protection System for BWR
(BWR-5 1100MWe class)



13-12 Outline of Advanced BWR (ABWR)

(1) History of Advanced BWR Development

The development of ABWR had been performed in collaboration with the electric power companies and BWR plant fabricators as a part of the MITI third advanced and standardization program from 1981 to 1985. The activities were various area from the basic design to many cooperation study of main components etc. The application of ABWR to an actual plant has been decided after 1985.

The followings are the main targets of development.

(a) Improvement of safety and reliability
(b) Reduction of radioactive dose rate of workers
(c) Reduction of amount of radioactive waste
(d) Improvement of operability and maneuverability
(e) Improvement of economy

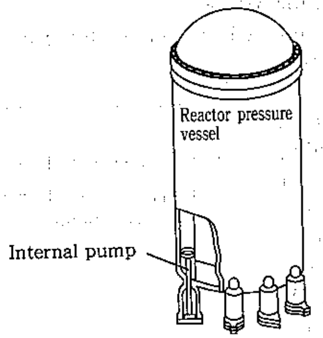
The results of development had been adopted in the actual design for Kasiwazaki Kariwa 6 and 7. Their constructions had been done under a series of license procedure. Kasiwazaki Kariwa 6, which became the first plant as ABWR, has started a commercial operation at August, 1996 and Kashiwazaki Kariwa 7 at July 1997.

(2) Features of ABWR

(a) Internal Pump (RIP)

Instead of the reactor recirculation pump which was located outside the reactor pressure vessel (RPV) in the existing BWR, the internal pump which is directly installed in the RPV has been adopted. As the result, the large size external piping of the recirculation system connected to RPV has been eliminated and the reactor core could be completely covered after the assumed design base accident (LOCA) and it's safety has been improved.

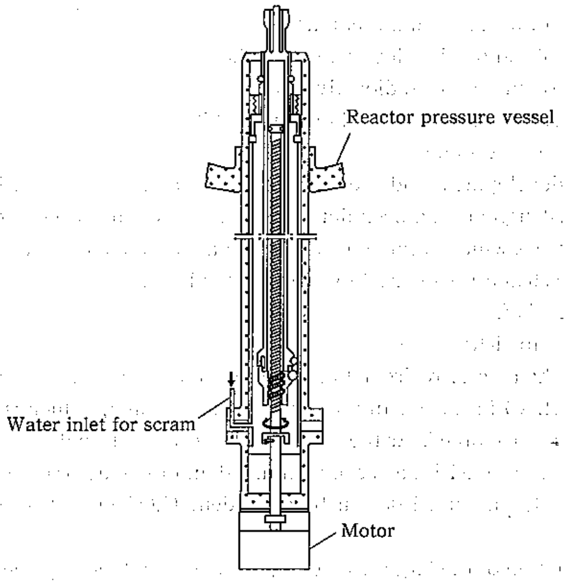
The elimination of the large size piping of the recirculation system brought the following important advantage. (a) Expectation of reduction of radiation exposure at the work in the containment vessel during an annual inspection (b) Reduction of the reactor building volume with the compact containment vessel.



(b) Advanced Control Rod Drive (FMCRD)

In the design of ABWR, advanced control rod drive (FMCRD) has been adopted. FMCRD has two drive mechanisms. The one is a traditional hydraulic drive for reactor scram and the other is a fine motion drive by a step motor for shim operation, which can adjust the position of the control rod finely.

The FMCRD is possible to move multiple control rods at the same time so that the plant startup period can been shortened. The reliability of the plant has been also improved because of diversity of control rod drive mechanisms.



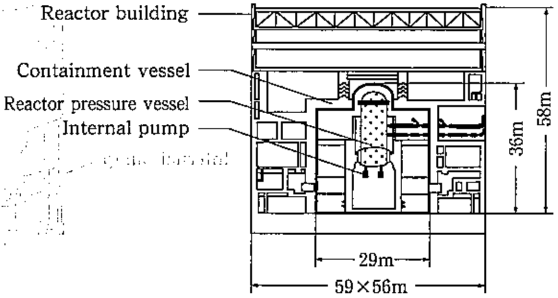
Electrical motor drive + Hydraulic drive

(c) Reinforced Concrete Containment Vessel (RCCV)

RCCV, which has excellent economy performance and higher safety, has been adopted as the containment vessel for ABWR.

RCCV consists of the reinforced concrete with the pressure boundary function and a steel liner with the protection function against leakage.

The gravity center of RPV, RCCV and reactor building could be lowered because of the elimination of the recirculation external piping. High seismic capability has been obtained because RCCV is integrated with the reactor building.



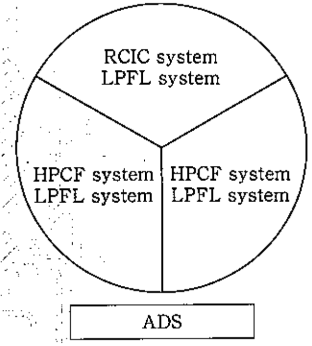
(d) Main Control Panel

In the design of ABWR, the main control panel consists of the main panel on which all monitoring and operational functions are provided and the large display panel by which all operators can hold important information on plant operation in common. As the result of these design, effective and sophisticated operation during normal operation, and easy and confirmable operation during accident could be possible. The range of the automatic operation such as FMCRD operation has been enlarged so that reduction of operator load has been achieved.

(e) Optimization of Emergency Core Cooling System (ECCS)

In the design of ABWR, it was not necessary to assume the break of a large size piping because of the adoption of the internal pump. The ECCS network up to BWR 5 has been re-evaluated fundamentally and the network for ABWR has been newly developed.

The new ECCS network is three independent divisions and consists 2 high pressure core flood (HPCF) systems, 1 reactor core isolation cooling (RCIC) system, 3 low pressure flood (LPFL) systems which is one operation mode of the residual heat removal (RHR) system and 1 automatic depressurization system (ADS).



The RCIC system is also given the ECCS function to enhance the capability of high pressure cooling function.

(f) High Efficiency Large Turbine

The power of ABWR has been increased higher than the existing BWR (1100MW). In order to achieve this power efficiently, the high efficiency turbine with final stage blade of 52 inches, reheat cycle and heater drain pump up system has been adopted and the overall thermal efficiency has been improved.

(3) System Configuration

The overall system configuration of ABWR is shown in the Fig.1.

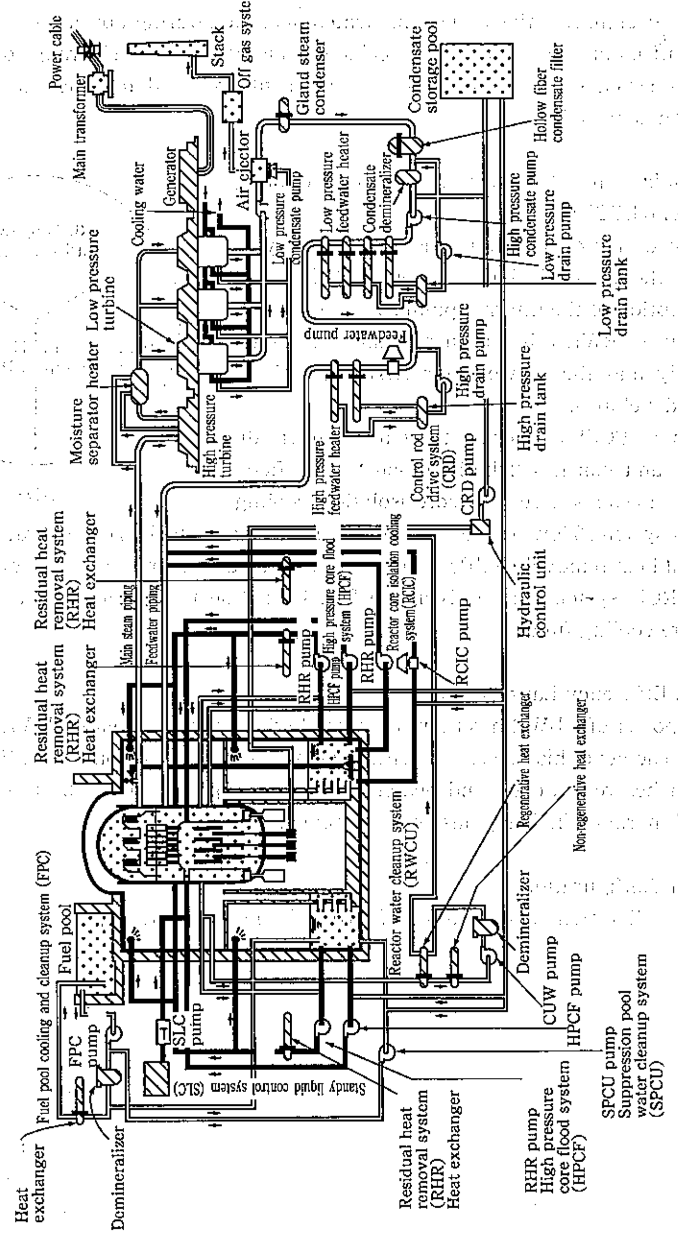


Fig. 1 System Outline of ABWR Nuclear Power Station

13-13 Outline of PWR

(1) Specification of Main Parameters for PWR Standard Plant

Items	Sub-items	Specifications				
		Main parameters	500MWclass	800MWclass	1100MWclass	1500MWclass
Core and Fuel	Core	Core thermal output(MWt)	1,650	2,652	3,411	4,451
		Total reactor coolant flow rate (t/h)	30.3×10^6	45.7×10^6	60.1×10^6	77.3×10^6
		Reactor coolant temperature at reactor vessel inlet (℃)	288.1	283.6	289.2	288.7
		Reactor coolant temperature at reactor vessel outlet (℃)	322.7	321.1	324.9	325.0
		Operating pressure (MPa[gage])	15.4	15.4	15.4	15.4
		Number of reactor coolant loops	2	3	4	4
	Fuel	Number of assemblies	121	157	193	257
		Fuel rod array	14×14	17×17	17×17	17×17
		Number of control rod clusters	29	48	53	69～85
Reactor coolant system	Reactor vessel	Inner diameter (m)	3.4	4.0	4.4	5.2
		Overall height (inner) (m)	11.5	12.1	12.9	13.6
		Maximum allowable pressure (MPa [gage])	17.2	17.2	17.2	17.2
		Maximum allowable temperature (℃)	343	343	343	343
	Steam generator	Number	2	3	4	4
		Maximum allowable pressure of shell side (MPa[gage])	7.48	7.48	8.17	8.17
		Maximum allowable pressure of tube side (MPa[gage])	17.2	17.2	17.2	17.2
ECCS	Accumulator injection system	Volume (m³)	57	41	38	90
		Number of tanks	2	3	4	4
	High pressure injection system	Charging & Safety injection pump flow (m³/h)	—	147	—	—
		Safety injection pump flow (m³/h)	160	—	320	300
		Number of pumps	2	3	2	4
	Low pressure injection system	L.P. injection pump (residual heat removal pump) flow (t/h)	454	852	1,020	—
		Number of pumps	2	2	2	—
Containment vessel	Containment vessel	Type	(Steel containment vessel) Upper : semi-sphere, lower : cylinder with bowl	(Steel containment vessel or Steel containment vessel with thick wall) Upper : semi-sphere, lower : cylinder with bowl	(Prestressed concrete containment vessel) Upper : semi-sphere, lower : cylinder with flat bottom	(Prestressed concrete containment vessel) Upper : semi-sphere, lower : cylinder with flat bottom
	Containment spray system	Number of systems	2	2	2	4

(2) Assembly of Reactor and Reactor Core Internals for PWR

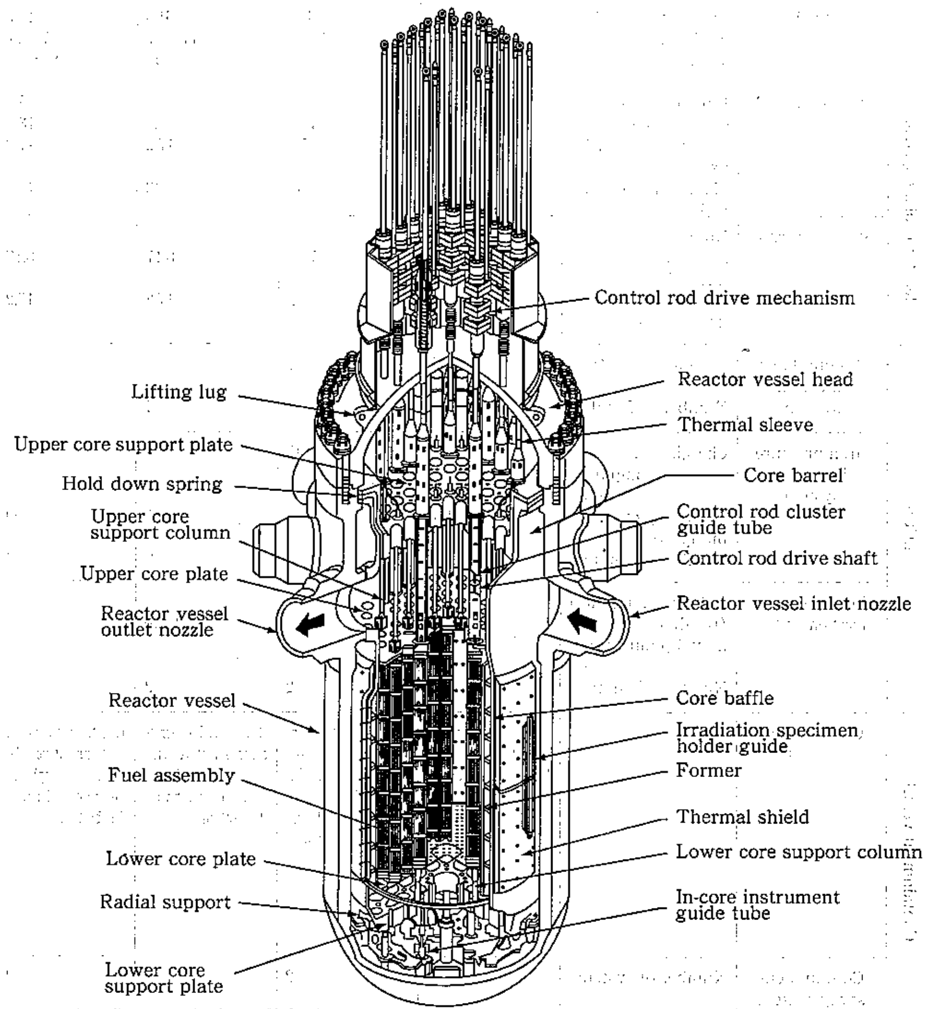
The reactor core internals supporting the fuel assembly consist of the upper core support assembly and the lower core support assembly roughly.

The reactor coolant enters into the reactor vessel through the inlet nozzles provided in the upper shell of the reactor vessel from the cold legs and flows downward in the annulus between the reactor vessel and the core barrel and turns to flow upward in the lower plenum and enter into the bottom region of the core in the almost uniform flow distribution.

The reactor coolant absorbs the thermal energy generated from the fuel rods while flowing upward around the fuel rods and is heated and is mixed in the upper core plenum after passing through the upper core plate and is supplied into the hot legs through the outlet nozzles provided in the upper shell of the reactor vessel.

The upper core support assembly, which consists of the upper core plate, the upper core support plate and the upper core support columns, supports the top end of the fuel assembly and the control rod cluster guide tube and the thermocouples for measuring the reactor coolant temperature etc are attached to the upper core assembly. The upper core support assembly is assembled to the top of the core barrel which is one of the lower core support assembly.

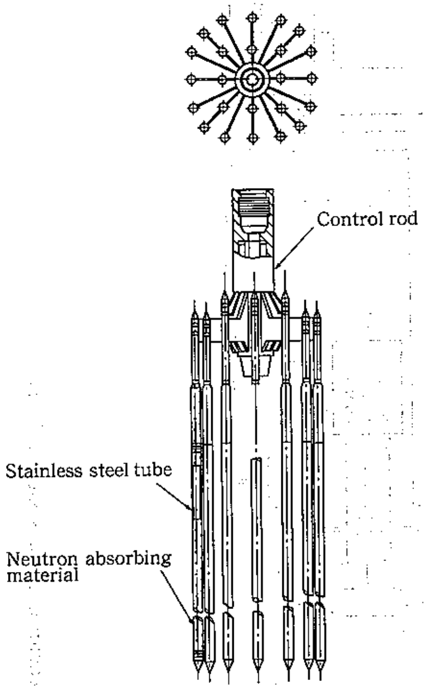
The lower core support assembly, which consists of the core barrel, the lower core plate, the lower core support plate, etc. fixes the fuel assembly in the correct position. The annular flow path is formed between the reactor vessel and the core barrel.



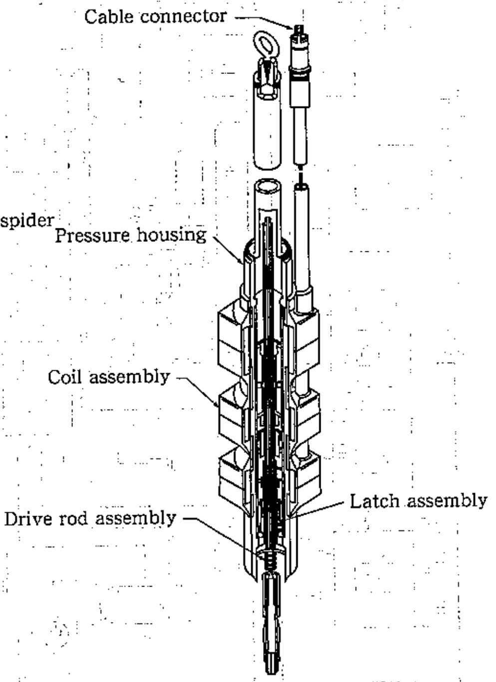
(3) Control Rod and Control Rod Drive Mechanism for PWR

A control rod is a stainless steel tube containing a neutron absorption material and one cluster consists of 16 to 24 control rods.

The assembly of the control rod cluster and the control rod drive mechanism are shown in the following drawings.



Assembly of the control rod cluster



Assembly of the control rod drive mechanism

(4) Power Control for PWR

The reactor power is controlled keeping the core in the critical condition, compensating the excess reactivity with the neutron absorber. In PWR, the control rod and chemical shim are used as the neutron absorber.

(a) Control method by the control rods

The control rods can control the rapid reactivity change occurred by the reactor shutdown or the load change. In this control method, the reactor coolant temperatures measured at the inlet and outlet of the steam generators are averaged by each averaging temperature unit, and the average temperature is averaged by the averaging temperature averaging unit. This averaged temperature becomes an initiation signal to drive the control rod. On the other hand, the first stage pressure of the high pressure turbine is nearly proportional to the load and the load condition can be obtained from this pressure.

The signal of the reference average temperature corresponding to the load can easily be calculated by the pre-determined average temperature program.

By comparing these two signals (the actually measured average temperature and the reference temperature calculated by the pre-determined program), the operation of the control rod cluster such as the withdrawal, the insertion and the stop is controlled and the velocity control of the cluster is also controlled in response to the difference.

Besides, a neutron flux is used as an auxiliary signal of the operating velocity of the control rod. When tripping the reactor, the signal of the trip also cut off the power circuit for the control rod drive mechanism and the control rods are rapidly inserted in the core by gravity and so the reactor is shut down safely.

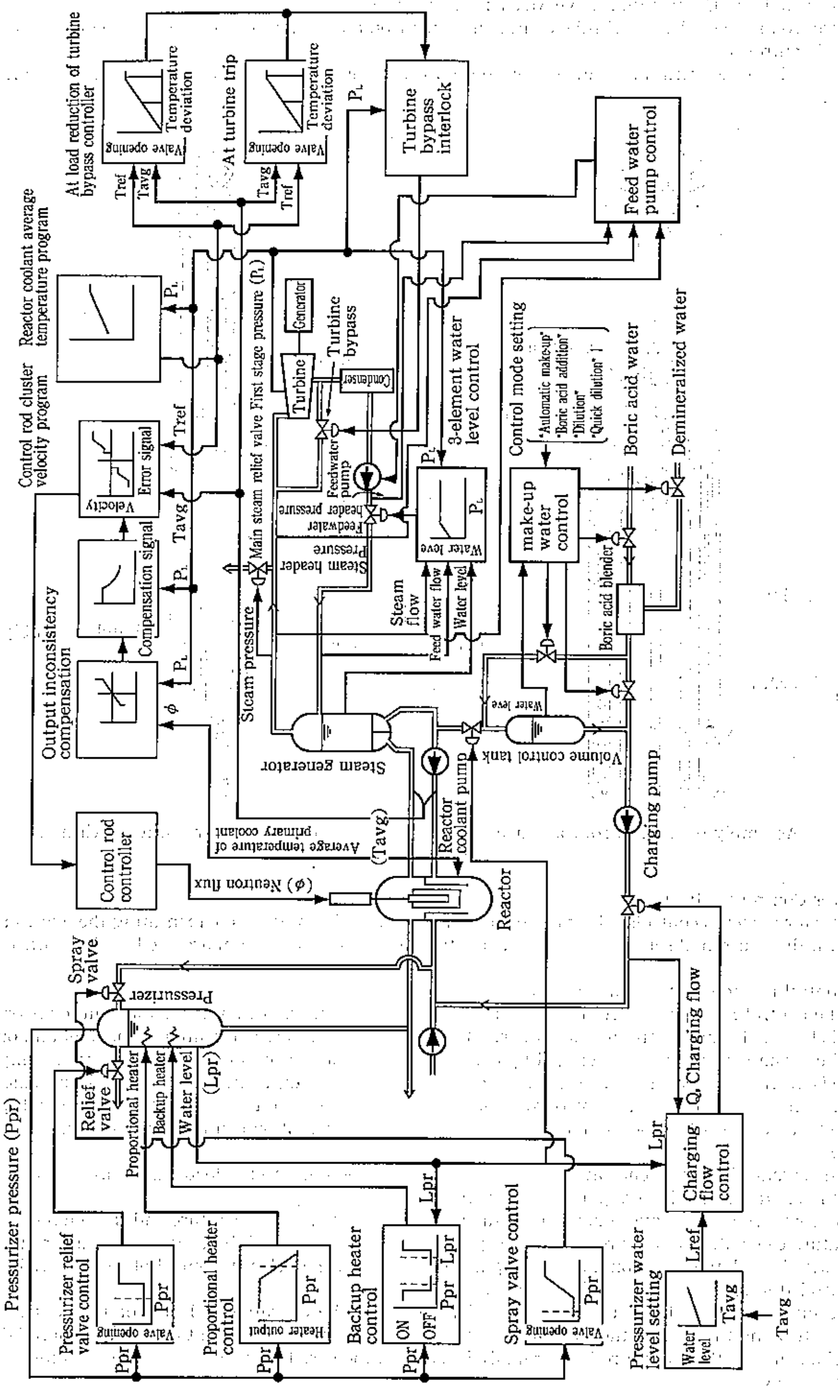


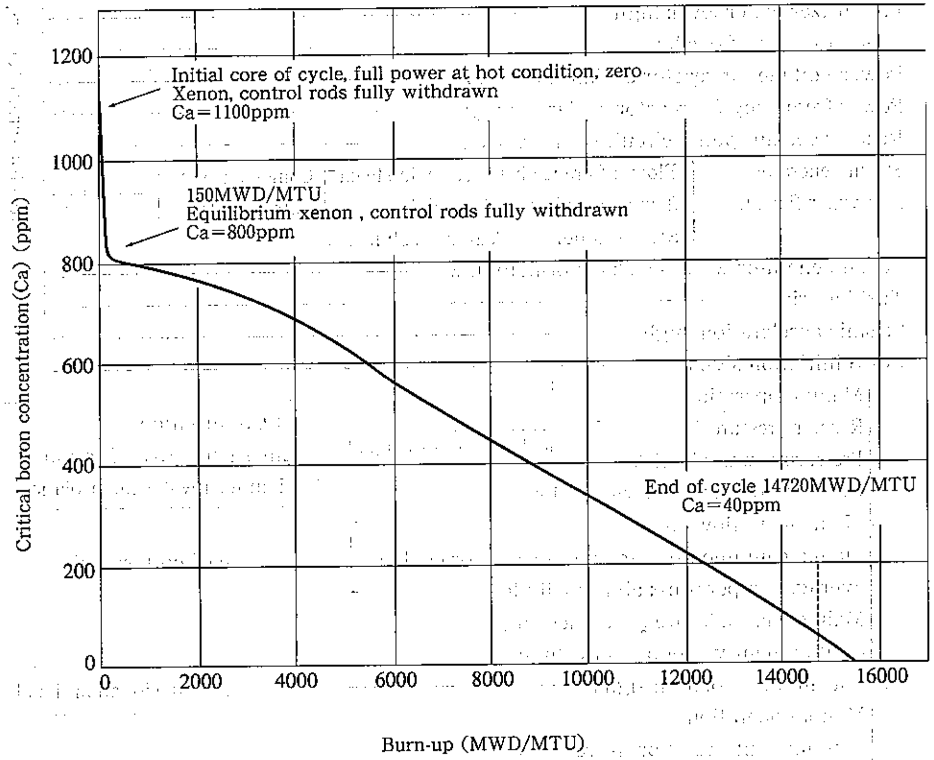
Fig.1 Reactor Control System (PWR)

(b) Control method by the chemical shim

The chemical shim compensates the change of xenon concentration resulting from change of the neutron flux and controls the change of reactivity resulting from burning of the fuel. This method is the way to control the concentration of boron having large neutron absorption cross section.

In order to increase the concentration of boron in the reactor coolant, the boric acid with high concentration is injected into the reactor coolant by the charging pump of the chemical and volume control system.

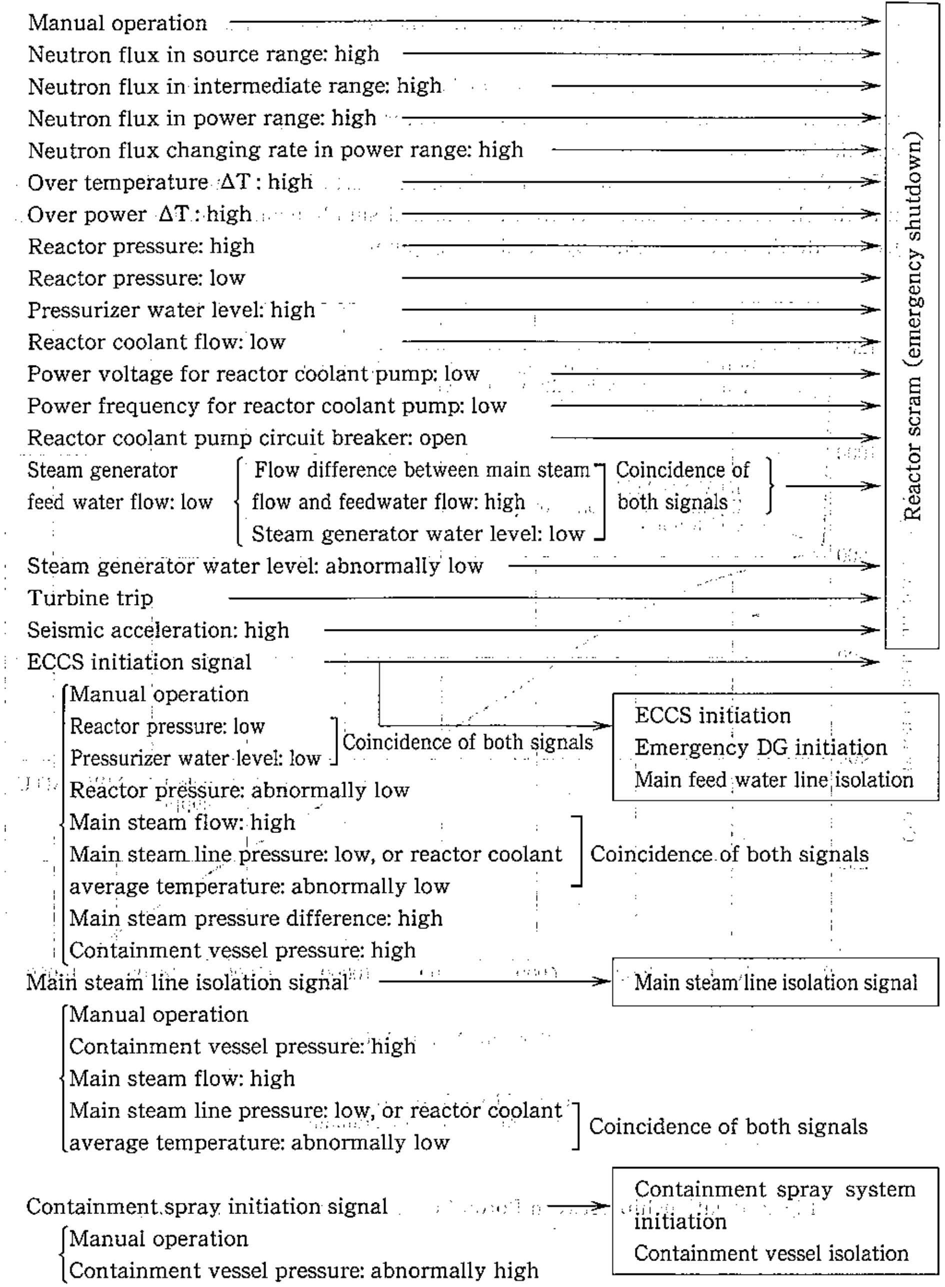
In order to decrease the concentration of boron, a part of the reactor coolant is drained into the chemical and volume control system and simultaneously purified water is injected into the reactor coolant by the charging pump.



MWD=Mega Watt Day
MTU=Metric Ton of Uranium

Fig. 2 Relationship between Boron Concentration and Fuel Burnup

(5) Outline of the Reactor Protection System for PWR (800MWe class)



13-14 Outline of Advanced PWR (APWR)

(1) Development History of Advanced PWR

As a part of MITI improvement and standardization program of nuclear power station, the collaboration for APWR with the electric power companies and the plant suppliers had been proceeded from 1982 to 1987.

The more sophisticated design had been achieved by incorporating PWR operating experiences, maintenance experiences, and state of the art techniques in addition to these results of development. The followings are the main targets of development.

(1) Improvement of safety (4 trains of ECCS, advanced accumulator, no exchanging of recirculation path at accident)
(2) Improvement of reliability (improvement of reactor internals, steam generator and reactor coolant pump)
(3) Reduction of amount of radioactive exposure (lowering of source intensity, automation of maintenance work/use of robot)
(4) Reduction of amount of radioactive waste (lowering of generating amount, improvement of volume reducing treatment technique)
(5) Improvement of operability and maneuverability (new main control panel, adoption of digital control protection device)
(6) Improvement of economy (large power and large capacity, reduction of construction cost, saving of uranium resource, improvement of plant availability)

APWR is under the planning as Tsuruga 3 and 4 of The Japan Atomic Power Inc.

(2) Design of Main Facilities for APWR

(a) Core and Fuel

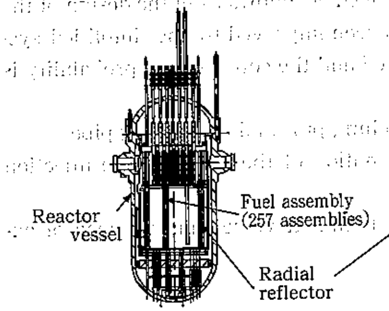
The reactor core for APWR is a large core with 257 advanced fuel assemblies which consists of 17 by 17 rods array. Including the improvement of fuel economy, its design has high flexibility for diversity of operation as MOX fuel or high burnup core by adopting the following measures.

1) Number of control rods: variable setting of number of control rods in response to load scale of MOX fuel
2) Increase of length of fuel plenum
3) Fuel assembly
   ① Adoption of advanced fuel cladding with improved corrosion resistance
   ② Increase of fuel total length by 130mm
   ③ Adoption of zircaloy grid

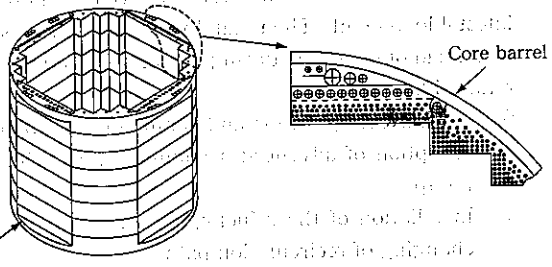
(b) Reactor Internals

The inside diameter of the reactor vessel was enlarged to approx. 5.2m to house the large sized core. Concerning the reactor internals, the 3 following items were improved by the adoption of a radial reflector. The countermeasure against core flow induced vibration has been taken in response to large sized reactor internals.

1) Saving of uranium resource by efficient use of neutron
2) Large reduction of bolt/screw number from approx. 2000 to approx. 50
3) Reduction of neutron irradiation to the reactor vessel to approx. 1/3 of the existing 4 loop plant



Assembly of core region

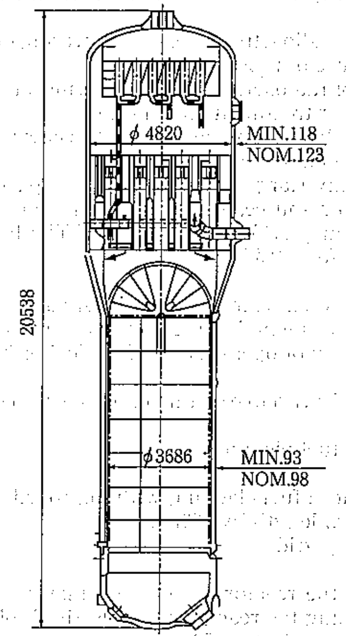


Structure of piled ring type blocks

(c) Steam Generator

Steam generator for APWR was changed from the 52F type for the latest 4 loop plant to the 70F-1 type to respond to the scale up of the reactor core. The material of the heat transfer tube is the same as TT690 alloy used in the precursory plant and has a good performance against corrosion and erosion.

The tube size was changed from 7/8 inches which has been used in the existing plant to smaller 3/4 inches in order to be more efficient and make smaller from the stand point of economy, seismic design, etc.



Advanced PWR Steam Generator

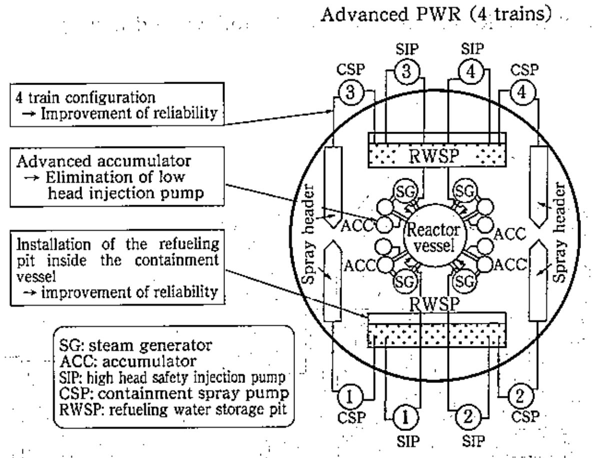
(d) Emergency Core Cooling Systems

Emergency core cooling systems have been improved as follows from the design of the latest 4 loop plant. The reliability of the plant has been improved by the simplified system. Load of operators during an accident is reduced and the core damage probability is reduced by one order.

① 4 trains configuration and elimination of branching pipe and connecting pipe

② Adoption of advenced accumulator, and elimination of the low pressure injection pump

③ Installation of the refueling pit inside the containment vessel, and no need of exchanging of recirculation path



Outline of the advanced design of ECCS

(e) New Main Control Panel

In order to make the plant operation easy and safe, the main control panel was changed to a control panel of compact console type based on the knowledge by human engineering, by which can be performed the monitor of the components and the operation on the TV screens.

The adoption of a touch type operation system has brought the followings.

① Unified indication of monitoring information and operation information

② Small sized main control panel (operation in chair)

③ Qualitative improvement of indication information

(f) Steam Turbine

For larger power and larger capacity, the turbine has incorporated high performance and high efficiency. The length of the final stage blade for the latest 4 loop plant was 44 inches, but that for APWR is changed to 54 inches to improve turbine efficiency. And the efficiency improvement of 0.5% has been achieved by the adoption of the impeller designed by the fully three dimensional flow.

(3) System Outline

System outline of APWR plant is shown in the following drawing.

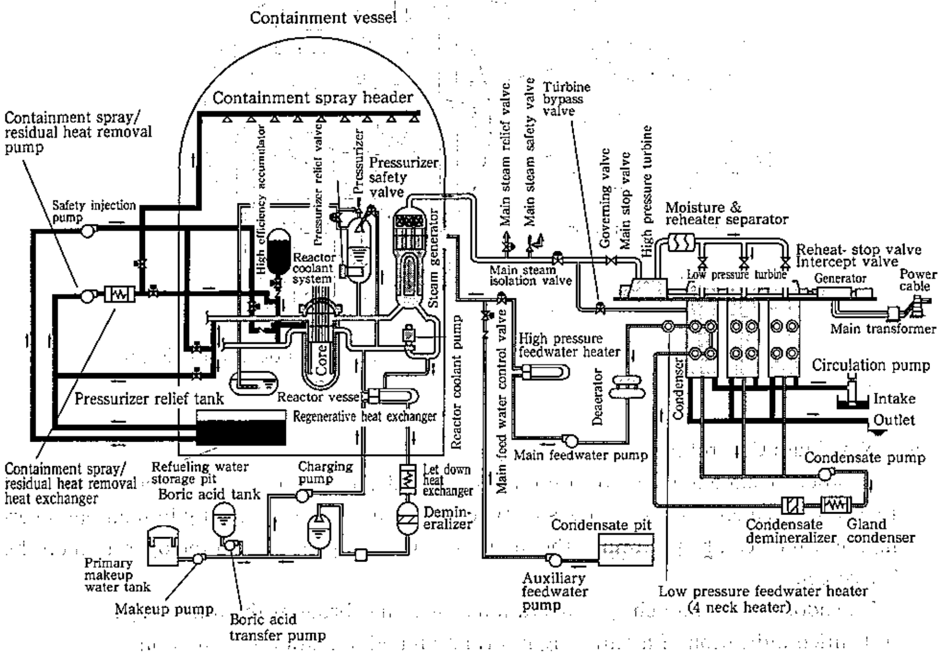


Fig. 1 System Outline of APWR Nuclear Power Station

13-15 Outline of FBR

(1) Specification of Main Parameters for FBR

Items	Sub-items	Specifications		
		Parameters	Experimental reactor [JOYO] (MK-II)	Prototype reactor MONJU Electric output : 280 MW
Core and Fuel	Core	Thermal output (MWt)	100	714
		Core flow (t/h)	2200	15360
		Coolant temperature Inlet/outlet (℃)	370/500	397/529
		Number of cooling loop Primary/Secondary	2/2	3/3
	Fuel	Number of fuel assemblies	67	198
		Fuel array	127-rod equilateral triangle	169-rod equilateral triangle
Reactor cooling system	Reactor vessel	Inner diameter (m)	Approx. 3.6	Approx. 7.1
		Hight (m)	Approx. 10	Approx. 17.8
		Maximum operating pressure top/bottom MPa [gage]	0.71/0.1	0.98/0.2
		Max.design temperature (℃)	550	420/550
	Primary cooling system	Number of intermediate heat exchanger	2	3
		Number of circulation pump	2	3
	Secondary cooling system	Number of steam generator	—	3 evaporators & 3 superheaters
		Number of circulation pump	2	3
Reactivity control system	Control rod	Number of control rods	6	13
		Backup reactor shut-down rods	—	6
		Neutron absorption material	B_4C	B_4C
Engineered safety facilities	Reactor containment	Type	Upper : semi-sphere, lower : vertical cylinder with bowl mirror at bottom	Upper : semi-sphere, lower : vertical cylinder with bowl mirror at bottom
		Inner diameter (m)	28	Approx. 49.5
		Height (m)	54.3	Approx. 79

(Source: Nuclear Power Generation Handbook (1997) edited by the Nuclear Power Generation Section in the Public-Servicing Undertaking Dept., Agency of Natural Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-Sha)

(2) Assembly of the Reactor and the Core for FBR

The reactor of FBR basically consists of the reactor vessel, the reactor internals, the fuel, the control rods, etc. The core consists the core fuel assemblies located at the center of the core, the blanket fuel assemblies located outside the core fuel assemblies peripherally and the neutron shield assemblies.

The liquid metal sodium of the coolant injected into the bottom plenum of the reactor vessel from the primary coolant inlet piping flows upward in the core fuel assemblies and absorbs the heat generated from the core fuel assemblies and is heated.

The hot liquid metal sodium is introduced to the shell side of the intermediate heat exchanger through the reactor vessel outlet nozzle from the upper plenum of the reactor vessel and through the primary coolant exit piping.

The fuel assemblies is loaded and removed through the rotation plug of the reactor vessel.

(3) Control Rods and Control Rod Drive Mechanism for FBR

The control rod consists of the regulating control rod (for fine and coarse regulating) and the back-up control rod, or the regulating control rod and the safety control rod. The element of control rod is a stainless steel tube encasing the boron carbide (B_4C) with enriched ^{10}B and the control rod assembly consists of multiple control rod elements. The control rod is driven by the device provided with the motor.

(4) Power Control for FBR

The reactivity control resulting from the reactor shutdown or the load change is performed changing the position of the regulating control rod in response to the demand signal from the reactor control system.

The temperature and pressure of the main steam is automatically controlled to be constant fundamentally.

The power control system of the reactor controls the speed of the fine regulating control rod and simultaneously keeps the temperature of the sodium at the reactor outlet the specified temperature in response to the main control signal which is the deviation between the temperature of the sodium at the reactor outlet and the programmed value from the power demand device and the auxiliary control signal which is the deviation between the neutron flux signal and the programmed signal of the reactor power from the power demand device.

The power control system of the plant controls the primary main coolant flow rate and the secondary main coolant flow rate in proportion to the demand signal from the power demand devices to meet the load characteristics and finely controls the fine regulating control rod at the same time so that the temperature of the sodium at the outlet of the reactor vessel corresponds to the predetermined temperature from the power demand devices.

The steam pressure detection system of the turbine system detects the pressure fluctuation resulting from the change of the demand from the power demand device. The opening of the turbine control valve is automatically controlled in response to the fluctuation so that the main steam pressure is constant. As the result, the power of the turbine is controlled.

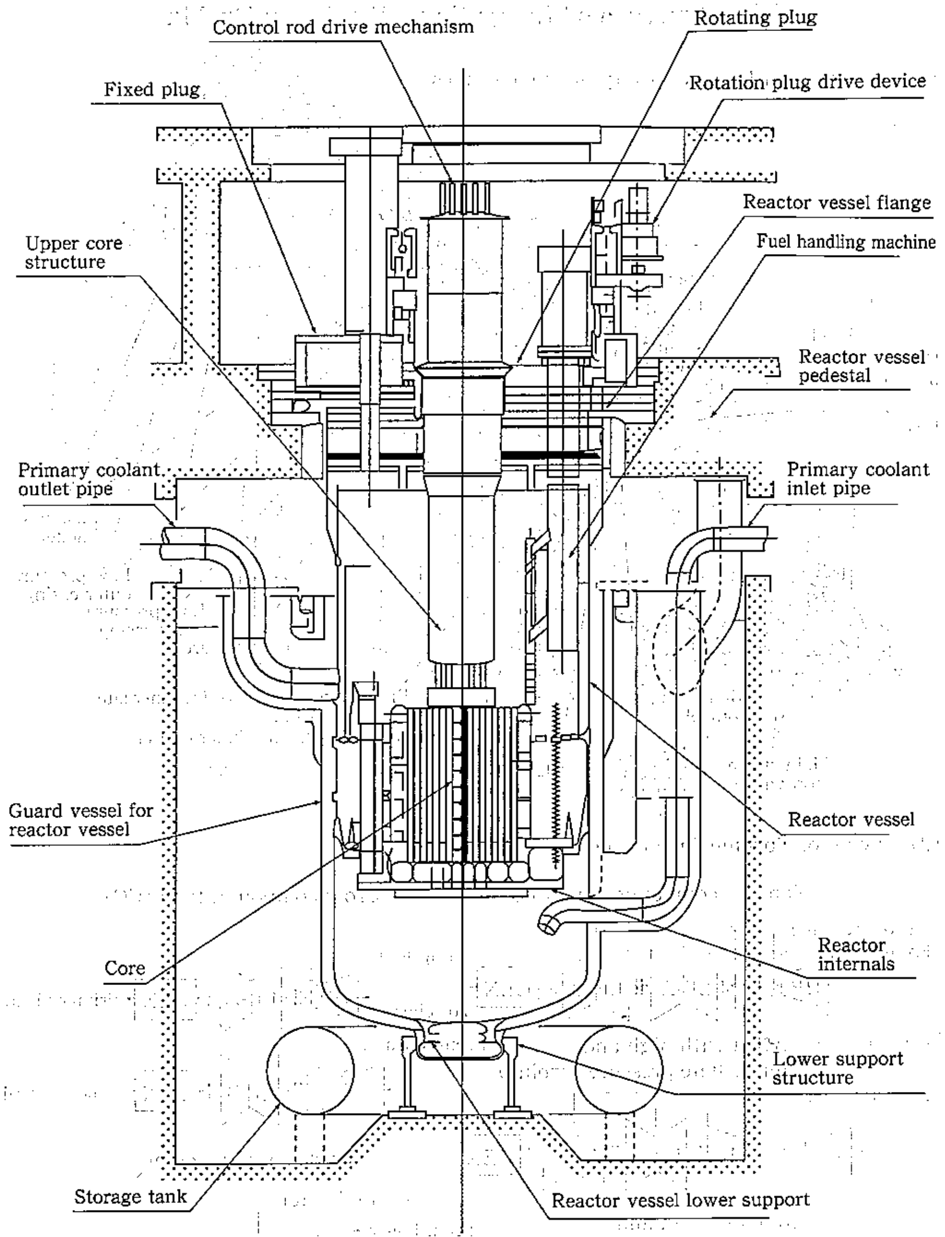


Fig. 1 Reactor Assembly for FBR (MONJU)

(Source: Nuclear Power Generation Hand Book (1997) edited by the Nuclear Power Generation Section in the Public-Service Undertaking Dept., Agency of Natural Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-sha)

12-6 Characteristics of Cladding Materials

Major characteristics of cladding materials

Characteristics / Materials	Chemical composition (Wt%)	Density (g/cm^3) (Room temp.)	Melting point (℃)	Thermal conductivity (W/m•K)	Linear expansion coefficient ($\times 10^{-6}$/K)	Cross section of thermal neutron absorption (barn)	Compatibility with coolant		
							H_2O	CO_2	Na
Beryllium Be	Simplex	1.85	1,283	167 (100℃) 130 (300℃) 92 (700℃)	11.3 (20℃) 19.1 (800k)	0.009	○	○ (equal or less than 600℃)	○
Magnesium alloy A−12	1.0Aℓ, 0.01Be	1.74	650	157	25.8 (20～100℃) 28.2 (20～300℃) 29.9 (20～500℃)	0.059±0.0042	×	○ (400～500℃)	×
Aluminium alloy 1,100	99%Aℓ Si+Fe=1	2.71	643～657	218	23.5 (20～100℃) 24.6 (20～200℃) 25.6 (20～300℃)	0.23	○ (100～300℃)	○	×
Aluminium alloy 6,063	0.7Mg, 0.4Si	2.70	616～651	213	23.4 (20～100℃) 24.5 (20～200℃) 25.5 (20～300℃)	0.23	Ditto	Ditto	Ditto
Zirconium alloy Zr−2	1.2～1.7Sn { 0.07～0.20Fe 0.05～0.15Cr 0.03～0.08Ni	6.55	1,852	14.6	6.5 (20～350℃)	0.21	○	×	○
Zirconium alloy Zr−4	1.2～1.7Sn { 0.18～0.24Fe 0.07～0.13Cr ≦0.0070Ni	6.55	1,852	14.6	6.5 (20～350℃)	0.21	○	×	○
Vanadium V	Simplex	5.87	1,917	29	8.4 (20℃) 10.9 (800k)	5.04	—	—	○
Niobium Nb	Simplex	8.57	2,468	55.3	7.2 (20～100℃) 7.4 (20～200℃) 7.5 (20～300℃)	1.1	○	○	○
Austenitic stainless steel SUS304	18～20Cr, 8～10.5Ni, equal or less than 2Mn, equal or less than 1Si, equal or less than 0.08C	8.03	1,399～1,454	16.3 (100℃) 18.8 (300℃)	14.7 (20℃) 17.5 (500k) 20.2 (800k)	3	○	○	○
Nickel alloy Inconel 600	72Ni, 15Cr, 8Fe 0.5Cu	8.51	1,410	15.1 (100℃)	11.5 (0～100℃)	4.03	○	○	—

Reference: Metal's Handbook, edited by The Japan Institute of Metals (1990), Rika Nenpyo (Chronological Scientific Tables) (1999), edited by National Astronomical Observatory and Metal's Data Book, (1974), edited by The Japan Institute of Metals, published by Maruzen Co., Ltd. etc.

13-1 Outline of Main Types of Nuclear Power Reactors

(1) Types of Nuclear Power Reactors

There are various types in nuclear power reactors by the combination of the shapes and the kind of the assembly elements of the reactor such as the fuel, the moderator, and the coolant. The followings are typical types of nuclear power reactors;

(a) Graphite moderated, carbon dioxide gas cooled reactor (called Calder Hall type or Magnox reactor)
(b) Light water moderated and cooled pressurized water reactor (PWR: Pressurized water reactor)
(c) Light water moderated and cooled boiling water reactor (BWR: Boiling water reactor)
(d) Advanced graphite moderated, carbon dioxide gas cooled reactor (AGR: Advanced gas cooled reactor)
(e) Graphite moderated, helium cooled reactor (HTGR: High temperature gas cooled reactor)
(f) Heavy water moderated (light water or heavy water cooled) reactor (HWR: Heavy water reactor)
(g) Liquid metal cooled fast breeder reactor (LMFBR: Liquid metal cooled fast breeder reactor)
(h) Light water reactor of old USSR type (RBMK-Graphite moderated, light water cooled, channel type and VVER-Pressurized light water reactor)

(2) Outline of Main Reactor Types

(a) Calder Hall Type

(i) General Description

The prototype of this reactor was developed in England and France. The main assemblies of the reactor consist of piled graphite blocks, which function as the moderator and the reflector.

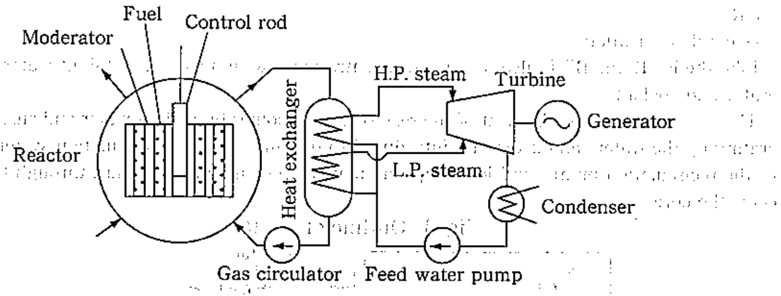
The fuel is a metal rod of natural uranium coated with Magnox (magnesium alloy) and is inserted into the multiple hole (vertical or horizontal) dug in the moderator.

The reactor core is housed in a spherical or cylindrical steel containment.

Heat generated in the reactor core is transferred to pressurized carbon dioxide gas flowing in the groove of the fuels.

The carbon dioxide gas is circulated between the reactor and the tube side of the heat exchanger by the gas compressor.

Fig. 1 Outline of Calder Hall Reactor



(ii) Features

The reactor core consists of the fuel assemblies with metal rods of natural uranium and the graphite blocks of the moderator, so that its size is large. The cost of the fuel is low, while the construction cost is high.

Carbon dioxide gas is used as the primary coolant, so that large heat exchanger is required. The drive power for the circulator is also large.

As the reactor core is the structure of piled blocks, the special consideration is required to meet aseismic requirement. The secondary steam (turbine plant side) is controlled by the double pressure method to give the optimum condition to the relation of the difference between the temperature at inlet of the heat exchanger and that at outlet, and the thermal efficiency of the turbine. The refueling can be carried out during power operation.

(b) PWR

(i) General Description

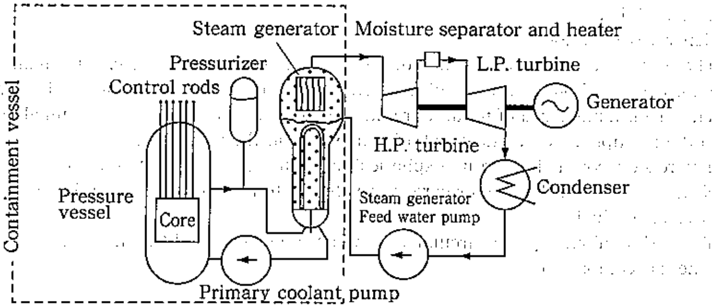
PWR is one type of light water moderated and cooled reactor, which uses low-enriched uranium dioxide sintering pellets as the fuel.

Light water (the primary coolant) heated in the reactor core is circulated between the reactor and the steam generator by the primary coolant pump. High pressure and temperature steam to drive the turbine is generated by exchanging the heat between the primary coolant and the secondary coolant (light water) in the steam generator.

(ii) Features

Since the turbine is driven by the clean steam generated in the secondary side of the steam generator, the turbine and related equipments are free from radioactive contamination. Relatively slow reactivity fluctuation by fuel burnup is controlled by adjusting the concentration of boron in the primary coolant. In this operation, distortion of the power distribution is very small and the operation is easy, because of all control rods are withdrawn fully. The water quality is well controlled because of the primary coolant system is a closed loop.

Fig. 2 Outline of PWR



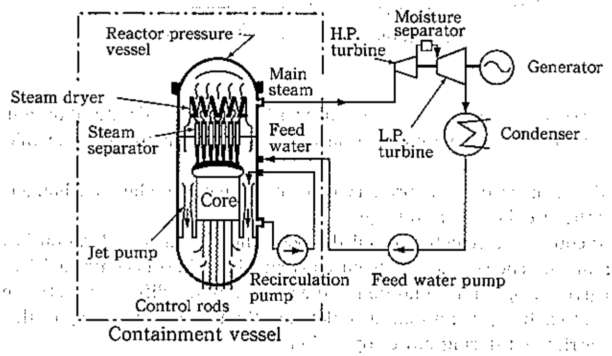
(c) BWR

(i) General Description

Like the PWR, the BWR also uses low-concentration uranium as fuel and light water as the moderator and coolant.

The steam is generated by heat of the reactor core (cooling by boiling water and steam, and moderating by the water) and is directly introduced to the turbine. The recirculation system consisting of the recirculation pumps and jet pumps circulates large amount of coolant through the core and cools the core.

Fig. 3. Outline of BWR



(ii) Features

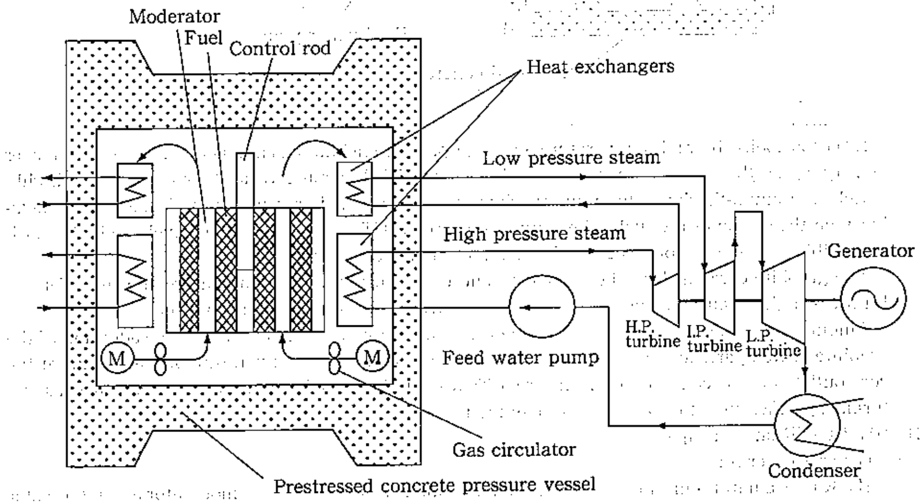
The power density of BWR is approximately limited to half of PWR in accordance with the relation of boiling phenomena and nuclear physics, because the steam is generated in the core and is usually existed in the core. The steam generator is not necessary to generate steam, but the steam to drive the turbine is slightly radioactive. The control of the reactor power is normally performed by the variation of the recirculation flow rate.

(d) AGR

(i) General Description

AGR had been developed in England as an advanced development of the Magnox reactor and their related facilities are almost similar to those in the Magnox reactor. The primary system such as the heat exchanger and the gas circulator is enclosed in the prestressed concrete pressure vessel with the reactor. The primary coolant flows upward in the fuel channels and next flows downward through the heat exchanger. The low enriched uranium is used as the fuel and the material of the fuel cladding is stainless steel.

Fig. 4 Outline of AGR



(ii) Features

AGR could use the newly high efficient steam turbine if the temperature of the carbon dioxide gas would be raised higher and the steam condition would be improved. The core size is large because of the low power density. There is less radioactive waste. Refueling can be carried out during power operation.

(e) HTGR

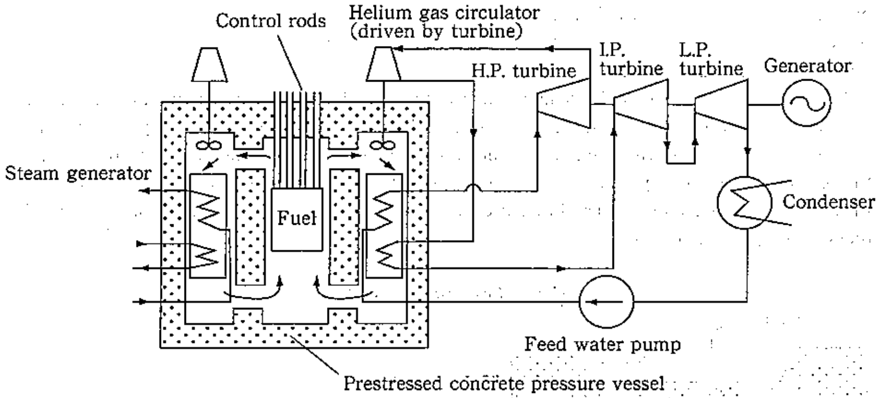
(i) General Description

HTGR had been independently developed in US, England and Germany (West Germany) simultaneously. This reactor is graphite moderated, helium gas cooled reactor using graphite coated high-enriched uranium-thorium as the particle fuel.

There are two types in the structure to enclose the fuel core, the control rod and the primary coolant system such as the heat exchanger and the helium circulator. The one is the integrated structure enclosed in a prestressed concrete pressure vessel and the other is a small modular type using a steel pressure vessel.

There are two types in the shape of the fuel element in HTGR: the one is the prism type (hexagonal graphite block) developed in England and USA, the other is the pebble bed type developed in Germany (West Germany).

Fig. 5 Outline of HTGR



(ii) Features

HTGR is cooled by high temperature and high pressure helium gas and is possible to have power density higher than that of other gas cooled reactors. HTGR can use various combinations of highly enriched uranium-thorium, plutonium-thorium and low enriched uranium as the fuel and has a flexibility on the option of the fuel. The conversion ratio of HTGR can be comparatively so high that it is possible to make use of resources for the nuclear fuel efficiently.

The graphite core has large heat capacity and can withstand high temperature and the safety of HTGR is high because of the adoption of the prestressed concrete pressure vessel.

Amount of radioactive waste from the plant is comparatively small because of the adoption of the graphite coated particle fuel and the helium of the coolant. If the temperature of the coolant at the core outlet could become higher in future, HTGR could be used for multiple purposes such as gas turbine, gasification of coal and steel manufacture.

(f) HWR (ATR only in Japan)

(i) General Description

HWR uses a natural uranium as the fuel mainly and heavy water as the moderator and light water (SGHWR-England) and heavy water (CANDU-Canada) as the coolant. The advanced thermal reactor (ATR) developed by Japan Nuclear Cycle Development Institute is planned to use a mixed oxide fuel of natural uranium and plutonium (MOX) as the fuel and heavy water as the moderator and light water as the coolant.

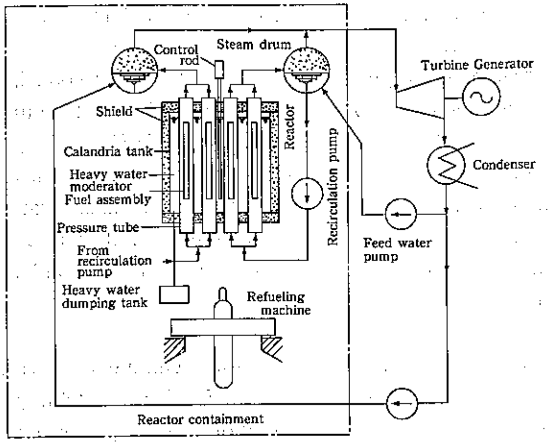
The core assembly of ATR consists of the calandria tank and multiple pressure tubes made of zirconium alloy and penetrates the calandria tank at both end and enclose a fuel assembly per a tube. The coolant circulates in the pressure tube and the steam is generated.

The control rods of HWR is inserted into the heavy water with low temperature and atmosphere in the calandria tank from above and the heavy water dumping function which reduces the level of the heavy water as the moderator rapidly at an emergency and keeps the reactor subcritical is provided as the back up device.

(ii) Features

In the design of ATR, neutrons generated by fission are mainly moderated to sufficient low energy level in the heavy water so that neutrons has less effect of resonance absorption of plutonium. As the result, both uranium and plutonium are used evenly on the nuclear fission. The refueling is performed from the bottom of the reactor and the facility can make refueling during plant operation.

Fig. 6 Outline of HWR



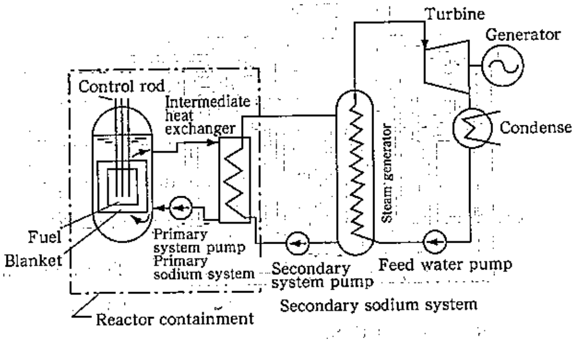
(g) LMFBR

(i) General Description

LMFBR uses high-enriched uranium or plutonium as the fuel, and the core is surrounded by the blanket loading natural uranium and liquid metal sodium is used as the coolant.

Heat generated in the core is removed from the core by liquid metal sodium circulating through the core and is transferred to the secondary sodium system at the intermediate heat exchanger. Superheated steam is generated at the steam generator in the secondary sodium system and drives the turbine.

Fig. 7 LMFBR



(ii) Features

Nuclear fission is carried out by fast neutron so that a moderator is not necessary in LMFBR. LMFBR can breed the plutonium of the nuclear fissile material. This means that it can breed plutonium (new fuel) more than the fuel (enriched uranium or plutonium) consumed. The power density of the core is so high that the core size becomes compact. The design of the core and the instruments and control system is crucial to the safety because of the large amount of high-enriched uranium or plutonium.

(h) LWR of old USSR (Russia)

1) Graphite Moderated, Light Water Cooled, Channel Type Reactor (RBMK)

(i) General Description

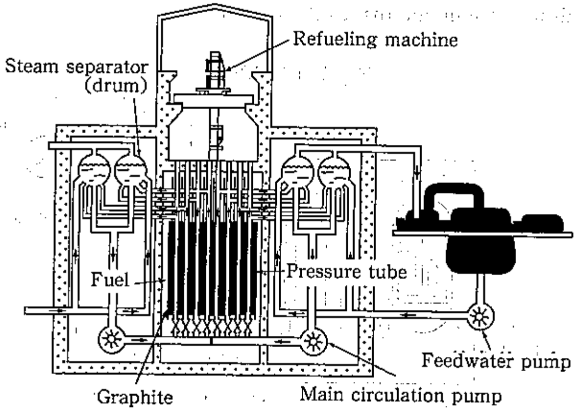
RBMK reactor is graphite moderated, light water cooled, channel type, boiling water reactor which uses approx. low- enriched (^{235}U of 2%) uranium oxide as the fuel and is the reactor developed originally by old USSR. The light water of the coolant is supplied into the fuel channels through the header by the circulation pump and is heated and is evaporated and flows up into the steam separator. After steam separating, dry steam is introduced into the turbine and electric power is generated. The steam exhausted from the turbine is condensed in the condenser and is returned to the steam separator.

(ii) Features

The one of characteristics of the reactor of channel type which does not use a large steel pressure vessel is not to require the fabrication technique of the large and precise plant. The refueling can be carried out during power operation by the refueling machine which is installed at the top of the graphite blocks.

The void reactivity coefficient of the various reactivities for RBMK is so large positive that RBMK has a tendency to be unstable at a low power. And the containment vessel which has a critical function to prevent radioactive materials from releasing to the environment is not provided.

Fig. 8 Outline of RBMK



*Resources of USSR

〔Source: Nuclear Handbook, editorially supervised by Asada, et al, published by Ohmsha Ltd. (1989)〕

2) Pressurized Light Water Reactor (VVER)

(i) General Description

USSR pressurized light water reactor is called VVER and there are two types such as VVER-440 with 6 loops and VVER-1000 with 4 loops. The primary loops consists of 6 loops and each loop consists of the main primary circulation pump, the steam generator, valves and austenitic pipe with inner diameter 50cm. The secondary system consists of the steam generator of horizon type, the turbine-generator, the feedwater heater, pump, valves and piping. The containment vessel was not provided in the early plant.

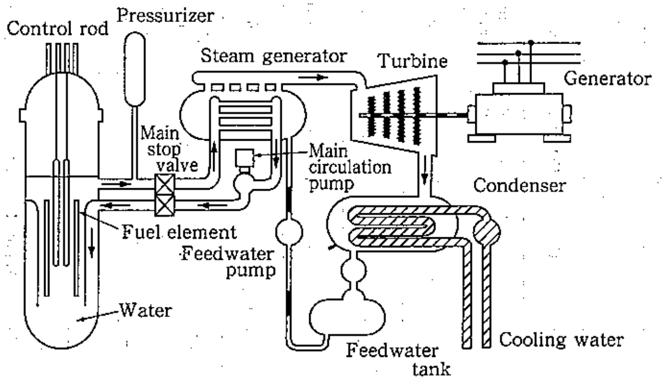
(ii) Features

A heat exchanger of a horizontal type was used as the steam generator in order to reduce potential corrosion problems of the heat transfer tube. The fuel assembly encloses 126 fuel rods in the hexagonal outer box and the pipe arranged in the center of the box is the support structure of the spacer of the fuel elements. The length of active fuel is short and 2.5 m.

The pressure vessel is provided with 12 nozzles for the inlet／the outlet of the coolant and these nozzles are located at two columns. 4 nozzles for the emergency core cooling are also provided. The pressure vessel is divided into two parts, upper shell and lower shell and transferred to the site by the railroad.

The containment vessel essential to the safety is not provided in the standard plant of VVER-440. Therefore, Lovissa nuclear power station in Finland changed to install the containment vessel of the ice condenser type additionally and enhances the confinement function for radioactive materials.

Fig. 9 Outline of VVER



*Pamphlet of Loviisa (Finland)

〔Source: Nuclear Handbook, editorially supervised by Asada, et al, published by Ohmsha Ltd. (1989)〕

13-2 Specifications for Various Types of Reactors

Parameters	Reactor type	PWR	BWR	HWR		Mognox reactor	AGR	HTGR	LMFBR	LWR of old USSR	
		(Standard type)	(Standard type)	Heavy water cooling type	Advanced thermal reactor					RBMK (graphite moderator/light water cooling channel)	VVER (PWR)
Unit output, gross (MWe)		1,180	1,100	788	165	166	660	342	250	1,000	1,000
Fuel	Type	UO_2	UO_2	UO_2	UO_2-PuO_2	Uranium metal	UO_2	UO_2-ThC_2	UO_2-PuO_2	UO_2	UO_2
	Enrichment (%)	2 ~ 3	2 ~ 3	Natural uranium	U1.5 / Natural uranium Pu0.67	Natural uranium	2.1~2.6	93	Pu enrichment Inside: 19.2 Outside: 27.1	Approx.2	3.3~4.4
Moderator	Material	Light water	Light water	Heavy water	Heavy water	Graphite	Graphite	Graphite	None	Graphite	Light water
Coolant	Type	Pressurized light water	Boiling light water	Pressurized heavy water	Boiling light water	Pressurized carbon dioxide	Pressurized carbon dioxide	Pressurized helium	Liquid sodium	Light water	Pressurized light water
	Pressure (MPa[gage])	15.4	6.93	11	6.67	1.41	4.15	4.83	0	6.86	15.7
	Temperature at inlet/outlet (℃)	289/325	216/286	261/299	277/284	207/386	317/654	404/777	400/560	270/284	290/322
Steam condition (at turbine inlet)	Pressure super-heat/reheat (MPa[gage])	Approx.5.79	6.55	4.22	6.23	H.P. 4.44 L.P. 1.64	15.9/3.82	16.5/3.92	16.0/3.28	6.37	5.88
	Temperature, superheater /reheater (℃)	Approx.274	282	253	279	H.P. 355 L.P. 357	538/538	538/538	510/510	280	274.3
Plant efficiency (%)		34.5	33	31.3	29.6	28.3	43.2	40.7	44	31.9	33.3
Nuclear characteristics	Power density (kWt/l)	100	50	Approx.11	Approx.12	Approx.1.0	Approx.2.8	6.3	406	Approx.4	108.0
	Burnup(MWD/t)	27,000 ~33,000	27,000 ~39,500	9,600	17,000	3,000	18,000	100,000	50,000 ~100,000	18,500	40,000
Power plant (examples)				Bruce (Canada)	Fugen (Japan)	Tokai-1 (Japan)	Hunter Stone B (U.K.)	Fort St. Vrain (USA)	Phoenix (France)	Chernobyl (Ukraine)	Balakovo (Russia)

13-3 Safety Design of Nuclear Reactor

(1) Fundamental Concept of Safety Design

The fundamental concept of safety design for the nuclear reactor is the protection of the public and the workers in the facility from radiation exposure and the concept of defense in depth is taken in the design.

The bases of concept of defense in depth are: First is to prevent the occurrence of abnormal incidents. Second is to prevent the abnormal incidents from developing to the accidents. Third is to prevent the radioactive materials from releasing to the environment outside the plant, if developed into the accidents.

(a) Prevention of Occurrence of Abnormal Incidents (Safety Measures of Level 1)

For countermeasure to prevent occurrence of abnormal incidents, these equipments are designed to be able to withstand the temperature and load applied to them during operation. For the facilities which erroneous operation and malfunction affect crucially the safety of the power plant, equipments and materials with high performance and high quality are used and the concept of fail safe system and interlock system are also taken in the design.

A fail safe system means the concept that the system is designed to become stable to ensure the safety of the plant, even if the a failure in a part of the system occurs.For instance, when the electrical power for the control rod drive device is lost for some reason, it is designed for the control rod to be automatically inserted into the core by gravity or the hydraulic system and for the reactor to be shut down safely. An interlock system means the system to prevent the occurrence of abnormal incidents by human error. For instance, it is designed for the control rod not to be withdrawn, even if an operator try to withdraw a control rod mistakenly.

Except the above, equipments essential to safety is designed and fabricated under the complete program of quality assurance. The power station is forced to shut down the reactor and to disassemble and inspect these components once annually by law. If the performances of these components can or may not meet the criteria determined by the law, the proper measures such repairs is taken immediately.

(b) Prevention of Development into Accident (Safety Measures of Level 2)

The countermeasures to prevent abnormal incidents from developing to accidents are to detect abnormal condition early and to take the proper measures such as a plant shutdown before abnormal incidents does not develop to accidents, even if abnormal incidents occurs.

For example, when a pin hole occurs in the heat transfer tube of the steam generator during power operation and the primary coolant leaks into the secondary cooling system, the automatic monitoring system to be able to detect some leakage, which may be very small, is provided in PWR.

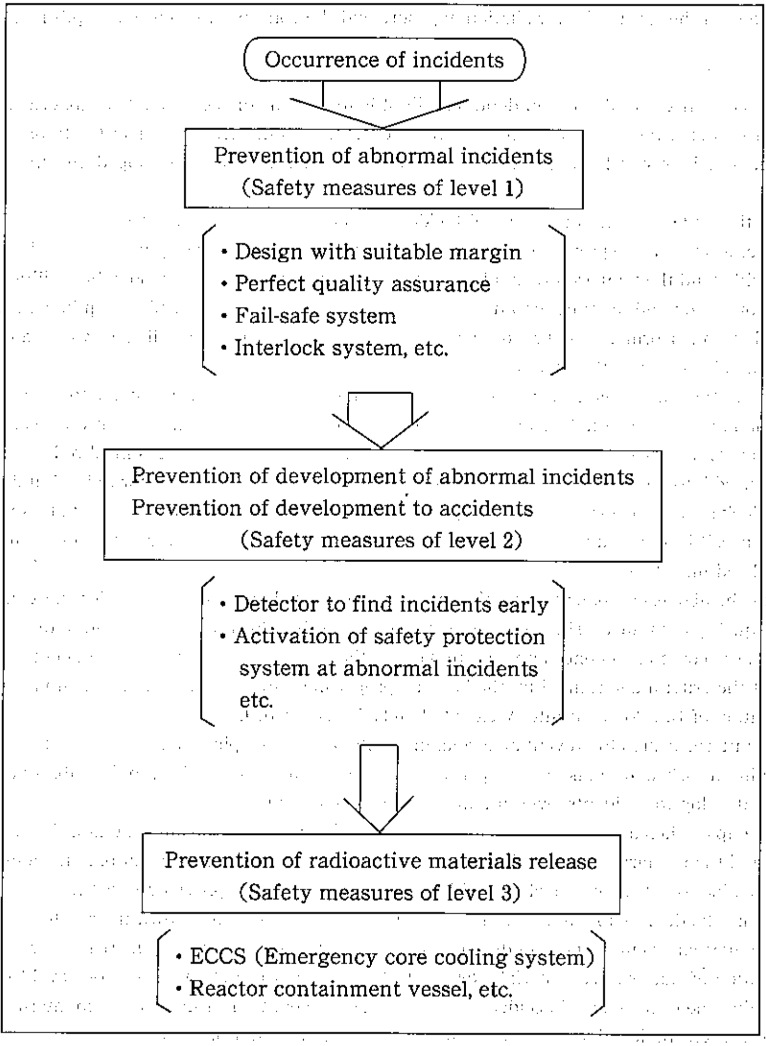
There are the devices to automatically insert the control rod and shut down the reactor, when detecting the abnormal or emergency condition which the reactor pressure rapidly increases for some reason.

(c) Prevention of Radioactive Materials Release to Environment (Safety Measures of Level 3)

Assuming the occurrence of accidents in spite of above countermeasures, other countermeasures are taken to prevent radioactive materials from releasing into the environment.

For instance, the emergency core cooling system (ECCS) and the reactor containment vessel are provided to mitigate the influence of the loss of accident coolant (LOCA), assuming the guillotine break of the piping of the primary coolant system in the Japanese nuclear power station. These facilities are designed and fabricated with sufficient margin of performance and mechanical strength and these functions of these facilities are kept to be performed by careful inspection and maintenance after starting the commercial operation.

Concept of Defense in Depth



〔Source: White Paper on Nuclear Safety in 1991, edited by Japan Atomic Energy Safety Commission〕

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(2) Confinement of Radioactive Materials

In general, a nuclear reactor plant is providing with multi barriers to prevent radioactive materials produced in the reactor from releasing to the environment.

First barrier: Fuel pellet	The pellets of uranium dioxide (UO_2) being the fuel element of a light water reactor has a superior retentive capability of fission products (FP) and most of FP produced in the pellets is confined in the pellets.
Second barrier: Fuel cladding	The fuel cladding enclosing the fuel pellets is the barrier to confine FP released from the fuel pellets.
Third barrier: Reactor coolant pressure boundary	The reactor coolant pressure boundary is the piping and the equipments which is filled with the reactor coolant and which is in the same pressure as the reactor. This boundary forms the pressure barrier during normal operation and under severe condition at transients and accidents and also is the barrier of FP release next to the fuel cladding.
Fourth barrier: Containment vessel boundary	The containment vessel boundary is the pressure barrier after loss of coolant accident. This boundary consists of the containment vessel and the piping penetrating the containment vessel which is designed to form a final barrier against releasing of radioactive materials in principle.
Fifth barrier: Reactor building	The reactor building prevents FP from releasing to the environment outside the plant.

〔The reactor pressure boundary and the containment vessel boundary for a light water reactor are defined in the electric technology guide book, JEAG 4602-1986, published by the Japan Electric Association〕

The following drawing shows the concept of confinement of radioactive materials for PWR.

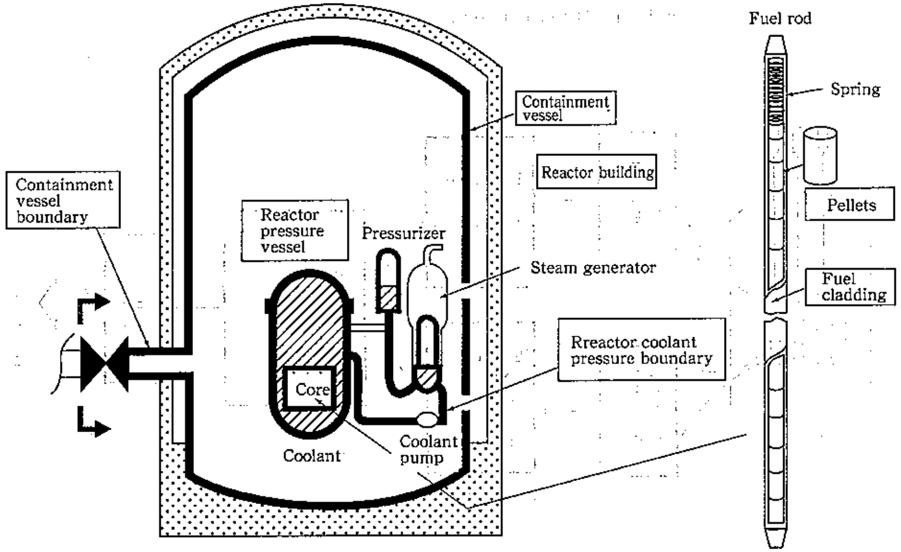
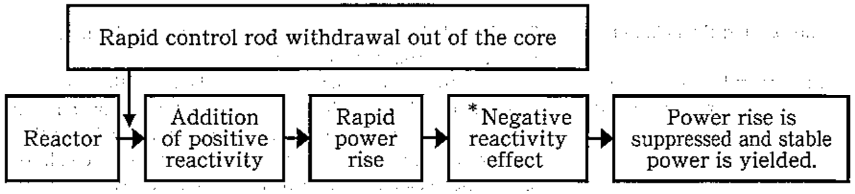


Fig. 1 Conceptual Drawing of Confinement of Radioactive Materials (for PWR)

(3) Self Control Capability of a Reactor

A light water reactor has inherent self-control capability by feedback of negative reactivity against power increase. As shown in the following drawing, a reactor has the capability of self control limiting the increase of the reactor power, if the control rod is rapidly withdrawn out of the core and the positive reactivity is rapidly added.



* Negative reactivity effect : There are abnormal withdrawal, projection and drop of the control rods as the examples of the incidents of rapid addition of positive reactivity in a light water reactor. When the reactor power increases by these incidents, the temperature of the fuel rises and a resonance absorption of neutron by uranium increases. As the result, Doppler's effect which decrease the reactivity occurs. As the temperature of the moderator also rises, it's density lowers or the moderating rate of neutron is reduced by the effect of the void generated by boiling. It is called negative reactivity effect or self-control capability that when the power increases, the reactivity is naturally reduced.
(Source: Nuclear Power Generation hand Book (1982) edited by the Nuclear Power generation Section in the Public-service Undertaking Dept., Agency of Natural Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-Sha)

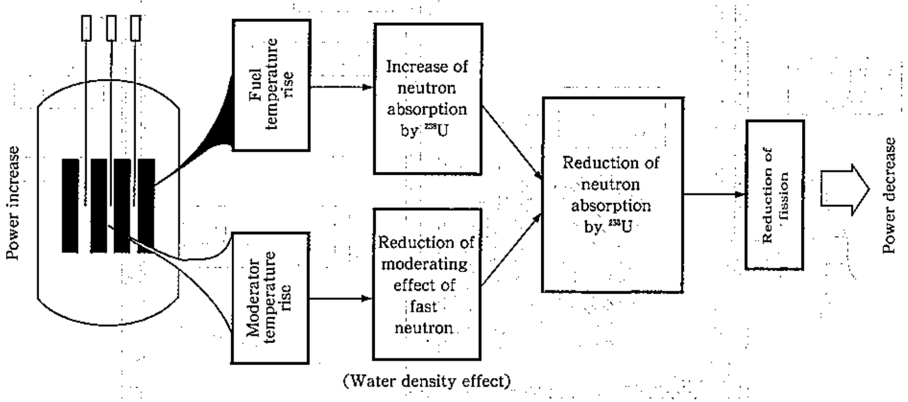


Fig. 2 Self-Control Capability

(4) Emergency Core Cooling System (ECCS) for LWR

Emergency core cooling system (ECCS) which is one of the engineered safety facilities injects the cooling water (boric acid for PWR) into the reactor at loss accident of the primary coolant to prevent the fuel from deteriorating by excessive heating and from reacting the cladding (zirconium) with water. The containment spray system sprays the cooling water into the containment vessel and decreases the internal pressure and takes in the floating iodine in the gas not to release from the containment. Strictly speaking, the containment spray system is not included in the ECCS.

The pumps and piping in the ECCS is designed with multiplicity and diversity. The drive power for these pumps can be supplied from the emergency power system. Therefore, the ECCS can perform their functions and ensure the safety of the reactor at all assumed accidents.

The ECCS is designed to be tested their functions periodically during plant operation.

(a) ECCS for BWR

The ECCS network for BWR 5 type is shown in **Fig. 3**. The purpose and the function of the ECCS are following.

1) Low Pressure Core Spray System

The low pressure core spray system has a function to spray the cooling water above the core in conjunction with the low pressure injection system and the high pressure core spray system at large break accidents. At small/medium break accidents in which the reactor pressure does not decrease rapidly, first, the automatic depressurization system forces the reactor to depressurize and after that the low pressure core spray system can inject the cooling water into the reactor. The low pressure core spray system sprays the suppression pool water above the fuel assemblies through the spray nozzle of the spray headers attached the upper shroud and cools the fuel.

2) Low Pressure Core Injection system

The low pressure core injection system is one of some operation modes of the residual heat removal system. The low pressure core injection system has a function to cool the fuel in conjunction with the low pressure core spray system and the high pressure core spray system at large break accidents. At small/medium break accidents, the low pressure core injection system also has the function to cool the fuel in conjunction with the automatic depressurization system. The low pressure core injection system can directly inject the suppression pool water inside the core shroud and cool the fuel by flooding the fuel to the height of two third at the break of the piping of the recirculation system.

3) High Pressure Core Spray System

The high pressure core spray system has a function to inject the cooling water into the reactor over all pressure range at assumed accident of piping break. At large break accidents, the high pressure core spray system cools the fuel in conjunction with the low pressure core spray system and the low pressure injection system and at small/medium break, has the function to cool the fuel only. The high pressure core spray system sprays the cooling water above the fuel assemblies through the spray nozzle of the spray headers attached the upper shroud and cools the fuel.

4) Automatic Depressurization System

The automatic depressurization system has the function to cool the fuel in conjunction with the low pressure core spray system and the low pressure injection system when the high pressure core spray system does not function at small/medium break accidents.

5) Residual Heat Removal system

The residual heat removal system has five operation modes which are independent functionally. Two other modes are described here.

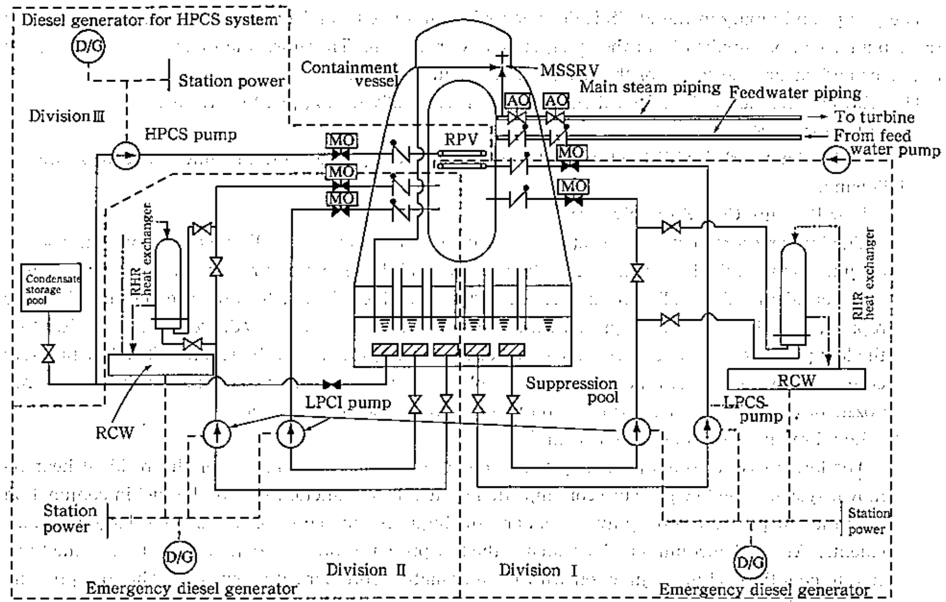
(i) Suppression pool water cooling system

When the temperature of the suppression pool water is increased, the suppression water cooling system takes in the suppression water and cools it by the heat exchanger and return it to the suppression pool.

(ii) Containment Spray Cooling System

At loss accident of the primary coolant, the containment spray cooling system sprays the suppression pool water into the containment vessel to condense a steam and decrease the inner pressure of the containment vessel.

Fig. 3 Network of ECCS (BWR 5 type, 1100MWe class)



RCW: Reactor building closed cooling water system
RPV: Reactor pressure vessel
MSSRV: Main steam safety relief valve
HPCS: High pressure core cooling system
LPCS: Low pressure core cooling system
RHR: Residual heat removal system

(b) ECCS for PWR

The ECCS network for PWR type is shown in **Fig. 4**. The purpose and the function of the ECCS are following.

1) Accumulator Injection System

At loss accident of the primary coolant, the accumulator injection system injects the water with boric acid into the reactor with the reactor pressure decreasing and keeps the reactor subcritial and prevents the fuel from melting due to delay of the water injection by the high and low pressure injection system.

2) Safety Injection System

(i) High Pressure Injection System

At loss accident of the primary coolant, the high pressure injection system injects the water with boric acid stored in the refueling water storage tank into the reactor vessel through the piping of the primary coolant and ensures to cool the fuel and to keep the core subcritical. The charging pump connected the primary coolant loop can increase the amount of the injection water.

(ii) Low Pressure Injection System

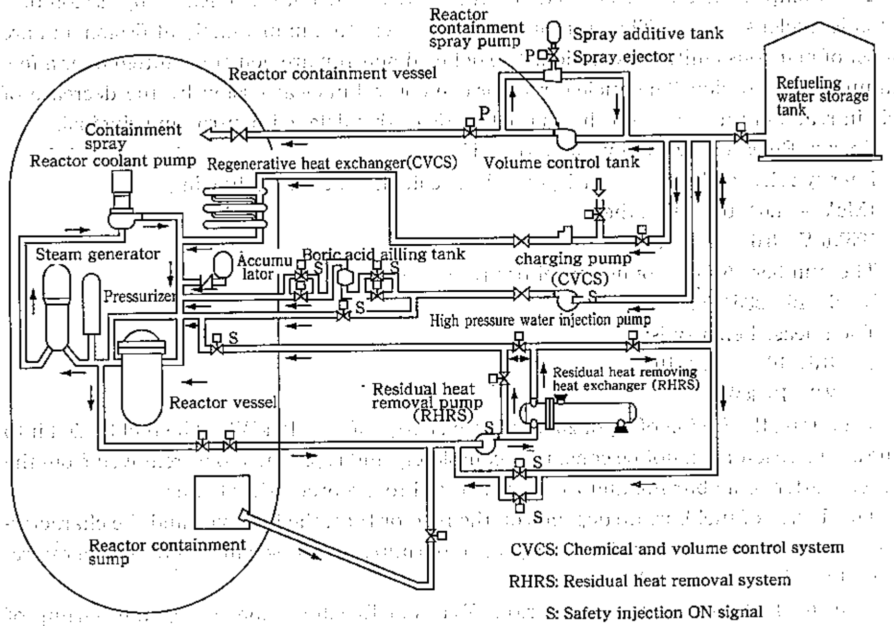
At loss accident of the primary coolant, the low pressure injection system injects the water with boric acid stored in the refueling water storage tank into the reactor vessel through the piping of the primary coolant and ensures to cool the fuel and to keep the core subcritical. After all water with boric acid stored in the refueling water storage tank being injected, the water in the sump installed at the bottom of the containment vessel is taken by the residual heat removal pumps and is cooled by the residual heat removal heat exchanger and is injected into the reactor vessel. Therefore, the necessary water source is ensured continuously.

The high pressure injection system can also inject the sump water into the reactor vessel through the bypass line from the outlet of the RHR heat exchanger. The RHR system can be used to remove decay heat during the reactor shutdown and is in standby during normal operation as the low pressure injection system. Both functions are not required at the same time and there is no problem on safety.

(iii) Containment Spray System

At loss accident of the primary coolant, the containment spray system injects the water with boric acid stored in the refueling water storage tank into the containment vessel and decrease the inner pressure rapidly. At the same time, the chemical additive in the tank is added into the water with boric acid and removes iodine in the gas of the containment vessel. After all water with boric acid stored in the refueling water storage tank being injected, the water in the sump installed at the bottom of the containment vessel is taken by the containment spray pumps and is injected into the containment vessel again.

Fig. 4 Network of ECCS for PWR (1100MWe class)



CVCS: Chemical and volume control system
RHRS: Residual heat removal system
S: Safety injection ON signal
P: Containment spray pump ON signal

13-4 Physics of Nuclear Reactor

(1) Nuclear Fission Reaction

(a) Reaction Equation

$$^{235}_{92}U+^{1}_{0}n \longrightarrow ^{x}_{a}A+^{y}_{b}B+(2\sim3)^{1}_{0}n+(\text{energy})$$

As the result of the nucleus fission of ^{235}U, 2 fission products, a few neutrons are produced and some energy is released. The nuclear reactor makes use of this released energy.

(b) Total Usable Energy per Fission of an Atomic Nucleus

In units of MeV

Energy type	^{233}U	^{235}U	^{239}Pu
Kinetic energy of fission fragment	163	168	172
Total energy of gamma ray	14	14	14
Total energy of fission neutron	5	5	5.8
Total energy of beta ray	8	8	8
Total	190	195	200
Number of prompt fission neutrons	2.51	2.47	2.91
Ratio of delayed neutrons	0.0026	0.0064	0.0021

2.47 prompt neutrons are emitted and the energy of 195MeV is released by fission of a atomic nucleus of ^{235}U. The prompt neutrons are emitted immediately at fission and are most of neutrons emitted by fission. The delayed neutron are neutron emitted over a few minutes after fission. The nuclear reactor can control nuclear fission by the decrease of chain reaction rate based on the characteristic of this delayed neutron in principal.

(c) Energy Released by Fission of 1g of ^{235}U

Energy released by fission of 1g of ^{235}U is calculated as the following.

$1\text{MeV} = 1.6\times10^{-13}\text{W}\cdot\text{s}$, then

$195\text{MeV}=8.6\times10^{-18}\text{kWh}$

The number (N) of atomic nuclei per 1g of ^{235}U:

$N=6\times10^{23}/235\fallingdotseq2.5\times10^{21}$

The released energy is:

$W=8.6\times10^{-18}\times2.5\times10^{21}$

$\quad=2.2\times10^{4}\text{kWh}$

Therefore, the fission of 1g of 235U release energy of 2.2×10^{4}kWh. The fuel loaded into the actual reactor can not be consumed completely and is planned to be removed from the reactor after some burnup and to be transferred to a reprocessing factory.

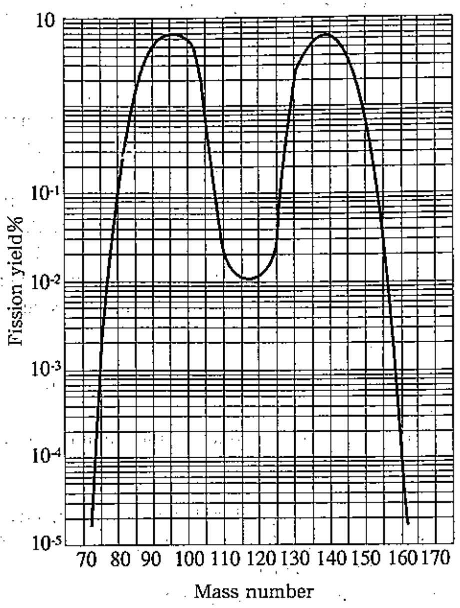
The degree of fuel burnup depends on the reactor type, the fuel type and the characteristics of the reactor. Generally, the degree of burnup is expressed in unit of the energy released per 1ton of the fuel (MWD/t).

Refer to "13-2 Specifications of Various Types of Reactors" concerning the burnup of various reactors.

(2) Fission Products and Their Decay Heat

(a) Fission Yield (%) of ^{235}U

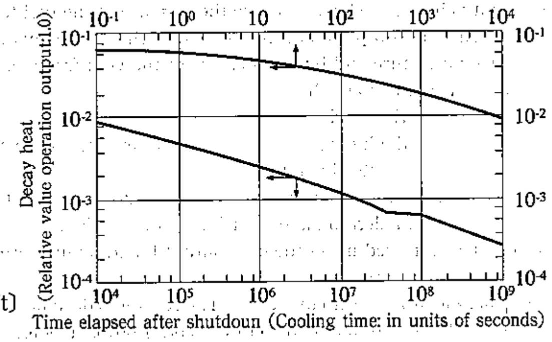
The range of the mass number of the fission products A and B is from 72 to 161. The range of atomic number is from 30 of Zn to 66 of Dy. The right drawing shows the fission yields of the fission products of ^{235}U.



(b) Major Fission Products

Near mass number of 95		Near mass number of 139	
Products	Half time	Products	Half time
$^{83}_{35}Br$	2.3 hours	$^{132}_{52}Te$	77.7 hours
$^{85}_{36}Kr$	10.8 years	$^{133}_{53}I$	20.3 hours
$^{91}_{38}Sr$	9.67 hours	$^{137}_{55}Cs$	30.0 years
$^{91}_{39}Y$	58.8 days	$^{130}_{56}Ba$	84 minutes
$^{95}_{40}Zr$	65.5 days	$^{153}_{62}Sm$	47.1 hours

(c) Decay Heat Curves of Fission Products (infinite irradiation)



〔Source: ANS-5.1, Oct, 1971-Draft〕

(3) Breeding Reaction Equation

$$^{238}U+^{1}_{0}n\rightarrow{}^{239}U\xrightarrow[(23.5\text{minutes})]{\beta}{}^{239}Np\xrightarrow[(2.35\text{days})]{\beta}{}^{239}Pu$$

$$^{232}Th+^{1}_{0}n\rightarrow{}^{233}Th\xrightarrow[(22.2\text{minutes})]{\beta}{}^{233}Pa\xrightarrow[(27\text{days})]{\beta}{}^{233}U$$

Note: The values enclosed in parentheses means half life.

The materials as ^{238}U or ^{232}Th do not undergo nuclear fission, but after these materials absorbed neutron and undergo twice β decay, these become converted to fissile materials of ^{239}Pu or ^{233}U.

A breeder reactor makes use of such a reaction and produce fissile material (such as ^{239}Pu or ^{233}U) greater than be consumed. But, in the conventional reactors (such as a thermal reactor), the amount of fissile material converted is less than be consumed.

13-5 Reactivity Change and Operation of Nuclear Reactor

(1) Effective Multiplication Factor

The nuclear reactor consists of the nuclear fuel, the moderator to decrease the energy of the neutron emitted by fission, and the neutron reflector surrounding the core. The control rod to be neutron absorption material is inserted or withdrawn to control the operation of the reactor.

It is assumed that the neutrons of N_1 are absorbed into the fuel. Most of the absorbed neutrons are absorbed into the fissile materials and a few prompt neutrons are emitted per fission. These neutron flux collide with the moderator and become the thermal neutron and diffuse in the core.

In this process, some of the neutrons are absorbed into the moderator or leak out of the core. The remaining neutrons N_2 is absorbed in the fuel as next thermal neutrons. The effective multiplication factor is defined as the ratio of these neutrons (N_1 and N_2).

$$K_{eff} = \frac{N_2}{N_1}$$

The condition, Keff equals 1, is called the critical condition and the chain reaction continues at $K_{eff} \geqq 1$.

The reactivity is defined as the amount of deviation from the critical condition.

$$\rho = \frac{K_{eff}-1}{K_{eff}}$$

The core is designed with some excess reactivity to be $\rho>0$. Therefore, the reactor is normally operated keeping $\rho=0$ by controlling the position of the control rod.

(2) Reactivity Change

(a) Reactivity Change by Power

As the power of the reactor increases, the temperature of various parts of the core also increases and the reactivity changes. This is because the increase of the fuel temperature causes the changes of the degree of neutron absorption and the reactivity changes (generally decrease) by the increase of the moderator temperature and by the increase of the void fraction. Designating the initial reactivity by ρ_{ex}, reactivity is defined as follows,

$$\rho = \rho_{ex}+K_f t_f+K_m t_m+K_v v+ \cdots\cdots$$

t_f, t_m, v: the increases of fuel temperature, moderator temperature, and void fraction from the steady state values

K_f, K_m, K_v: Doppler's coefficient (temperature coefficient of fuel), temperature coefficient of moderator, and void fraction coefficient

This can be expressed using the core output P and its increase ΔP as below.

$$\rho = \rho_{ex}+K_p\ (\Delta p/p)$$

The K_p is called the power coefficient. The reactor is designed for K_p to be negative. The outline values such as the reactivity coefficient of typical power reactors are shown in the next table.

	K_f (10^{-5}/℃)	K_m (10^{-4}/℃)	K_v (10^{-4}/%)	K_p ($10^{-3}/\Delta p/p$)	Excess reactivity (10^{-2})	Reactivity of control rod (10^{-2})
PWR	−2.3〜−5.6	0〜−7.8	+6〜−25	−25	+14	+7+20*
BWR	−1.5	—	−8	−45	+14	+18
HWR	−1.6	+2	〜0	−8.5	—	—

* Reactivity by chemical shim

(Source: Mechanical Engineers' Handbook, edited by the Japan Society of Mechanical Engineers, Part B6 (1986),135)

(b) Reactivity Change by Buildup of Fission Products

Some of the fission products have large absorption cross section and high fission yields. These materials cause negative reactivity effect. The important nuclides of these products in operation are Xe-135 and Sm-149. Xe-135 which is dependent on the power, is particularly important, because of Sm-149 is not dependent on the power.

The concentration of Xe-135 reaches to a equilibrium state after the reactor has been operated long time at a constant power. If the reactor is shut down after this long period operation, the concentration of Xe-135 become greater than the equilibrium value 8〜9 hours after shutdown by the decay of I-135 being the parents nuclide of Xe-135 and then decreases after that. Therefore, when restarting the reactor in a few hours after shutdown, the reactivity of the core has been decreased by the negative reactivity effect of Xe-135.

(c) Reactivity Change by Fuel Burnup

Burnup of the fuel brings the following phenomena.

1) Consumption of ^{235}U (decrease of reactivity)
2) Production of Pu, etc. (reactivity increase by buildup of fissile ^{239}Pu and ^{241}Pu)
3) Buildup of fission products (F.P.) (decrease of reactivity)
4) Decrease of burnable poison (increase of reactivity)

The reactivity of the core decreases in accordance with burnup as the summation of these four effects.

(3) Control of Operation

(a) Reactivity Control by Control Rod

The reactivity control by the control rod is used to control large reactivity and performs the following function.

1) To keep $K_{eff}<1$ with margin sufficient to compensate all excess reactivity during reactor shutdown.
2) To shut down the reactor by inserting all control rods into the reactor in the short time at the upset condition
3) To control the reactivity at big power fluctuation
4) To compensate the decrease of reactivity by burnup
5) To adjust the power distribution in the core as uniform as possible

(b) Reactivity Control by Control of the Recirculation Flow

If the recirculation flow rate is increased at the steady state operation with a constant power and a constant recirculation flow, the reactor power will be increased by being added the positive reactivity of the void effect because of the reduction of the void fraction. If the recirculation flow rate is decreased, the power will be decreased by the reverse effect (the increase of the void fraction and the negative reactivity).

BWR can control the power range from 60% of the rated to 100% by the control of the recirculation flow rate without moving the control rod. Therefore, this control way is used to respond the power control at load fluctuation, etc in BWR. This control way is easier than moving the control rod and limit the change of the power distribution small and has a merit of a small impact to the fuel.

(c) Reactivity Control by Concentration of Boric Acid

The boric acid is a material having large neutron absorbing effect and it's concentration change can be used to control the reactivity of the nuclear core. In PWR, a boric acid is dissolved into the primary coolant and the reactivity of the core is controlled adjusting the concentration of the boric acid in the primary coolant. The adjustment of the concentration of boric acid is done by adding the purified water (the dilution of the boron concentration) or by adding the boric acid of the high concentration (the addition of the boron).

This control way is used to control the following slow reactivity fluctuation.

1) Reactivity change by the temperature change of the primary coolant from cold condition to hot condition
2) Reactivity change by the concentration change of Xe and Sm
3) Reactivity change by the fuel burnup

For instance, when compensating the reactivity change resulting from the burnup by the adjustment of the boron concentration, the concentration of the boron is decreased corresponding to the reduction of the reactivity.

13-6 Coolants

Properties / Coolants	Density (kg/m^3)	Melting point (℃)	Boiling point at 1 atm (℃)	Specific heat (kJ/kgK)	Thermal conductivity (W/mK)	Absorption cross section (b*)
Light water (6.93MPa [gage]288℃)	736	0	100	5.40	0.565	0.66
H_2O (15.5MPa [gage]307℃)	712			5.65	0.544	
Saturated steam H_2O	46.2 (300℃)	—	—	5.99 (300℃)	0.0615 (300℃)	0.66
Heavy water D_2O	795 (316℃)	3.8	101	7.03 (316℃)	0.490 (316℃)	0.0011
Helium He (1.03MPa [abs])	0.093 (316℃)	—	—	5.228 (316℃)	0.155	0.0070
Sodium Na	831 (500℃)	97.8	883	1.2621 (500℃)	67 (500℃)	0.525
Carbon dioxide CO_2	1.976 (0℃,1atm)	—	—	0.850 (20℃)	1.51×10^{-2} (20℃)	0.0041

* 1b (barns) $=10^{-28}m^2$

13-7 Moderators

Property Comparison of Main Moderator Materials

Properties	Light water	Heavy water 99.75 [%] D_2O	Beryllium	Beryllium oxide	Graphite
Atomic weight or molecular weight	18.0	20.0	9.01	25.0	12.0
Density [kg/m^3]	1.00×10^3	1.10×10^3	1.84×10^3	2.80×10^3	1.62×10^3
N [cm^{-3}]	3.3×10^{22}	3.3×10^{22}	1.2×10^{23}	6.7×10^{22}	8.1×10^{22}
Scattering cross section (Epithermal neutrons) [b]	49	10.5	6.0	9.8	4.8
Absorption cross section (Thermal neutrons) [b]	0.66	0.0026	0.009	0.0092	0.0045
Macroscopic scattering cross section Σ_s(Epithermal neutrons) [cm^{-1}]	1.64	0.35	0.74	0.66	0.39
Macroscopic absorption cross section Σ_a(Thermal neutrons) [cm^{-1}]	0.022	0.000085	0.0011	0.00062	0.00037
Average logarithmic attenuation factor of energy produced in one-time collision ξ	0.93	0.51	0.206	0.17	0.158
Moderating power $\xi\Sigma s$ [cm^{-1}]	1.5	0.18	0.16	0.11	0.063
Moderating ratio $\xi\Sigma s/\Sigma a$	70	2,100	150	180	170
Diffusion Constant [cm]	0.18	0.85	0.61	0.56	0.92
Diffusion length [cm]	2.88	100	23.6	30	50
Fermi age [cm^2]	33	120	98	110	350
Travel [cm]	6.4	101	26	32	54

[Source: New Metallic Course, Nuclear Material(1962), The Japan Institute of Metals]

(1) The following properties should be required as the moderator.

(a) The neutron absorption shall be small as possible.

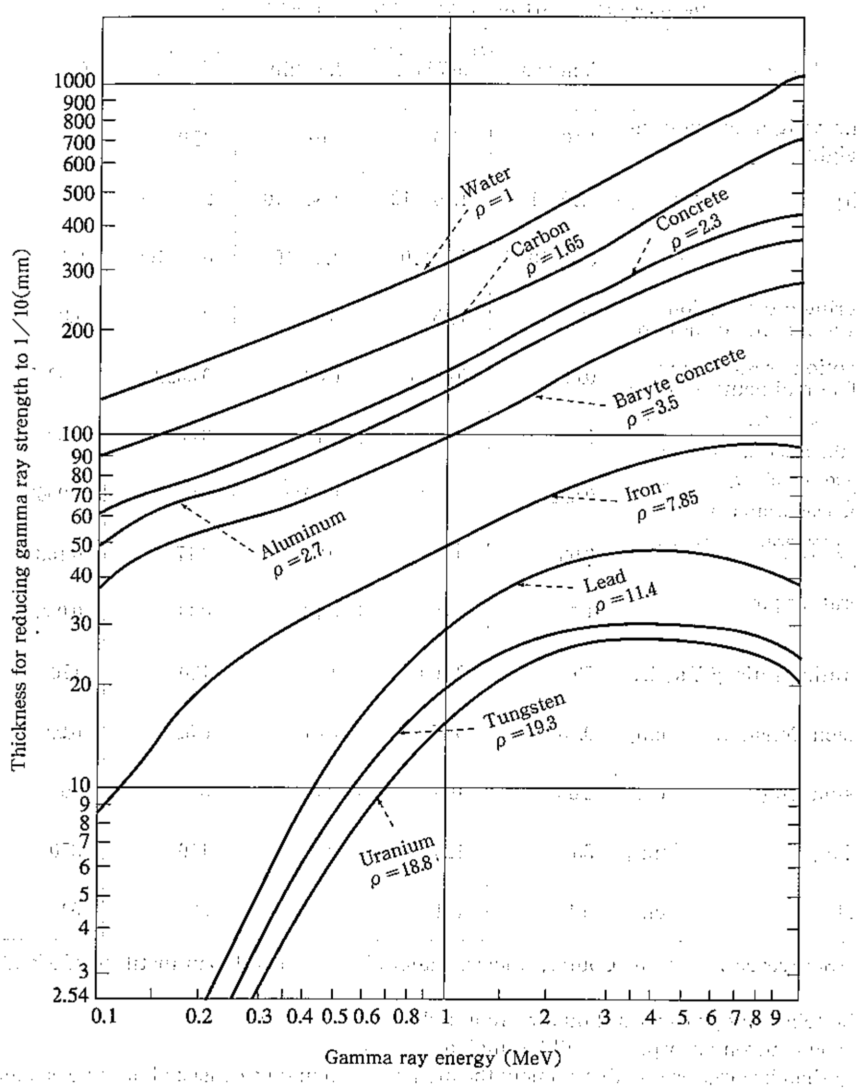
(b) ξ shall be large as possible, namely the moderator should be consisted of some elements with small atomic weight.

(c) Moderating power and moderating ratio shall be large as possible.

(2) Function of the reflector

The function of the reflector is to return neutrons, which are produced by fission in a reactor, into a reactor by scattering in order to prevents them from leaking out of a reactor and to enhance neutrons economics. The properties of reflector is required as same as moderator so that the material of a moderator is also used as a reflector in a thermal reactor.

13-8 Shielding Materials



(Note) 1. These curves show the thickness required to reduce the strength of gamma rays to 1/10, which is called 1/10 value layer. These values are based on the assumption that gamma rays is irradiating in linear flux.
2. "ρ" in this figure means specific gravity of each material.
3. Half thickness is obtained by multiplying the value shown in this diagram by $\log_{10}2=0.3010$

〔Source: Nuclear Power Generation Hand book (1982 Edition) edited by the Nuclear Power Generation Section in the Public -Service Undertaking Dept., Agency of Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-Sha〕

13-9 Materials for Neutron Absorption

Properties of Potential Materials for Neutron Absorption

Element	Atomic number	Density		Melting point (℃)	Isotope with large thermal neutron absorption cross section	Natural abundance of isotope in the left column (%)	Thermal neutron absorption cross section 〔b〕	Mecroscopic thermal neutron absorption cross section 〔cm⁻¹〕	Neutron absorbing reaction
		g/cc	10^{22}/cc						
Boron	5	2.3	14.0	2,300	Natural 10	(100) 20	750 3,800	97.0	n • α
Silver	47	10.5	5.9	960	Natural 107 109	(100) 51.35 48.65	63 31 87	3.7	n • γ
Cadmium	48	8.6	4.6	321	Natural 113	(100) 12.26	2,450 20,000	113.6	n • γ
Indium	49	7.3	3.8	156	Natural 113 115	(100) 4.23 95.77	196 58 207	7.5	n • γ
Gadrium	64	7.9	3.1	1,350	Natural 155 157	(100) 14.73 15.68	46,000 60,000 240,000	1400	n • γ
Hafnium	72	13.09	4.4	2,222	Natural 176 177 178 179 180	(100) 5.15 18.39 27.08 13.78 35.44	105 15 380 75 65 14	4.6	n • γ
Tantalum	73	16.65	5.5	2,996	181	100	21.3	1.18	n • γ

＊1b (barn) $=10^{-28}$m²

Comparison of Main Neutron Absorbing Materials

Material	Contents of major neutron poisons	Relative absorbing value with respect to hafnium
Stainless steel with boron	3.0w/o^{10}B	1.13
〃 〃	2.0w/o^{10}B	1.08
Hafnium	—	1.00
Silver-indium-cadmium alloy	80w/oAg, 15w/oIn, 5w/oCd	1.03
Silver-cadmium alloy	70w/oAg, 30w/oCd	0.92
Silver	—	0.88
Cadmium	—	0.88
Tantalum	—	0.71
Zircaloy 2 (Reference)	—	0.049

〔Source: Special Metal Materials by Ryouseki Mishima, Corona Publishing Co. Ltd. (1971)〕

13-10 Main Materials of Reactor

Major Materials of BWR and PWR

Item		Material	Remarks
Reactor pressure vessel	Body	Low alloy steel ($\frac{3}{4}Ni-\frac{1}{2}Mo-Cr-V$ or $Mn-\frac{1}{2}Mo-\frac{1}{2}Ni$)	SFVQ1A or SQV2A
	Nozzle	Low alloy steel ($\frac{3}{4}Ni-\frac{1}{2}Mo-Cr-V$)	SFVQ1A
	Bolt	Alloy steel rod ($2Ni-\frac{3}{4}Cr-\frac{1}{3}Mo$)	SNB24
Core internals		18Cr-8Ni, 18Cr-12Ni-2.5Mo, 72Ni-14Cr-6Fe	SUS304, 316 NCF600

13-11 Outline of BWR

(1) Specification of Main Parameters for BWR Standard Plant

Item	Sub-item	Specifications				
		Main parameters	500MWclass	800MWclass	1100MWclass	1350MWclass
Core & Fuel	Core	Core thermal output (MWt)	1.593	2,436	3,293	3,926
		Core flow (t/h)	23×10^3	36×10^3	48×10^3	52×10^3
		Steam pressure (MPa(gage))	6.93	6.93	6.93	7.07
		Steam temperature (℃)	286	286	286	287
		Number of coolant recirculation loops	2	2	2	—
	Fuel	Number of fuel assemblies	368	560	764	872
		Fuel rod array	8lines×8rows 9lines×9rows	8lines×8rows 9lines×9rows	8lines×8rows 9lines×9rows	8lines×8rows 9lines×9rows
Reactor	Reactor pressure vessel	Vessel I.D. (m)	4.7	5.6	6.4	7.1
		Vessel height (m)	21	22	22	21
		Maximum operating pressure (MPa(gage))	8.62	8.62	8.62	8.62
		Maximum operating temperature (℃)	302	302	302	302
	Steam separator	Number	108	163	225	349
	Steam dryer	Number of units	1	1	1	1
	Jet pump	Number	16	20	20	10 (Internal pump)
Reactivity control system	Control rod	Number	89	137	185	205
	Control rod drive system	Number of CRD	89	137	185	205
ECCS	L.P. core spray system	System flow (t/h)	744	1,050	1,440	—
		Number of pumps	2	1	1	—
	L.P. core injection system	System flow (t/h)	1,100	1,140	1,690	950
		Number of pumps	4	3	3	3
	H.P. core spray system	System flow (t/h)	681	320~1,050	350~1,580	180~730
		Number of pumps	1	1	1	2
	Automatic depressurization system	Number of valves	4	6	7	8
		Valve capacity (t/h)	375	375	375	380
		Maximum operating pressure (MPa(gage))	(Reactor pressure 7.78MPa [gage])	(Reactor pressure 7.78MPa [gage])	(Reactor pressure 7.78MPa [gage])	(Reactor pressure 7.92MPa [gage])
Reactor containment	Reactor containment	Type	MARK－I	Improved MARK-I	Improved MARK-I and Improved MARK-II	Reinforced concrete integrated with building
	Containment spray system	Number of systems	2	2	2	2

(2) Assembly of the Reactor and Core Internals for BWR

The principal reactor for BWR consists of the reactor pressure vessel (RPV), the core internals, the fuel, the control rods, and its drive system.

The RPV contains and supports the core fuel, and also contains the jet pumps. In the RPV, the flow path necessary for the coolant to flow through the core fuel, the flow path necessary for steam - water mixture out of the core to flow and the flow path for water and steam separated by the steam separator to flow are formed by some of reactor core internals.

The core fuel is enclosed inside the core shroud which isolates the upward flow of the coolant in the core and the downward flow of the coolant in the annulus between the RPV wall and the core shroud. All fuel assemblies in the core are respectively mounted on the fuel support mounted on the control rod guide tube.

Each control rod guide tube supports the weight of 4 fuel assemblies with one fuel support and is supported by the CRD housing penetrating the wall of the RPV bottom. The core support plate has the function to horizontally position the control rod guide tube at the top end. The top guide attached to the inside wall of the upper portion of the core shroud also has the function to support the top of the fuel assemblies horizontally.

One control rod is arranged among 4 fuel assemblies and is inserted into the core from the bottom of the core. The control rod is connected to the control rod drive (CRD) by the coupling device and the CRD is encased in the CRD housing which is welded to the RPV lower head and is fixed to the flange of the bottom of the housing.

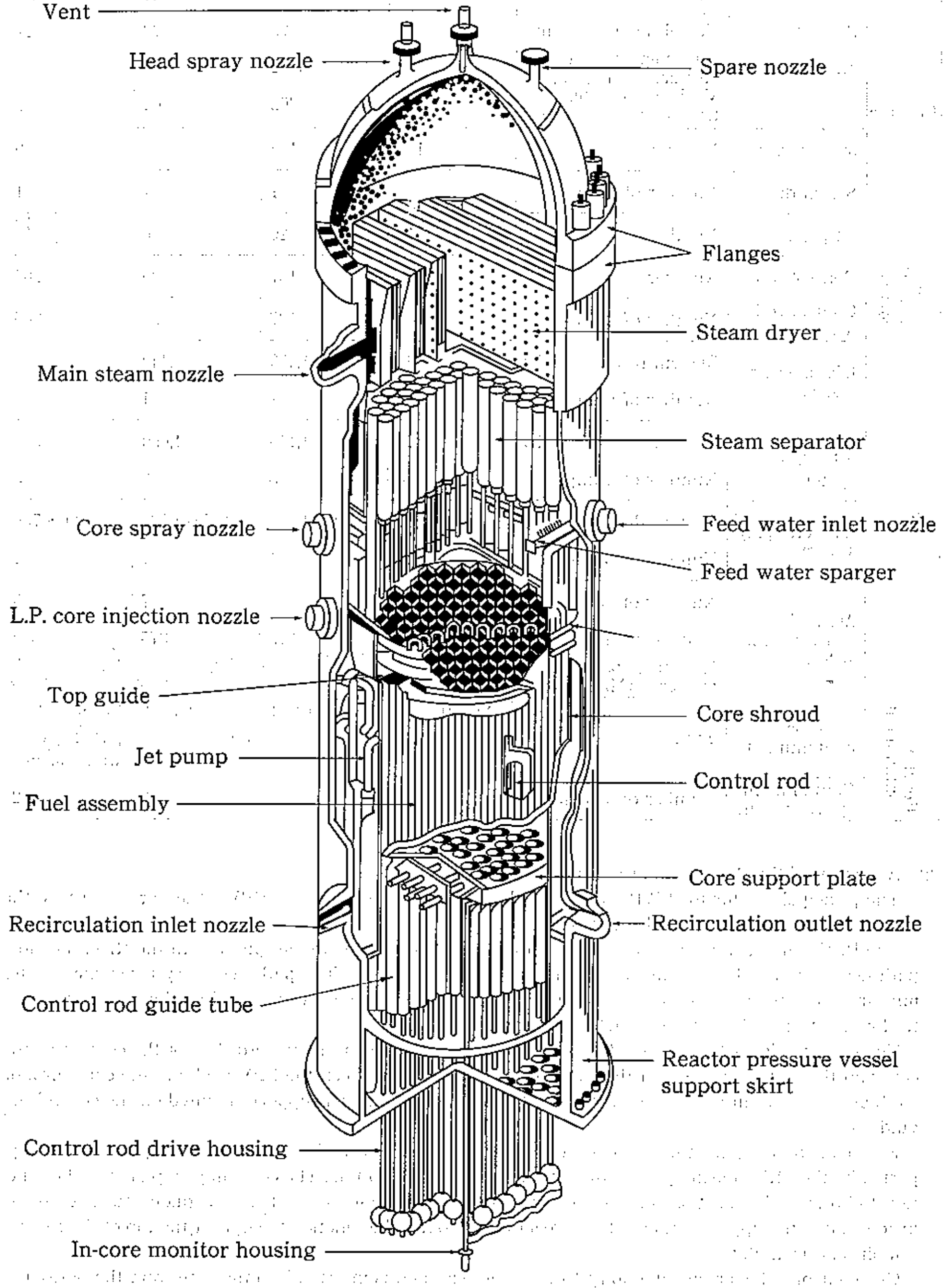


Fig. 1 Assembly of RPV and Reactor Core Internals for BWR

(3) Control Rod and Control Rod Drive for BWR

The control rod has the crucified blade to move up and down in gap formed by four fuel assemblies. The neutron absorber of the control rod is boron carbide and/or hafnium. There are a few types of the control rod assembly which uses boron carbide, hafnium and a combination of boron carbide and hafnium (Refer to the following drawing about the control rod with boron carbide).

The velocity limiter with a umbrella shape is attached to the lower end of the control rod to limit the addition rate of the positive reactivity at the control rod drop accident.

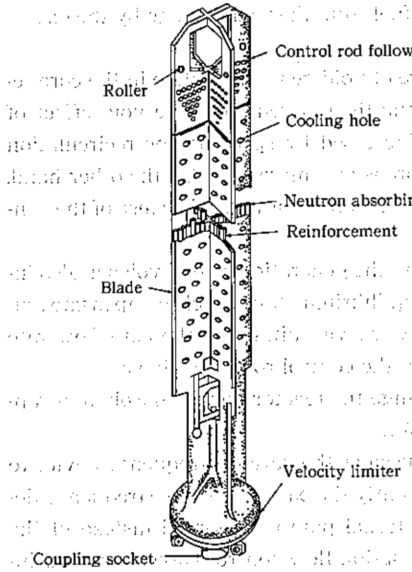


Fig. 2 Assembly of the Control Rod for BWR

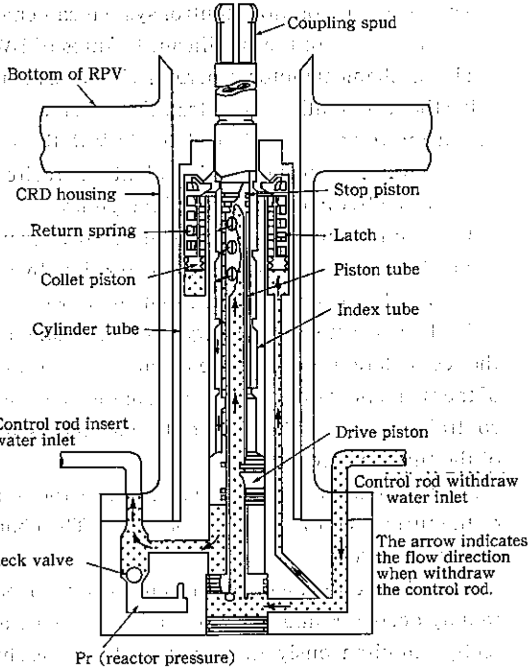


Fig. 3 Sectional Drawing of CRD for BWR

〔Source : Nuclear Power generation Hand book(1991) edited by the Nuclear Power Generation Section in the Public Service Undertaking Dept., Agency of Natural Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-sha〕

(4) Power Control for BWR

The reactor power is controlled by either of the following two methods :

(a) Changing the position of the control rods

(b) Changing the reactor core flow-rate

The method of (a) is to control the reactor power by changing the core reactivity by changing the position of the control rods manually from the main control room. The rod block monitor system is provided to protect the fuel from thermal damage by the excess withdrawal of the control rods.

The method of (b) is to make use of the change of void generation state in the core resulting from the variation of the core flow rate and the inherent negative void effect of BWR. For example, when the core flow rate is increased by speeding the recirculation pump up, the sweeping rate of void out of the core is also increased. On the other hand, the void ratio in the core decreases and the positive reactivity is added because of the generation rate of void does not change.

By this effect, the reactor power is increased and the generation rate of voids is also increased and the reactor power reaches to some equilibrium state which compensates an excess reactivity added temporally. The new power level suitable to the core flow rate can be achieved without changing the position of the control rods like above.

This recirculation flow control system can change the reactor power sharply and rapidly. This is one of the significant features of BWR.

The mechanical motor-generator (M/G) set is used as the variable frequency device to drive the recirculation pump traditionally, but recently the passive variable frequency device using thyristor is adopted. In ABWR, the internal pump is adopted instead of the recirculation pump and in other plant, the recirculation flow control valve was used instead of the frequency control of the pump.

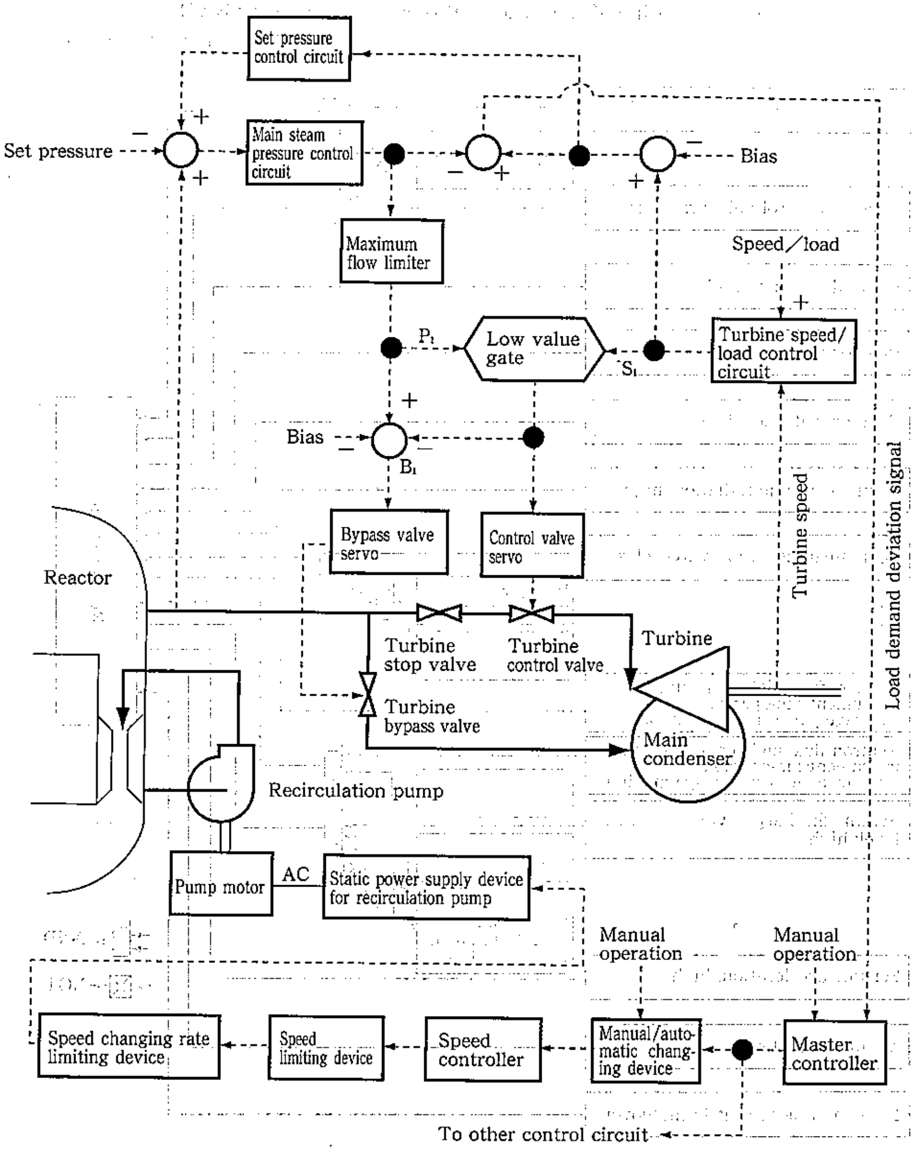
The main steam pressure constant control system is adopted as the control method of the turbine output. This method is possible by setting the input signal S1 to low value gate by 10% greater than the input signal P1.

As the load set signal changes, the subsequent load demand deviation signal changes the recirculation flow and the reactor power is also changed. In accordance with change of the steam flow rate, the signal from the main steam pressure control circuit changes the control valve opening and keeps the steam pressure constant and then the steam flow rate of the turbine is controlled.

In order to improve the initial response, the function to temporally adjust the opening of the turbine control valve is provided. The changing rate of the turbine output is approximately 30% /min.

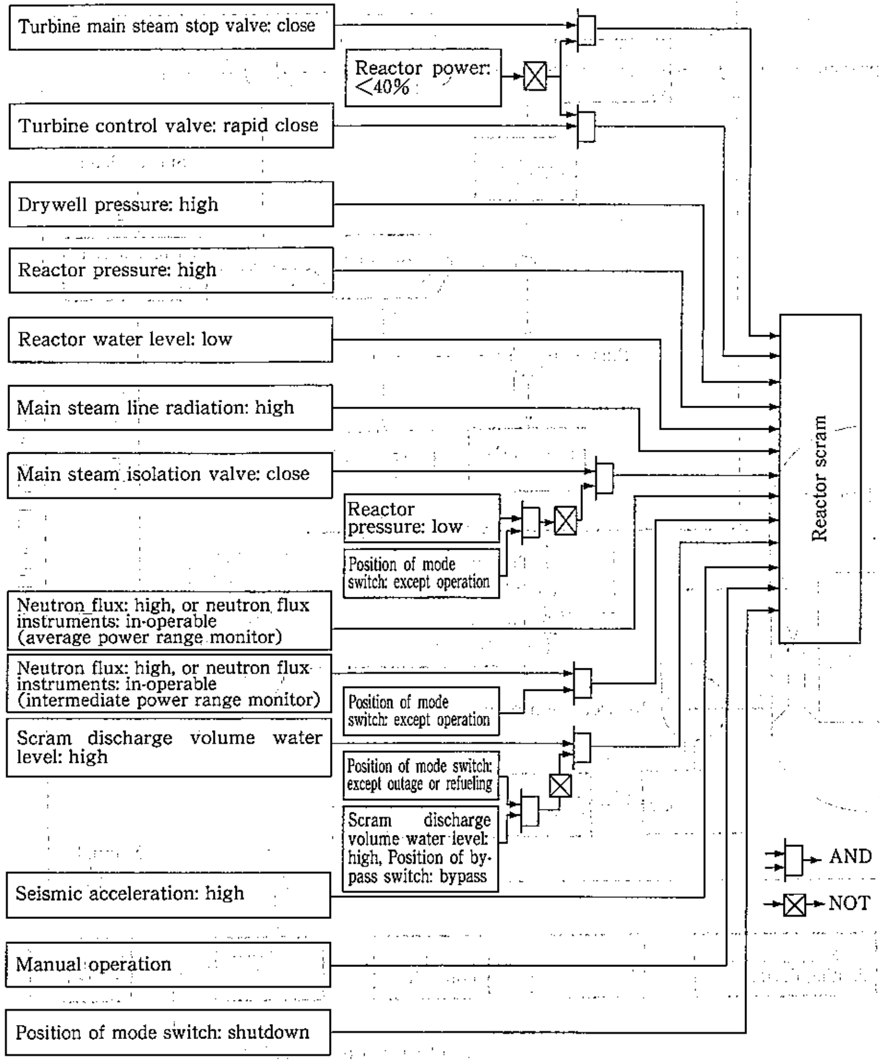
At load rejection incident, the output signal from the turbine speed/load control circuit rapidly decreases and passes the low value gate and make the control valve throttle directly. Simultaneously, the signal of B1 becomes high and opens the turbine bypass valve.

Fig. 4 Power Control Circuit Diagram for BWR Plant (1100MWe class)



(5) Reactor Protection System for BWR

Fig. 5 Outline of the Reactor Protection System for BWR
(BWR-5 1100MWe class)



13-12 Outline of Advanced BWR (ABWR)

(1) History of Advanced BWR Development

The development of ABWR had been performed in collaboration with the electric power companies and BWR plant fabricators as a part of the MITI third advanced and standardization program from 1981 to 1985. The activities were various area from the basic design to many cooperation study of main components etc. The application of ABWR to an actual plant has been decided after 1985.

The followings are the main targets of development.

(a) Improvement of safety and reliability
(b) Reduction of radioactive dose rate of workers
(c) Reduction of amount of radioactive waste
(d) Improvement of operability and maneuverability
(e) Improvement of economy

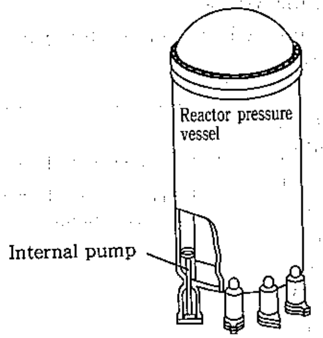
The results of development had been adopted in the actual design for Kasiwazaki Kariwa 6 and 7. Their constructions had been done under a series of license procedure. Kasiwazaki Kariwa 6, which became the first plant as ABWR, has started a commercial operation at August, 1996 and Kashiwazaki Kariwa 7 at July 1997.

(2) Features of ABWR

(a) Internal Pump (RIP)

Instead of the reactor recirculation pump which was located outside the reactor pressure vessel (RPV) in the existing BWR, the internal pump which is directly installed in the RPV has been adopted. As the result, the large size external piping of the recirculation system connected to RPV has been eliminated and the reactor core could be completely covered after the assumed design base accident (LOCA) and it's safety has been improved.

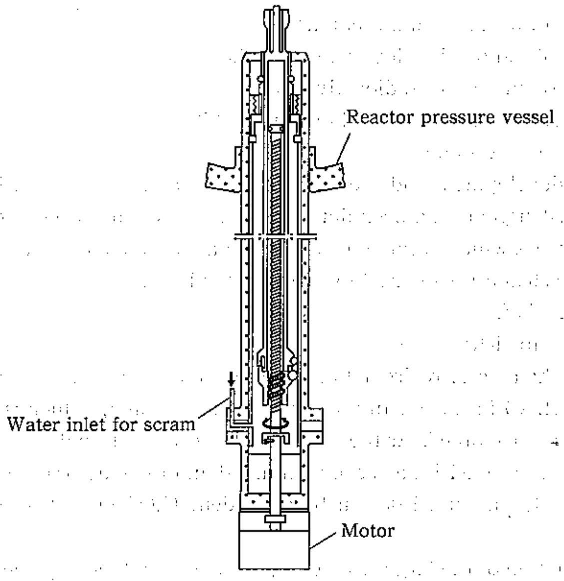
The elimination of the large size piping of the recirculation system brought the following important advantage. (a) Expectation of reduction of radiation exposure at the work in the containment vessel during an annual inspection (b) Reduction of the reactor building volume with the compact containment vessel.



(b) Advanced Control Rod Drive (FMCRD)

In the design of ABWR, advanced control rod drive (FMCRD) has been adopted. FMCRD has two drive mechanisms. The one is a traditional hydraulic drive for reactor scram and the other is a fine motion drive by a step motor for shim operation, which can adjust the position of the control rod finely.

The FMCRD is possible to move multiple control rods at the same time so that the plant startup period can been shortened. The reliability of the plant has been also improved because of diversity of control rod drive mechanisms.



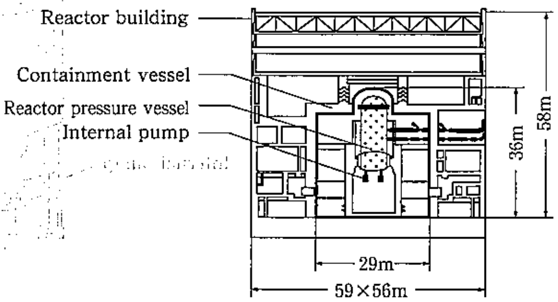
Electrical motor drive + Hydraulic drive

(c) Reinforced Concrete Containment Vessel (RCCV)

RCCV, which has excellent economy performance and higher safety, has been adopted as the containment vessel for ABWR.

RCCV consists of the reinforced concrete with the pressure boundary function and a steel liner with the protection function against leakage.

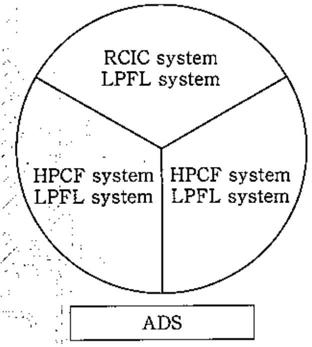
The gravity center of RPV, RCCV and reactor building could be lowered because of the elimination of the recirculation external piping. High seismic capability has been obtained because RCCV is integrated with the reactor building.



(d) Main Control Panel

In the design of ABWR, the main control panel consists of the main panel on which all monitoring and operational functions are provided and the large display panel by which all operators can hold important information on plant operation in common. As the result of these design, effective and sophisticated operation during normal operation, and easy and confirmable operation during accident could be possible. The range of the automatic operation such as FMCRD operation has been enlarged so that reduction of operator load has been achieved.

(e) Optimization of Emergency Core Cooling System(ECCS)



In the design of ABWR, it was not necessary to assume the break of a large size piping because of the adoption of the internal pump. The ECCS network up to BWR 5 has been re-evaluated fundamentally and the network for ABWR has been newly developed.

The new ECCS network is three independent divisions and consists 2 high pressure core flood (HPCF) systems, 1 reactor core isolation cooling (RCIC) system, 3 low pressure flood (LPFL) systems which is one operation mode of the residual heat removal (RHR) system and 1 automatic depressurization system (ADS).

The RCIC system is also given the ECCS function to enhance the capability of high pressure cooling function.

(f) High Efficiency Large Turbine

The power of ABWR has been increased higher than the existing BWR (1100MW). In order to achieve this power efficiently, the high efficiency turbine with final stage blade of 52 inches, reheat cycle and heater drain pump up system has been adopted and the overall thermal efficiency has been improved.

(3) System Configuration

The overall system configuration of ABWR is shown in the Fig.1.

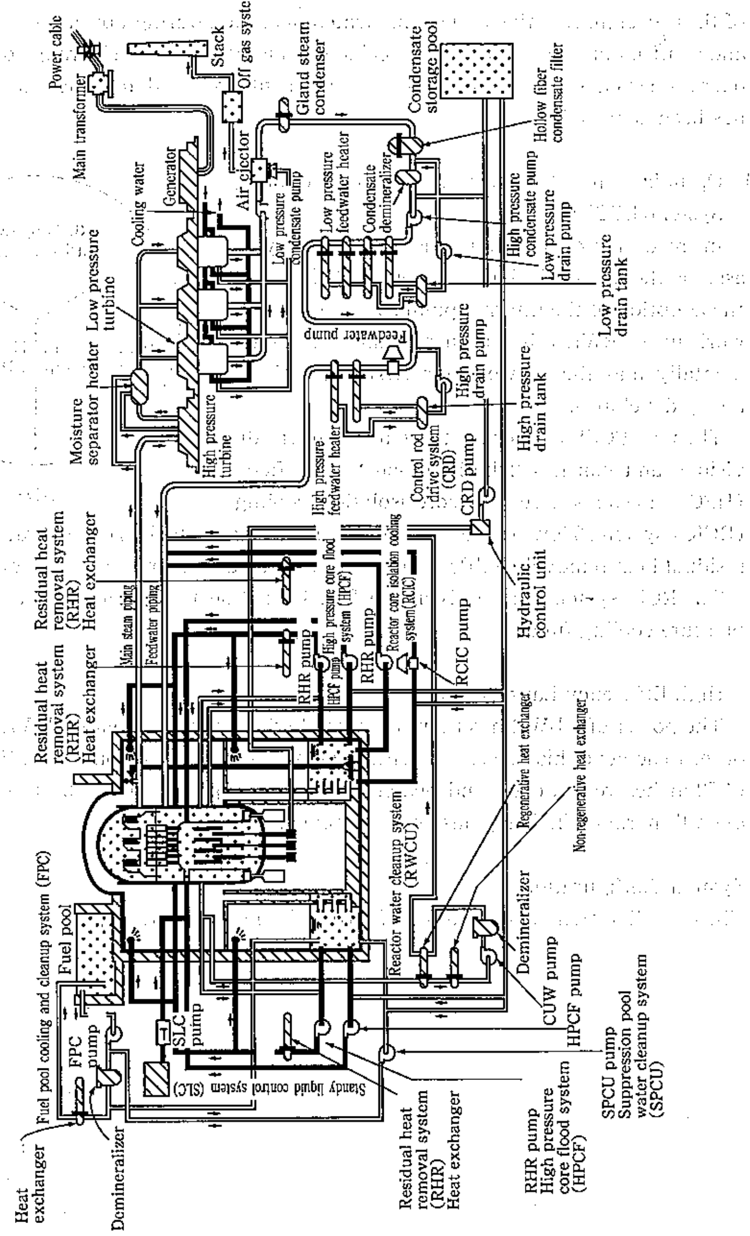


Fig. 1 System Outline of ABWR Nuclear Power Station

13-13 Outline of PWR

(1) Specification of Main Parameters for PWR Standard Plant

Items	Sub-items	Specifications				
		Main parameters	500MWclass	800MWclass	1100MWclass	1500MWclass
Core and Fuel	Core	Core thermal output(MWt) Total reactor coolant flow rate (t/h) Reactor coolant temperature at reactor vessel inlet (℃) Reactor coolant temperature at reactor vessel outlet (℃) Operating pressure (MPa[gage]) Number of reactor coolant loops	1,650 30.3×10^6 288.1 322.7 15.4 2	2,652 45.7×10^6 283.6 321.1 15.4 3	3,411 60.1×10^6 289.2 324.9 15.4 4	4,451 77.3×10^6 288.7 325.0 15.4 4
	Fuel	Number of assemblies Fuel rod array Number of control rod clusters	121 14×14 29	157 17×17 48	193 17×17 53	257 17×17 69～85
Reactor coolant system	Reactor vessel	Inner diameter (m) Overall height (inner) (m) Maximum allowable pressure (MPa [gage]) Maximum allowable temperature (℃)	3.4 11.5 17.2 343	4.0 12.1 17.2 343	4.4 12.9 17.2 343	5.2 13.6 17.2 343
	Steam generator	Number Maximum allowable pressure of shell side (MPa[gage]) Maximum allowable pressure of tube side (MPa[gage])	2 7.48 17.2	3 7.48 17.2	4 8.17 17.2	4 8.17 17.2
ECCS	Accumulator injection system	Volume (m³) Number of tanks	57 2	41 3	38 4	90 4
	High pressure injection system	Charging & Safety injection pump flow (m³/h) Safety injection pump flow (m³/h) Number of pumps	– 160 2	147 – 3	– 320 2	– 300 4
	Low pressure injection system	L.P. injection pump (residual heat removal pump) flow (t/h) Number of pumps	454 2	852 2	1,020 2	– –
Containment vessel	Containment vessel	Type	(Steel containment vessel) Upper : semi-sphere, lower : cylinder with bowl	(Steel containment vessel or Steel containment vessel with thick wall) Upper : semi-sphere, lower : cylinder with bowl	(Prestressed concrete containment vessel) Upper : semi-sphere, lower : cylinder with flat bottom	(Prestressed concrete containment vessel) Upper : semi-sphere, lower : cylinder with flat bottom
	Containment spray system	Number of systems	2	2	2	4

(2) Assembly of Reactor and Reactor Core Internals for PWR

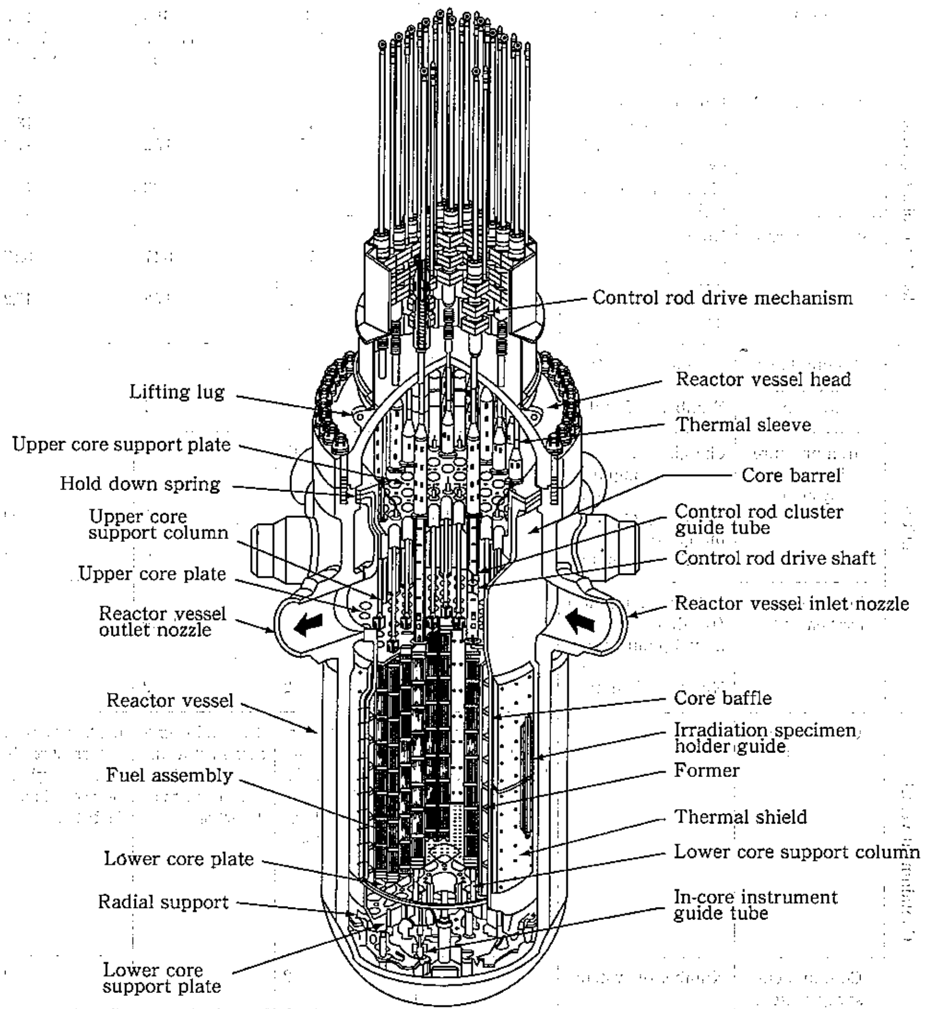
The reactor core internals supporting the fuel assembly consist of the upper core support assembly and the lower core support assembly roughly.

The reactor coolant enters into the reactor vessel through the inlet nozzles provided in the upper shell of the reactor vessel from the cold legs and flows downward in the annulus between the reactor vessel and the core barrel and turns to flow upward in the lower plenum and enter into the bottom region of the core in the almost uniform flow distribution.

The reactor coolant absorbs the thermal energy generated from the fuel rods while flowing upward around the fuel rods and is heated and is mixed in the upper core plenum after passing through the upper core plate and is supplied into the hot legs through the outlet nozzles provided in the upper shell of the reactor vessel.

The upper core support assembly, which consists of the upper core plate, the upper core support plate and the upper core support columns, supports the top end of the fuel assembly and the control rod cluster guide tube and the thermocouples for measuring the reactor coolant temperature etc are attached to the upper core assembly. The upper core support assembly is assembled to the top of the core barrel which is one of the lower core support assembly.

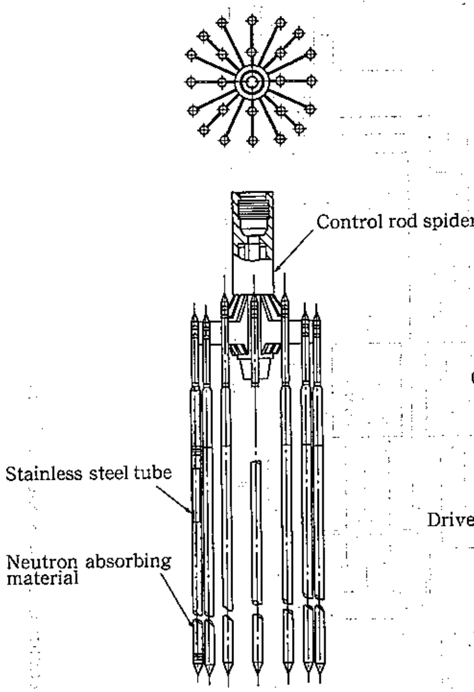
The lower core support assembly, which consists of the core barrel, the lower core plate, the lower core support plate, etc. fixes the fuel assembly in the correct position. The annular flow path is formed between the reactor vessel and the core barrel.



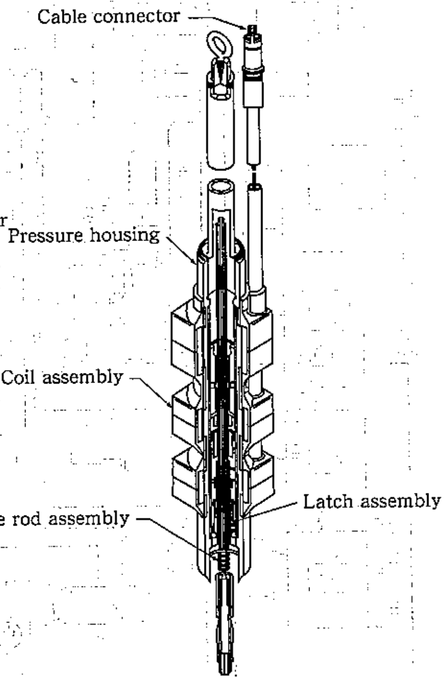
(3) Control Rod and Control Rod Drive Mechanism for PWR

A control rod is a stainless steel tube containing a neutron absorption material and one cluster consists of 16 to 24 control rods.

The assembly of the control rod cluster and the control rod drive mechanism are shown in the following drawings.



Assembly of the control rod cluster



Assembly of the control rod drive mechanism

(4) Power Control for PWR

The reactor power is controlled keeping the core in the critical condition, compensating the excess reactivity with the neutron absorber. In PWR, the control rod and chemical shim are used as the neutron absorber.

(a) Control method by the control rods

The control rods can control the rapid reactivity change occurred by the reactor shutdown or the load change. In this control method, the reactor coolant temperatures measured at the inlet and outlet of the steam generators are averaged by each averaging temperature unit, and the average temperature is averaged by the averaging temperature averaging unit. This averaged temperature becomes an initiation signal to drive the control rod. On the other hand, the first stage pressure of the high pressure turbine is nearly proportional to the load and the load condition can be obtained from this pressure.

The signal of the reference average temperature corresponding to the load can easily be calculated by the pre-determined average temperature program.

By comparing these two signals (the actually measured average temperature and the reference temperature calculated by the pre-determined program), the operation of the control rod cluster such as the withdrawal, the insertion and the stop is controlled and the velocity control of the cluster is also controlled in response to the difference.

Besides, a neutron flux is used as an auxiliary signal of the operating velocity of the control rod. When tripping the reactor, the signal of the trip also cut off the power circuit for the control rod drive mechanism and the control rods are rapidly inserted in the core by gravity and so the reactor is shut down safely.

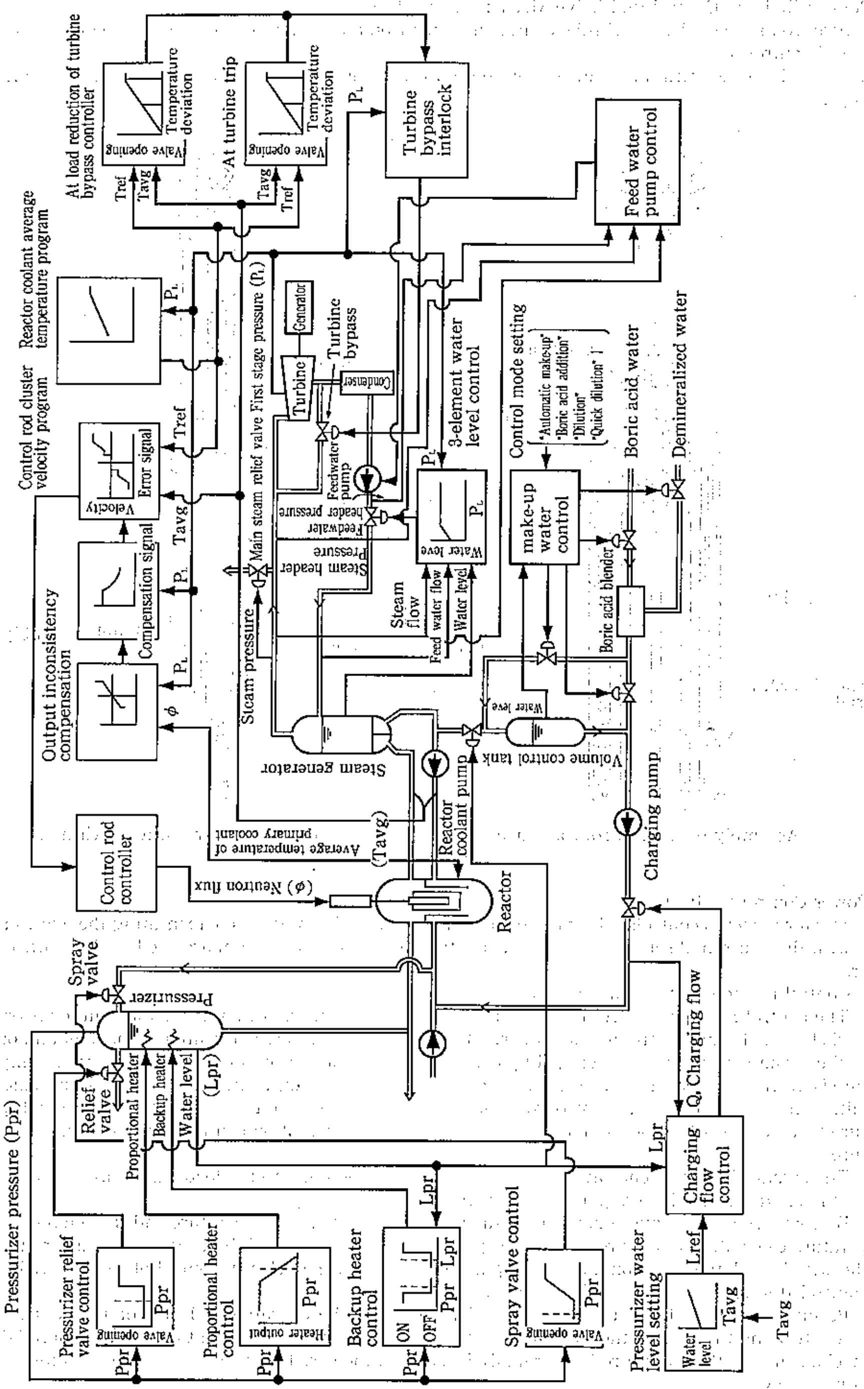


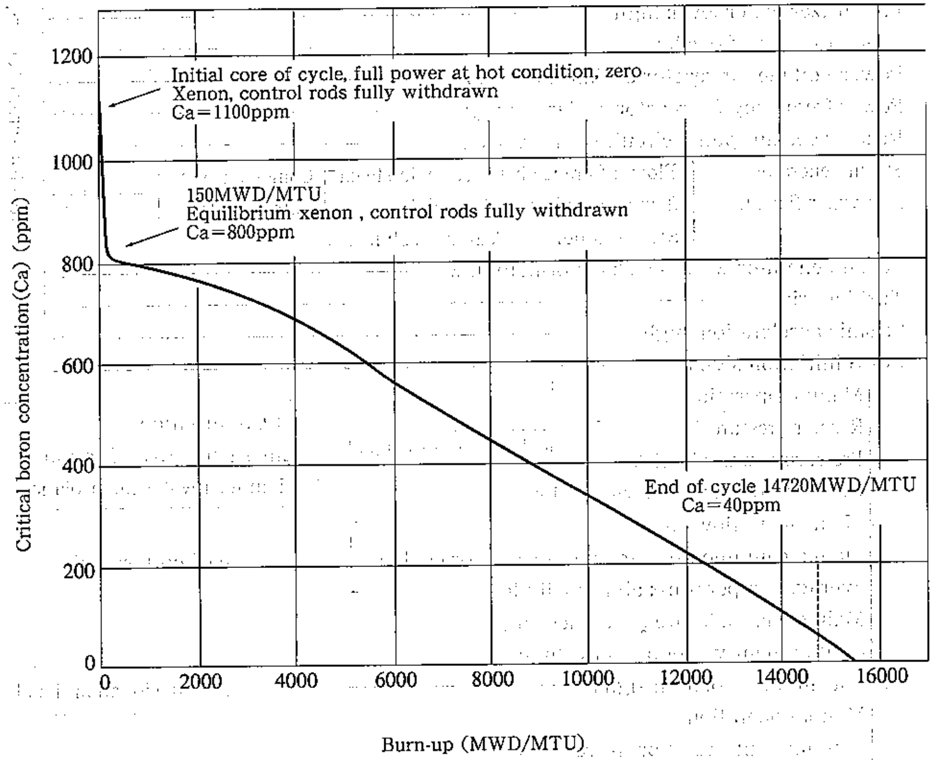
Fig.1 Reactor Control System (PWR)

(b) Control method by the chemical shim

The chemical shim compensates the change of xenon concentration resulting from change of the neutron flux and controls the change of reactivity resulting from burning of the fuel. This method is the way to control the concentration of boron having large neutron absorption cross section.

In order to increase the concentration of boron in the reactor coolant, the boric acid with high concentration is injected into the reactor coolant by the charging pump of the chemical and volume control system.

In order to decrease the concentration of boron, a part of the reactor coolant is drained into the chemical and volume control system and simultaneously purified water is injected into the reactor coolant by the charging pump.

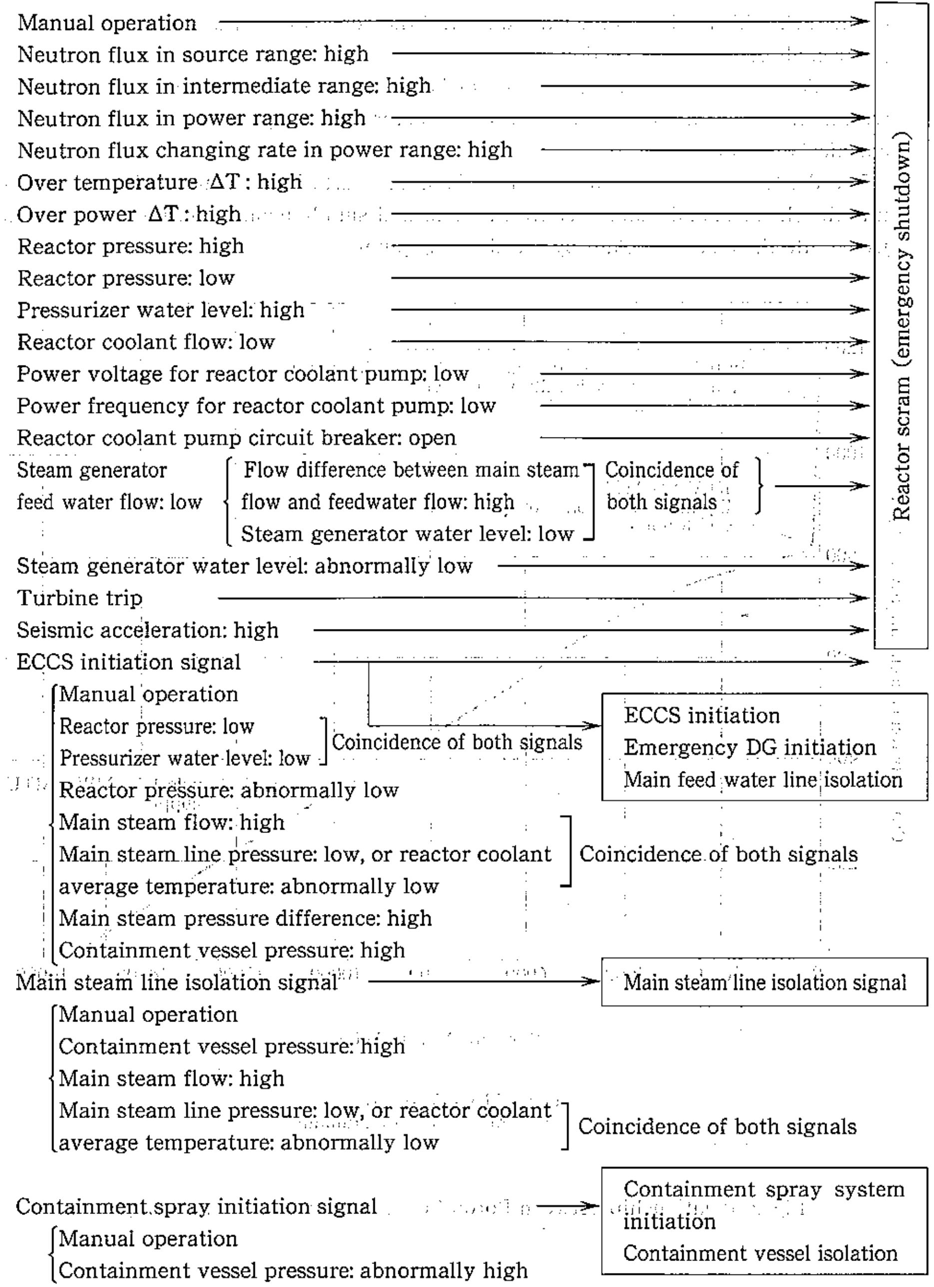


MWD=Mega Watt Day
MTU=Metric Ton of Uranium

Fig. 2 Relationship between Boron Concentration and Fuel Burnup

(5) Outline of the Reactor Protection System for PWR

(800MWe class)



13-14 Outline of Advanced PWR (APWR)

(1) Development History of Advanced PWR

As a part of MITI improvement and standardization program of nuclear power station, the collaboration for APWR with the electric power companies and the plant suppliers had been proceeded from 1982 to 1987.

The more sophisticated design had been achieved by incorporating PWR operating experiences, maintenance experiences, and state of the art techniques in addition to these results of development. The followings are the main targets of development.

(1) Improvement of safety (4 trains of ECCS, advanced accumulator, no exchanging of recirculation path at accident)
(2) Improvement of reliability (improvement of reactor internals, steam generator and reactor coolant pump)
(3) Reduction of amount of radioactive exposure (lowering of source intensity, automation of maintenance work/use of robot)
(4) Reduction of amount of radioactive waste (lowering of generating amount, improvement of volume reducing treatment technique)
(5) Improvement of operability and maneuverability (new main control panel, adoption of digital control protection device)
(6) Improvement of economy (large power and large capacity, reduction of construction cost, saving of uranium resource, improvement of plant availability)

APWR is under the planning as Tsuruga 3 and 4 of The Japan Atomic Power Inc.

(2) Design of Main Facilities for APWR

(a) Core and Fuel

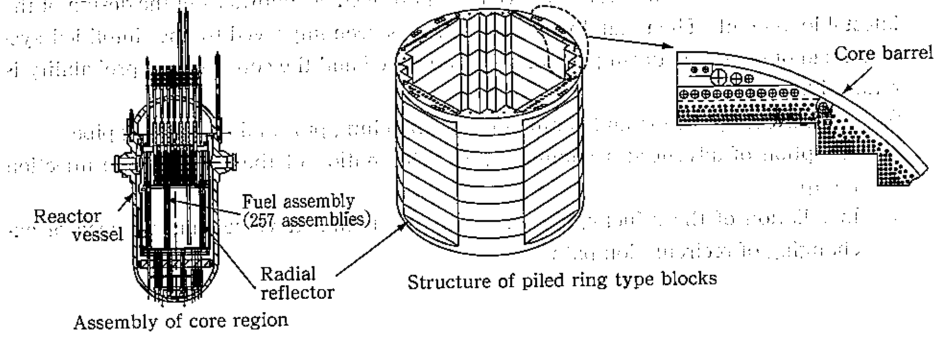
The reactor core for APWR is a large core with 257 advanced fuel assemblies which consists of 17 by 17 rods array. Including the improvement of fuel economy, its design has high flexibility for diversity of operation as MOX fuel or high burnup core by adopting the following measures.

1) Number of control rods: variable setting of number of control rods in response to load scale of MOX fuel
2) Increase of length of fuel plenum
3) Fuel assembly
   ① Adoption of advanced fuel cladding with improved corrosion resistance
   ② Increase of fuel total length by 130mm
   ③ Adoption of zircaloy grid

(b) Reactor Internals

The inside diameter of the reactor vessel was enlarged to approx. 5.2m to house the large sized core. Concerning the reactor internals, the 3 following items were improved by the adoption of a radial reflector. The countermeasure against core flow induced vibration has been taken in response to large sized reactor internals.

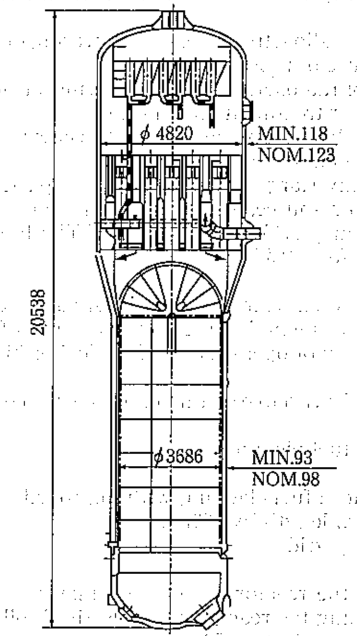
1) Saving of uranium resource by efficient use of neutron
2) Large reduction of bolt/screw number from approx. 2000 to approx. 50
3) Reduction of neutron irradiation to the reactor vessel to approx. 1/3 of the existing 4 loop plant



(c) Steam Generator

Steam generator for APWR was changed from the 52F type for the latest 4 loop plant to the 70F-1 type to respond to the scale up of the reactor core. The material of the heat transfer tube is the same as TT690 alloy used in the precursory plant and has a good performance against corrosion and erosion.

The tube size was changed from 7/8 inches which has been used in the existing plant to smaller 3/4 inches in order to be more efficient and make smaller from the stand point of economy, seismic design, etc.



Advanced PWR Steam Generator

(d) Emergency Core Cooling Systems

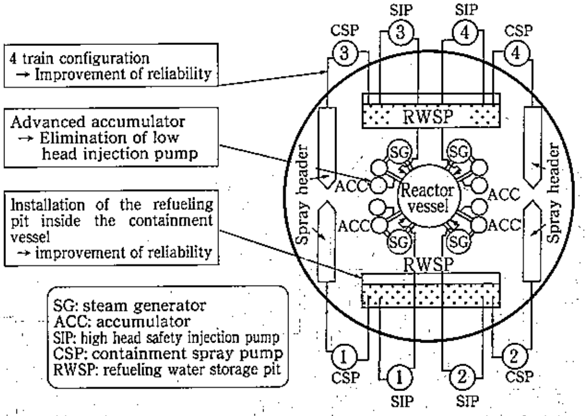
Emergency core cooling systems have been improved as follows from the design of the latest 4 loop plant. The reliability of the plant has been improved by the simplified system. Load of operators during an accident is reduced and the core damage probability is reduced by one order.

① 4 trains configuration and elimination of branching pipe and connecting pipe

② Adoption of advenced accumulator, and elimination of the low pressure injection pump

③ Installation of the refueling pit inside the containment vessel, and no need of exchanging of recirculation path

Advanced PWR (4 trains)



Outline of the advanced design of ECCS

(e) New Main Control Panel

In order to make the plant operation easy and safe, the main control panel was changed to a control panel of compact console type based on the knowledge by human engineering, by which can be performed the monitor of the components and the operation on the TV screens.

The adoption of a touch type operation system has brought the followings.

① Unified indication of monitoring information and operation information

② Small sized main control panel (operation in chair)

③ Qualitative improvement of indication information

(f) Steam Turbine

For larger power and larger capacity, the turbine has incorporated high performance and high efficiency. The length of the final stage blade for the latest 4 loop plant was 44 inches, but that for APWR is changed to 54 inches to improve turbine efficiency. And the efficiency improvement of 0.5% has been achieved by the adoption of the impeller designed by the fully three dimensional flow.

(3) System Outline

System outline of APWR plant is shown in the following drawing.

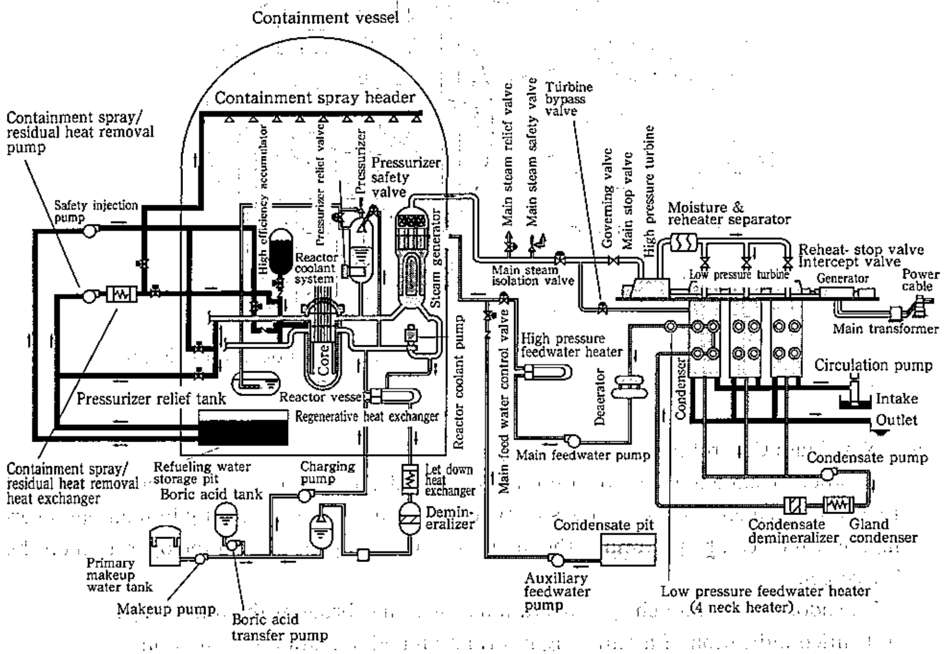


Fig. 1 System Outline of APWR Nuclear Power Station

13-15 Outline of FBR

(1) Specification of Main Parameters for FBR

Items	Sub-items	Specifications		
		Parameters	Experimental reactor [JOYO] (MK-Ⅱ)	Prototype reactor MONJU Electric output : 280 MW
Core and Fuel	Core	Thermal output (MWt)	100	714
		Core flow (t/h)	2200	15360
		Coolant temperature Inlet/outlet (℃)	370/500	397/529
		Number of cooling loop Primary/Secondary	2/2	3/3
	Fuel	Number of fuel assemblies	67	198
		Fuel array	127-rod equilateral triangle	169-rod equilateral triangle
Reactor cooling system	Reactor vessel	Inner diameter (m)	Approx. 3.6	Approx. 7.1
		Hight (m)	Approx. 10	Approx. 17.8
		Maximum operating pressure top/bottom MPa [gage]	0.71/0.1	0.98/0.2
		Max.design temperature (℃)	550	420/550
	Primary cooling system	Number of intermediate heat exchanger	2	3
		Number of circulation pump	2	3
	Secondary cooling system	Number of steam generator	——	3 evaporators & 3 superheaters
		Number of circulation pump	2	3
Reactivity control system	Control rod	Number of control rods	6	13
		Backup reactor shut-down rods	——	6
		Neutron absorption material	B_4C	B_4C
Engineered safety facilities	Reactor containment	Type	Upper : semi-sphere, lower : vertical cylinder with bowl mirror at bottom	Upper ; semi-sphere, lower : vertical cylinder with bowl mirror at bottom
		Inner diameter (m)	28	Approx. 49.5
		Height (m)	54.3	Approx. 79

(Source: Nuclear Power Generation Handbook (1997) edited by the Nuclear Power Generation Section in the Public-Servicing Undertaking Dept., Agency of Natural Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-Sha)

(2) Assembly of the Reactor and the Core for FBR

The reactor of FBR basically consists of the reactor vessel, the reactor internals, the fuel, the control rods, etc. The core consists the core fuel assemblies located at the center of the core, the blanket fuel assemblies located outside the core fuel assemblies peripherally and the neutron shield assemblies.

The liquid metal sodium of the coolant injected into the bottom plenum of the reactor vessel from the primary coolant inlet piping flows upward in the core fuel assemblies and absorbs the heat generated from the core fuel assemblies and is heated.

The hot liquid metal sodium is introduced to the shell side of the intermediate heat exchanger through the reactor vessel outlet nozzle from the upper plenum of the reactor vessel and through the primary coolant exit piping.

The fuel assemblies is loaded and removed through the rotation plug of the reactor vessel.

(3) Control Rods and Control Rod Drive Mechanism for FBR

The control rod consists of the regulating control rod (for fine and coarse regulating) and the back-up control rod, or the regulating control rod and the safety control rod. The element of control rod is a stainless steel tube encasing the boron carbide (B_4C) with enriched ^{10}B and the control rod assembly consists of multiple control rod elements. The control rod is driven by the device provided with the motor.

(4) Power Control for FBR

The reactivity control resulting from the reactor shutdown or the load change is performed changing the position of the regulating control rod in response to the demand signal from the reactor control system.

The temperature and pressure of the main steam is automatically controlled to be constant fundamentally.

The power control system of the reactor controls the speed of the fine regulating control rod and simultaneously keeps the temperature of the sodium at the reactor outlet the specified temperature in response to the main control signal which is the deviation between the temperature of the sodium at the reactor outlet and the programmed value from the power demand device and the auxiliary control signal which is the deviation between the neutron flux signal and the programmed signal of the reactor power from the power demand device.

The power control system of the plant controls the primary main coolant flow rate and the secondary main coolant flow rate in proportion to the demand signal from the power demand devices to meet the load characteristics and finely controls the fine regulating control rod at the same time so that the temperature of the sodium at the outlet of the reactor vessel corresponds to the predetermined temperature from the power demand devices.

The steam pressure detection system of the turbine system detects the pressure fluctuation resulting from the change of the demand from the power demand device. The opening of the turbine control valve is automatically controlled in response to the fluctuation so that the main steam pressure is constant. As the result, the power of the turbine is controlled.

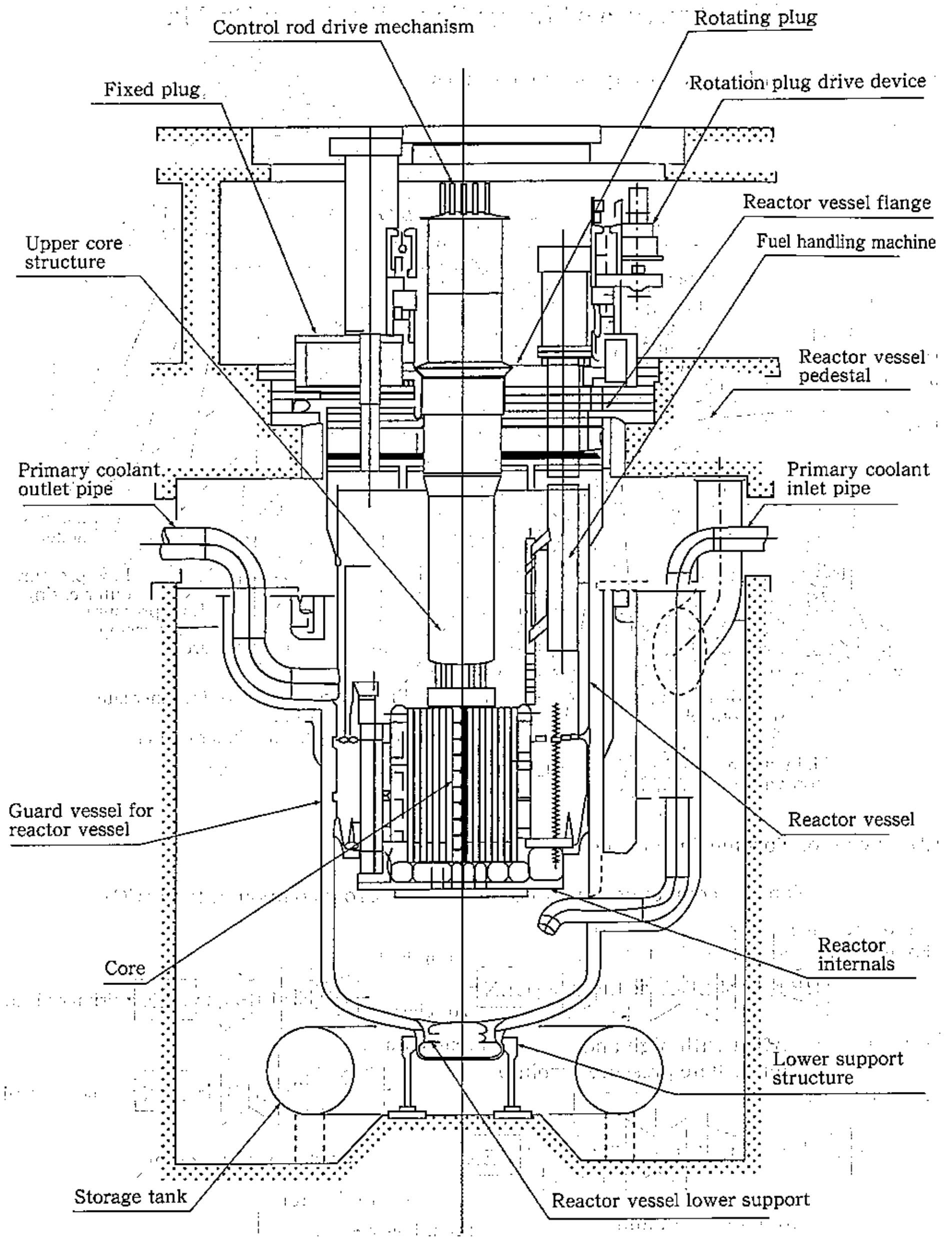
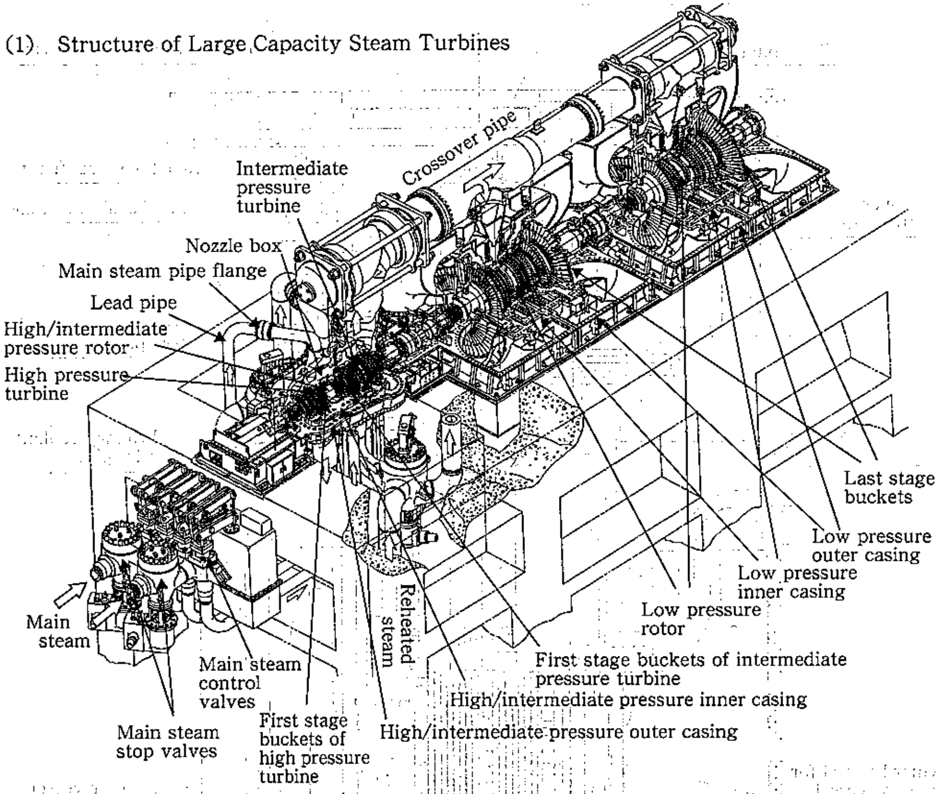


Fig. 1 Reactor Assembly for FBR (MONJU)

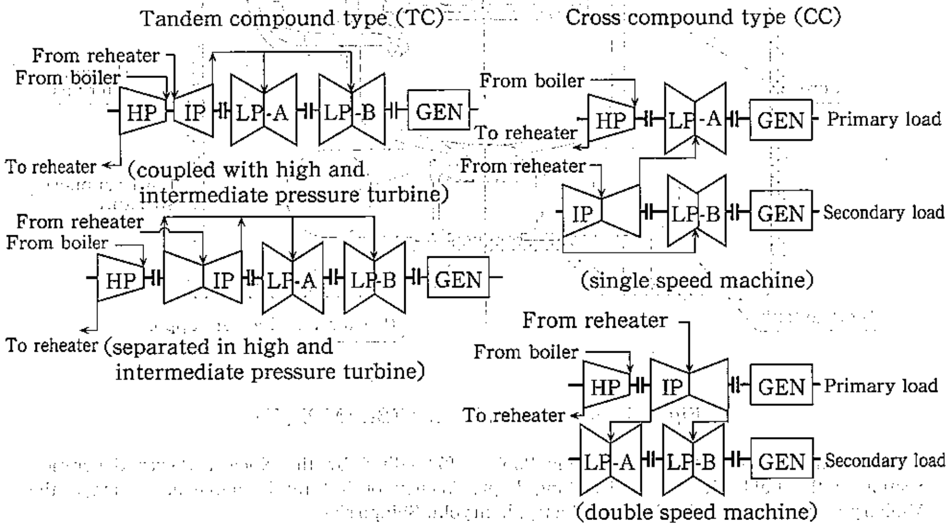
(Source: Nuclear Power Generation Hand Book (1997) edited by the Nuclear Power Generation Section in the Public-Service Undertaking Dept., Agency of Natural Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-sha)

14-1 Structure of Large Capacity Steam Turbines

(1) Structure of Large Capacity Steam Turbines



(2) Types of Turbine Arrangement



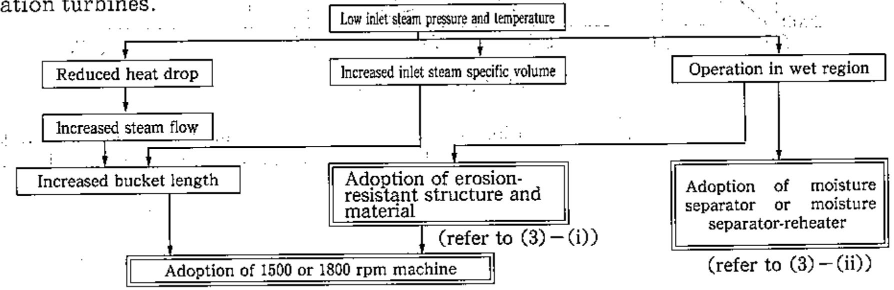
14-2 Types of Steam Turbine (cited from JIS B0127-1983)

No.	Type	Features	Applicable condition	Uses
1	Condensing turbine	Steam exhausted from turbine is condensed to obtain high vacuum in condenser, so that steam in turbine can be expanded to sufficiently low pressure.	If only electric power or mechanical power is required. If cooling water necessary to condense exhaust steam is available.	For mechanical drives, geothermal plant and heat recovery plant
2	Regenerative cycle turbine	Steam is extracted from the intermediate stage of the condensing turbine for heating the feed water to the boiler.	If better efficiency is required for a medium and small-size turbine. Others are the same as 1 above.	For electric power plant of cement works, iron works and mining.
3	Reheat cycle turbine	Steam is let out from the intermediate stage and is reheated and returned to the turbine for further expansion.	If high efficiency and large power are required. Used as a reheating and regenerative turbine, in general.	For large-size power plant
4	Back pressure turbine	Exhaust steam of the turbine is used for process steam of the factory or is discharged to the atmosphere.	If a large amount of process steam is needed at single pressure. Parallel operation of electric power and steam are required since there is a difference between the generated power and demanded electric power of the factory.	For power generation of a factory, for mechanical drives and for co-generation
5	Condensing Extraction turbine	Steam is extracted from the intermediate stage of a condensing turbine and is used for process steam, etc.	If a large amount of process steam is required for one or several types of works. If process steam is less than the demanded electric power.	For power generation of a factory, for mechanical drives and for co-generation
6	Back pressure extraction turbine	Steam is extracted from the intermediate stage of a turbine and is used for process steam, etc.	If a large amount of steam is required for more than two types of works Parallel operation of electric power and steam are required since there is a difference between the generated power and demanded electric power of the plant.	For power generation of a factory and for mechanical drives.
7	Mixed pressure turbine	Steam at different pressures is supplied to a turbine.	If only electric power or mechanical power is required. If low pressure steam should be recovered. If cooling water necessary to condense exhaust steam is available.	For power generation and mechanical drives in a factory needed heat recovery

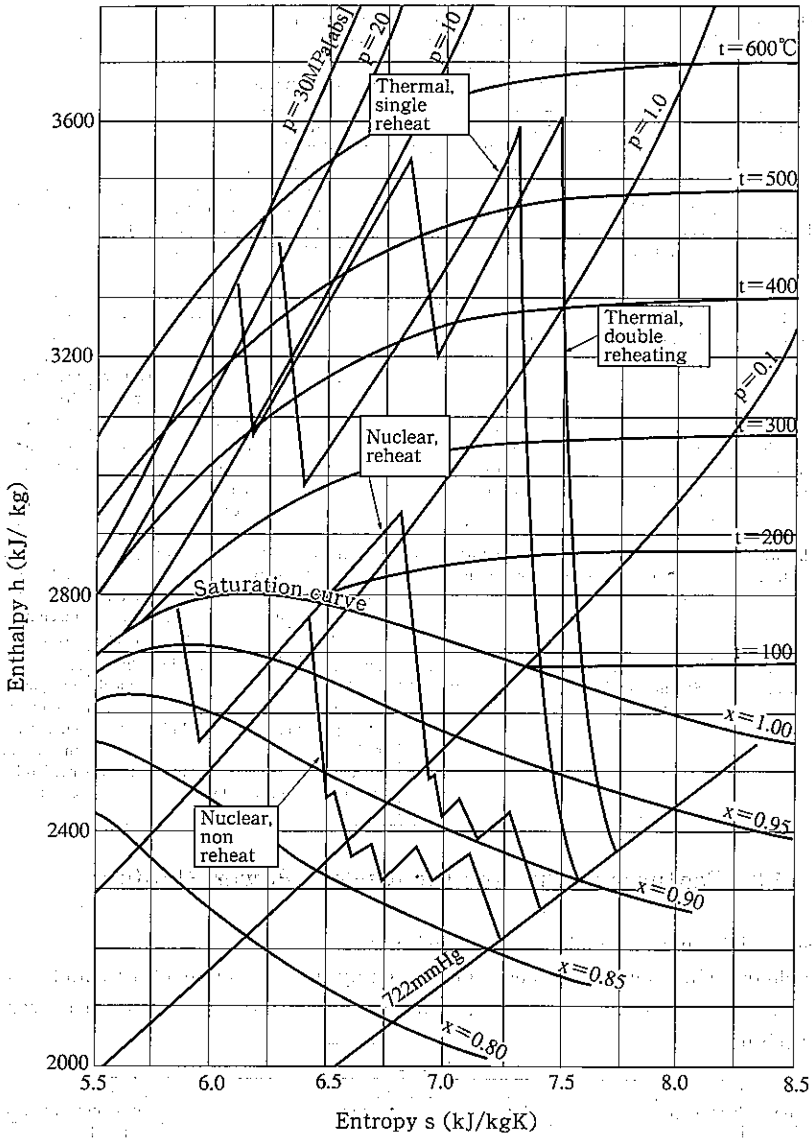
14-3 Features of Turbine for Nuclear Power Plants

(1) Special features of nuclear steam turbines

The nuclear turbines utilizing steam generated by light water reactors widely used at present have the features shown below in comparison with the conventional power generation turbines.



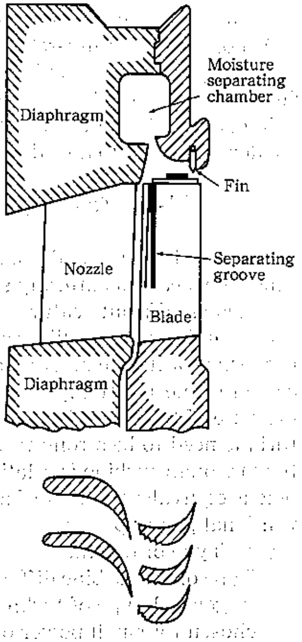
(2) Examples of expansion curves (mollier chart) of thermal and nuclear turbines



〔Source: "Research on Turbines and Generators", I. Concepts, Thermal and Nuclear Power Generation, Vol. 32, No. 7, p.698〕

(3) Prevention of erosion

The most important thing for a nuclear turbine is to prevent erosion caused by operation in the wet area. To prevent erosion, the best structure and material should be selected. In particular, the moving blades should be provided with a high performance moisture separator to remove moisture actively.



(i) Structure and material of turbine for erosion prevention (Example)

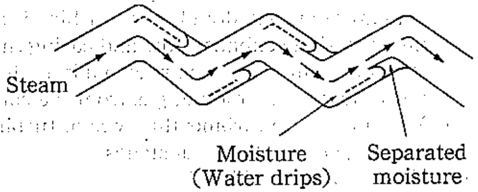
No.	Class	Position of erosion	Preventive measures
1	Impact erosion	Occurs due to impact of water drips. ① In particular, inlet of last stage blades. ② Stationary part for changing the direction of steam flow, in particular, the downstream of the drain holes and orifice etc.	① Applying stellite ② Attaching erosion-resistant metal to the parts subject to impact of water drips
2	Wire drawn erosion	Positions which must be free from steam leak but cannot be sealed completely Casing flanges and horizontal split surface of the diaphragm	① Using bolted structure as far as possible to prevent steam leak ② Covering sealing surface with erosion-resistant material to prevent initial erosion
3	Washing erosion	Occurs when washed by high speed steam and water mixture ① Nozzle and diaphragm ② Other positions with accelerated steam	Using high grade erosion-resistant material

(ii) Moisture separating

Moisture in a steam turbine not only causes erosion in the turbine but deteriorates the turbine performances. Thus, a variety of moisture separating mechanism are used.

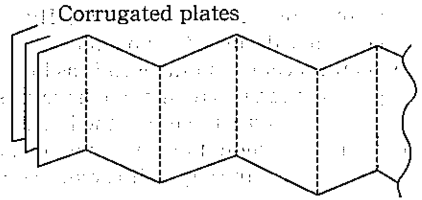
(ii)−1 Moisture separation in turbine

Moisture contained in the steam is captured by the grooves on the blade and blown out to the outer periphery by centrifugal force. Moisture separated as water flows in the moisture separating chamber between the diaphragms and is discharged outside of the turbine. For especially high moisture, grooved moisture separating blades and moisture separating diaphragm are used.



(ii) −2 Moisture separation and reheating out of turbine

A moisture separator or moisture separator-heater installed between the high pressure turbine and low pressure turbine separates moisture from steam. In general, corrugated plate or wire mesh type separator is used since it has high efficiency and reliability. Corrugated plates are installed inside the moisture separator. Steam containing moisture flows as changing its direction by the corrugated plates. When the



flow changes direction, moisture is separated from steam and water droplets in the flow are captured by the corrugated plates, and are discharged to the out by the gravitational force. The wire mesh type separator has stainless steel wires in the form of a scrubbing brush, which separate water drips.

(iii) Moisture separator-reheater

A moisture separator-reheater is assembled in a single barrel. Dry steam from which moisture is separated is heated by the main steam (or the turbine extraction steam) up to 70℃ to 80℃ and is fed to a low pressure turbine.

In general, the reheater is of fine tube type, heating steam flows inside the tube, and its condensate is fed to a feed water heater.

14-4 Features of Turbine for Geothermal Power Plants

Steam utilized in geothermal plants is different from that of conventional power plants because the steam is naturally spouted from underground sources or separated from hot water, and has significant features such as it contains erosive gases like as sulfured hydrogen (H_2S) and impurities like as scales of silica (Si) and calcium (Ca), florides, sand and etc. Properties of the steam are independently different on the site of steam production and applicable turbine is usually designed depending on the specified conditions of steam. Because pressure of the steam is mostly as low as saturated and below 1 MPa (abs), structures of the turbine need to be strong to wetness of steam like as nuclear turbines. Volume of the steam flow through turbine is relatively large to the power output, and accordingly size of the turbine is equivalent to that of low pressure turbines designed for twice or triple output in conventional power plants.

(1) Type of turbine

Type of the turbine differs from condition of steam, size of output, purpose of application. In general, type of turbine is chosen as below. Portable turbine assembled in factory is chosen for small power output requirement.

a. Back pressure turbine: This type of turbine is applicable for the case that the steam contains great amount of non-condensable gases so that the power required to lower the exhaust pressure is very significant, for the case the turbine has low usage factor and is needed to be portable, such as for construction, research and test, emergency power, etc., for the unit with small output and portable such as power generation for mining, and also for the case the unit output is smaller than several Mw s. High speed machines are selected in almost cases.

b. Condensing turbine: this type of turbine is applied in general. Depending upon the amount of output, double flow turbine is selected rather than single flow turbine, and number of the exhaust flow and casing increases from single to double. The exhaust steam pressure is chosen reasonably higher than conventional steam turbine, to keep power low for extracting gas from the condenser.

c. Mixed pressure turbine: this type of turbine is applied for the geothermal plant with flashing steam at several stages.

(2) Notes to be considered

a. It is required to provide moisture-separator at steam inlet of the turbine and to keep wetness of the steam below 1%. High performance separator is required especially for hot water flashing type plants.

b. As the steam from the well is as low as 1.3~0.4MPa (abs) and will reduce its quantity year by year, it is required to have reasonable margin when determining turbine capacity and design pressure at the inlet.

c. As a large amount of corrosive/non-condensable gases, moisture, and scale particles are mixed in the steam, it is required to consider for the turbine preventing from unfavorable defects such as corrosion, erosion, and deposit of scales.

d. The exhaust pressure as high as 10~13kPa [abs] is applicable, in considering higher altitude, large volume of gases and moisture, etc.

e. Metallic material should be selected under the sufficient consideration on facts resulted from corrosion tests by the gas obtained at the site.

f. At shutdown of the turbine, complete drainage is required especially, and cleaning by water and drying by heated air, etc. are desirable.

g. It should be considered to protect sticking of valves by foreign substances, so utilizing swing-check valve as main stop valve and butterfly valve as steam control valve.

h. As a measure against corrosion, it is favorable to use polymer like as epoxy paint rather than stainless steel.

14-5 Steam Rate, Heat Rate and Thermal Efficiency of Turbines

The performance of a steam turbine may be specified by any of steam rate, heat rate or thermal efficiency.

(1) Steam Rate

The steam rate means the quantity of steam necessary for the turbine to produce electric power of 1 kWh at the generator terminal. It is found as shown below.

Steam rate [W], $W = G_1/P_g$ 〔kg/kWh〕

where, G_1 = Inlet steam flow into turbine 〔kg/h〕

P_g = Output at the generator terminal 〔kW〕

The steam rate may also be found from the adiabatic heat drop in the turbine 〔 H_{ad} ,kJ/kg 〕, turbine efficiency 〔 η_t 〕, and generator efficiency 〔 η_g 〕 as shown below.

$$W = 3600/(H_{ad} \times \eta_t \times \eta_g) \qquad 〔\text{kg/kWh}〕$$

where, $H_{ad} = h_1 - h_2$

h_1: Enthalpy at inlet steam pressure P_1 and temperature t_1 〔 kJ/kg 〕

h_2: Enthalpy at pressure P_2 after adiabatic expansion from inlet steam pressure P_1 and temperature t_1 〔 kJ/kg 〕

The steam rate of a non-extraction and condensing type turbine and back pressure type turbine may be regarded as the performance of the turbine.

The steam rate provided η_t and η_g are 100% is called the theoretical steam rate [W_{th}] of a turbine.

$$W_{th} = 3600/(h_1 - h_2) \qquad 〔\text{kg/kWh}〕$$

(2) Heat Rate

The heat rate means the thermal energy necessary to produce electric power of 1 kWh at generator terminal. The heat rate of a turbine plant depends on not only the turbine efficiency but the inlet steam conditions, vacuum, number of turbine extraction stages, final feed water temperature, degree of reheating, etc.

The heat rate of a regenerative turbine HR is found as shown below.

$$HR = (G_1 h_1 - G_w h_w - g h_g)/P_g \qquad 〔\text{kJ/kWh}〕$$

where, G_1 : Turbine inlet steam flow 〔kg/h〕

h_1 : Enthalpy of inlet steam 〔kJ/kg〕

G_w : Feed water flow to boiler 〔kg/h〕

h_w : Enthalpy of feed water 〔kJ/kg〕

g : Steam flow extracted from turbine 〔kg/h〕

h_g : Enthalpy of steam extracted from turbine 〔kJ/kg〕

The heat rate of a reheating-regenerative turbine
HR is found as shown below.

$$HR = \left\{G_1 h_1 + G_R(h_R - h_r) - G_w h_w - g h_g\right\}/P_g \qquad 〔\text{kJ/kWh}〕$$

where, G_R : Quantity of steam flow to the reheater 〔kg/h〕

h_R : Enthalpy of steam from the reheater 〔kJ/kg〕

h_r : Enthalpy of steam to the reheater 〔kJ/kg〕

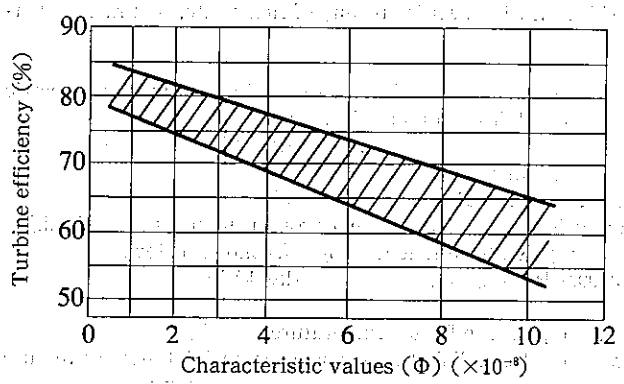
(3) Thermal Efficiency

The performance of a turbine plant is often expressed in the thermal efficiency. The thermal efficiency η_t is found from the specific heat rate using the equation below.

$$\eta_t = (3600/HR) \times 100 \quad [\%]$$

The performance of power plant is expressed as net heat rate or net thermal efficiency excluded internal energy consumption from the output at generator. To discriminate from them, the heat rate and thermal efficiency defined at the generator terminal are called as gross heat rate or gross thermal efficiency.

14-6 Actual Efficiencies of Medium and Small Steam Turbines (75000 kW class or less)



This figure shows the actual efficiencies of various condensing turbines, back pressure turbines and top turbines for the output from 600 to 75,000 kW and for the steam condition from 1.2MPa [abs]/300℃ to 11.3MPa [abs]/510℃.

$$\Phi = \text{Characteristic value} = \frac{P_1 - P_2}{G_1 \cdot N \cdot H_{ad}}$$

P_1 : Steam pressure at the turbine inlet MPa〔abs〕

P_2 : Pressure at the turbine outlet MPa〔abs〕

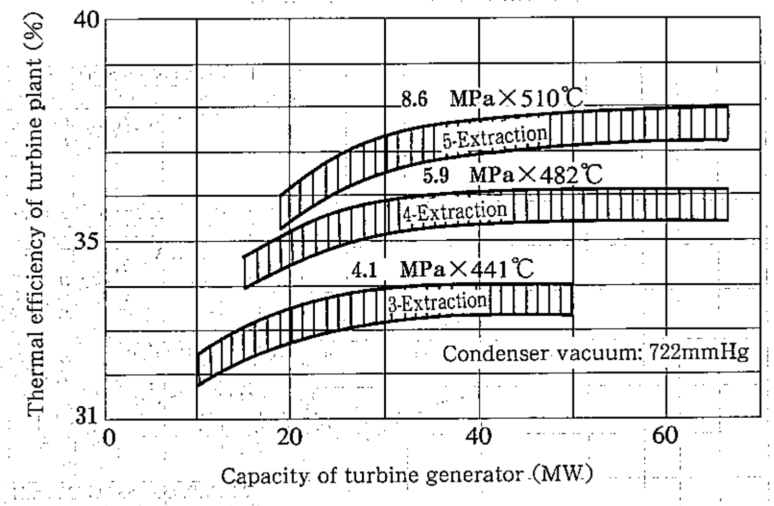
G_1 : Inlet steam flow to the turbine t/h

N : Revolution (Rotating speed) rpm

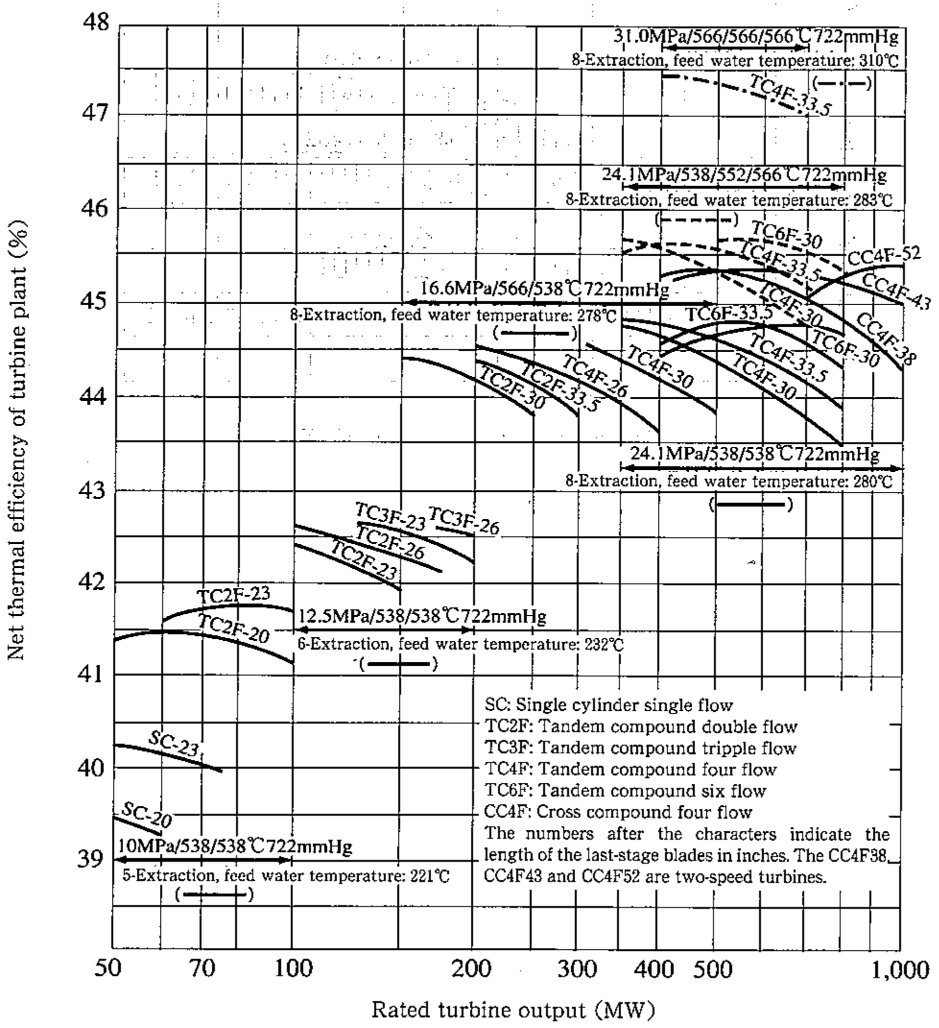
H_{ad} : Adiabatic heat drop kJ/kg

〔Source: New Characteristics for Comparison of the Medium and Small Steam Turbine Efficiencies, by Yasuo Tanaka, Journal of Mechanical Engineering Society, Vol. 61, No. 472, p. 515〕

14-7 Thermal Efficiencies of Medium Scale Non-Reheating Turbine Plants



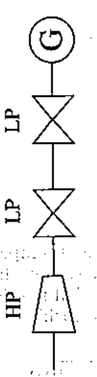
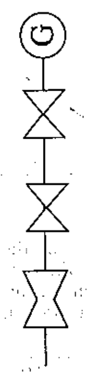
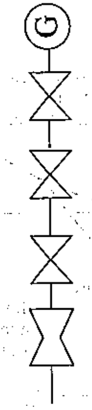
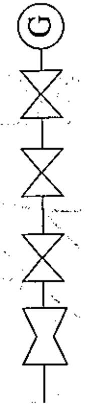
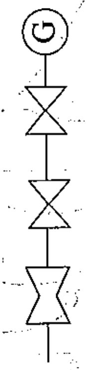
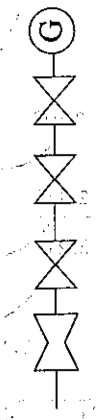
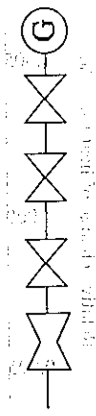
14-8 Turbine Types and Thermal Efficiencies of Turbine Plants (60 Hz reheating turbines)



Note:

$$\text{Net thermal efficiency of turbine plant} = \frac{\text{Generator output} - \text{Power of motor-driven boiler feed water pumps}}{\text{Heat input into turbine}}$$

14-9 Nuclear Turbine Types and Output Selection (Examples)

	Type	Casing arrangement HP LP LP	Output (MW)
50 Hz machines	TC 4 F-35″, 40″, 44″		350~600MW
	TC 4 F-41″, 44″, 52″		600~1,000MW
	TC 6 F-35″, 40″, 44″		650~1,050MW
	TC 6 F-41″, 44″, 52″		800~1,500MW
60 Hz machines	TC 4 F-38″, 40″, 44″		450~600MW
	TC 4 F-43″, 44″, 52″		600~1,000MW
	TC 6 F-38″, 40″, 44″		700~1,300MW
	TC 6 F-43″, 44″, 52″		800~1,500MW

[Source: Thermal and Nuclear Power Generation, Vol. 32, No. 7, p.698]

14-10 Relation of Turbine Plant Thermal Efficiency to Number of Feedwater Heaters and Feedwater Temperature

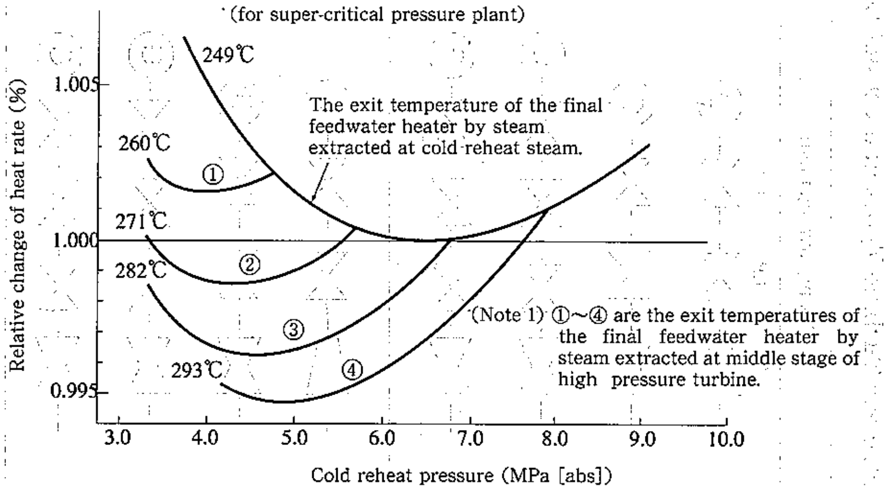
(1) Number of feed water heaters

The number of feed water heaters depends on the economic conditions including the performances to be improved, cost increase of additional heaters and costs of enlarging the turbine room as well as the restrictions on designing the turbines. The following shows the numbers of heaters, normally.

Thermal plants:	20,000～ 50,000kW	4 or 5 heaters
	50,000～100,000kW	5 or 6 heaters
	100,000～200,000kW	5, 6 or 7 heaters
	200,000kW～	6, 7 or 8 heaters
Nuclear plants:		6 or 7 heaters

(2) Optimum feed water temperature

The heat rate of reheat cycle turbine plants greatly differs with the reheat steam pressure and final feedwater temperature. The figure below shows the influences of the reheat steam pressure and final feed water temperature.



(3) The effect of number of feed water heaters on the performance of reheat cycle turbines

(a) For the case of unchanged extraction pressure for the last feedwater heater and added 1 stage of feedwater heater, the thermal efficiency changes as shown below:

Changing 6 heaters to 7 heaters: 0.15% better (Relative value)
Changing 5 heaters to 6 heaters: 0.20% better (Relative value)

(b) For the case of keeping the same extraction points and added 1 stage of feedwater heater, the thermal efficiency changes as shown below:

Changing 6 heaters to 7 heaters: 0.10% better (Relative value)
Changing 5 heaters to 6 heaters: 0.12% better (Relative value)

[Source: "Steam turbine performance and economics" by R.L. Bartlett, McGraw-Hill]

14-11 Correction Curves of Steam Rate and Heat Rate

The steam rate and heat rate of a turbine plant change when the conditions such as main steam pressure, main and reheat steam temperature, condenser vacuum, pressure drop of the reheating piping, auxiliary steam flow, make-up water quantity, etc. are deviated from the rated values. The degree of correcting the steam consumption and heat rate differs with turbines. The curves shown below are examples for the correction of the heat rate under the designated conditions. These curves show correction factors for the rated output. In case of partial load, another correction factors must be applied.

[method of application] change in heat rate %

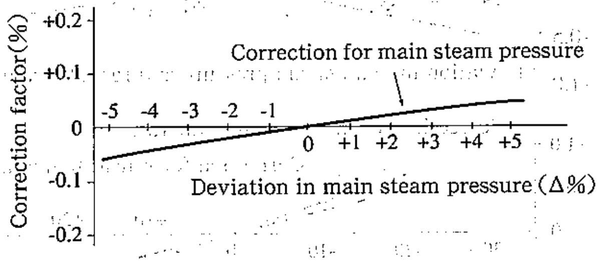
$$HR' = HR\left(1+\frac{\text{Correction factor (\%)}}{100}\right)$$

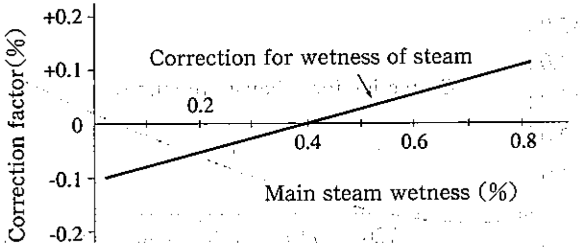
Where, HR′: Heat rate in the given conditions
HR: Heat rate in the rated conditions

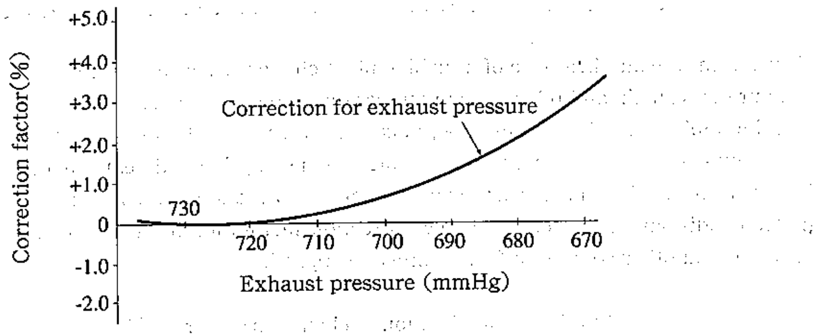
(1) Nuclear Turbines

Rated conditions

Output: 1,100,000kW	Vacuum: 722mmHg
Main steam pressure: 6.55 MPa[gage]	Make-up water: 0%
Main steam wetness: 0.4%	Final feed water temperature: 215.5℃



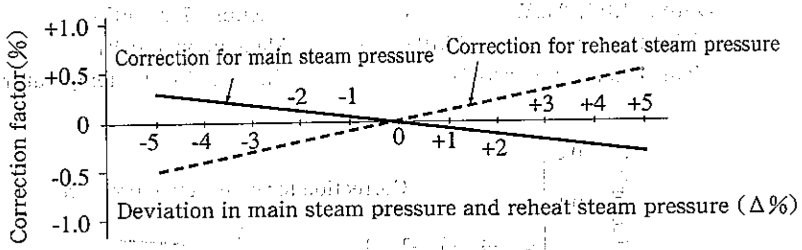


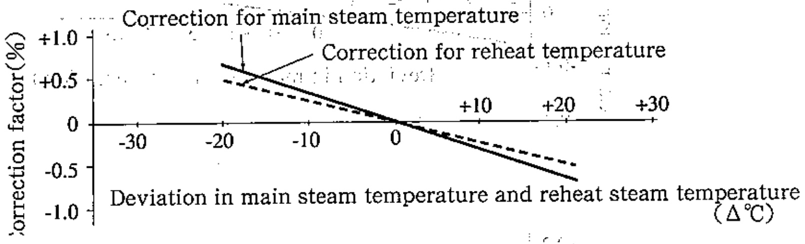


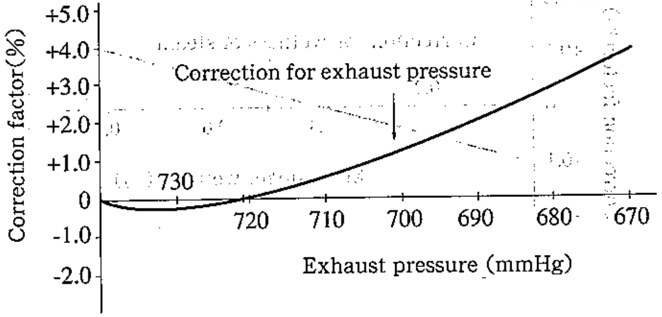
(2) Thermal Turbines

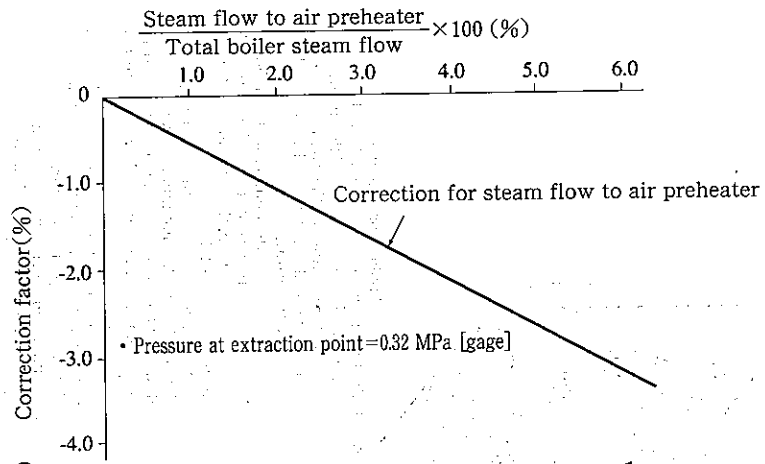
Rated conditions

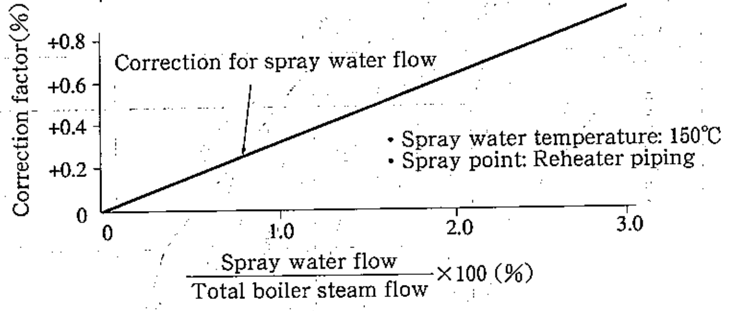
Output: 600,000kW
Main steam pressure: 24.1 MPa[gage]
Main steam temperature: 538℃
Reheat steam temperature: =566℃
Pressure drop in reheater: 8%
Exhaust pressure: 722mmHg
Make-up water: 0%
Final feed water temperature: 277.6℃

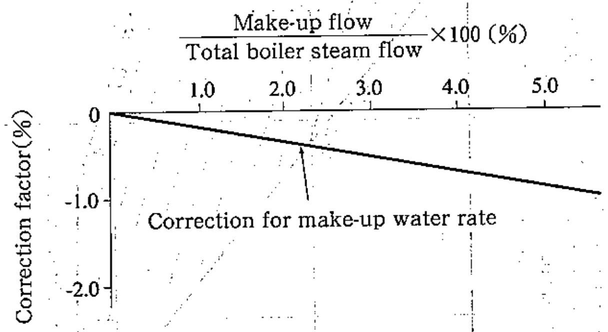












14-12 Examples of Steam Rate Diagram for Industrial Turbines

Turbine inlet flow, extraction steam flow and generator output of a turbine plant, concurrently supplying steam for factory use, have reciprocal relationship. The maximum and minimum steam flow at the each extraction point are restricted by the turbine structure and the allowable temperatures of the materials. In addition, the maximum output is restricted by the generator capacity. Since the relationship among the inlet steam flow, extraction flow and generator outputs are complicated, turbine makers make a steam rate diaphragm of turbines, which are used as operating guides.

The following show the examples of steam rate diagram and usage.

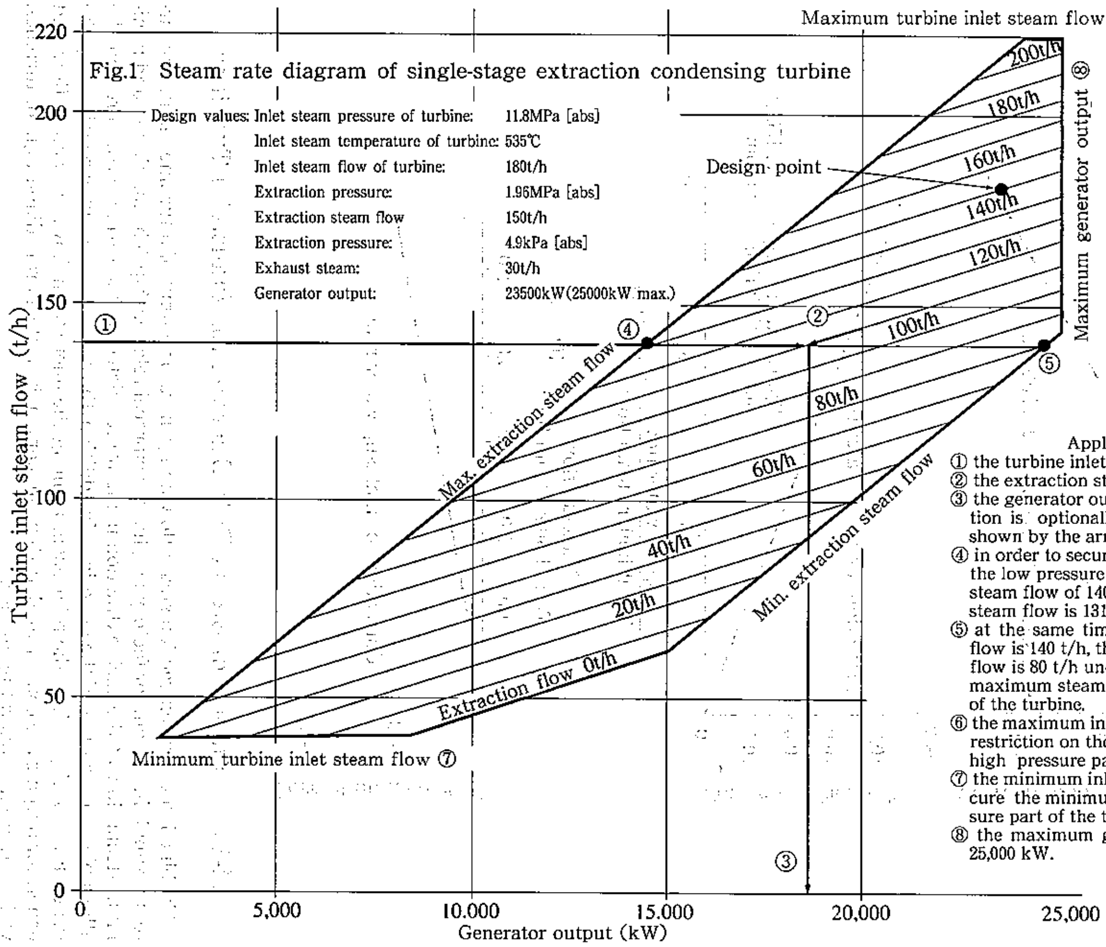


Fig.1 Steam rate diagram of single-stage extraction condensing turbine

Design values:
Inlet steam pressure of turbine: 11.8MPa [abs]
Inlet steam temperature of turbine: 535℃
Inlet steam flow of turbine: 180t/h
Extraction pressure: 1.96MPa [abs]
Extraction steam flow 150t/h
Extraction pressure: 4.9kPa [abs]
Exhaust steam: 30t/h
Generator output: 23500kW(25000kW max.)

Application example:

① the turbine inlet flow as 140 t/h, and
② the extraction steam flow as 110 t/h, then
③ the generator output at the rated steam condition is optionally determined as 18,500kW as shown by the arrow.
④ in order to secure the minimum steam flow to the low pressure part of the turbine at the inlet steam flow of 140 t/h, the maximum extraction steam flow is 131 t/h.
⑤ at the same time when the rated inlet steam flow is 140 t/h, the minimum extraction steam flow is 80 t/h under the limit regarding to the maximum steam flow to the low pressure part of the turbine.
⑥ the maximum inlet steam flow is 220 t/h, by the restriction on the maximum steam flow to the high pressure part of the turbine.
⑦ the minimum inlet flow is 40 t/h, in order to secure the minimum steam flow to the high pressure part of the turbine.
⑧ the maximum generator output is shown as 25,000 kW.

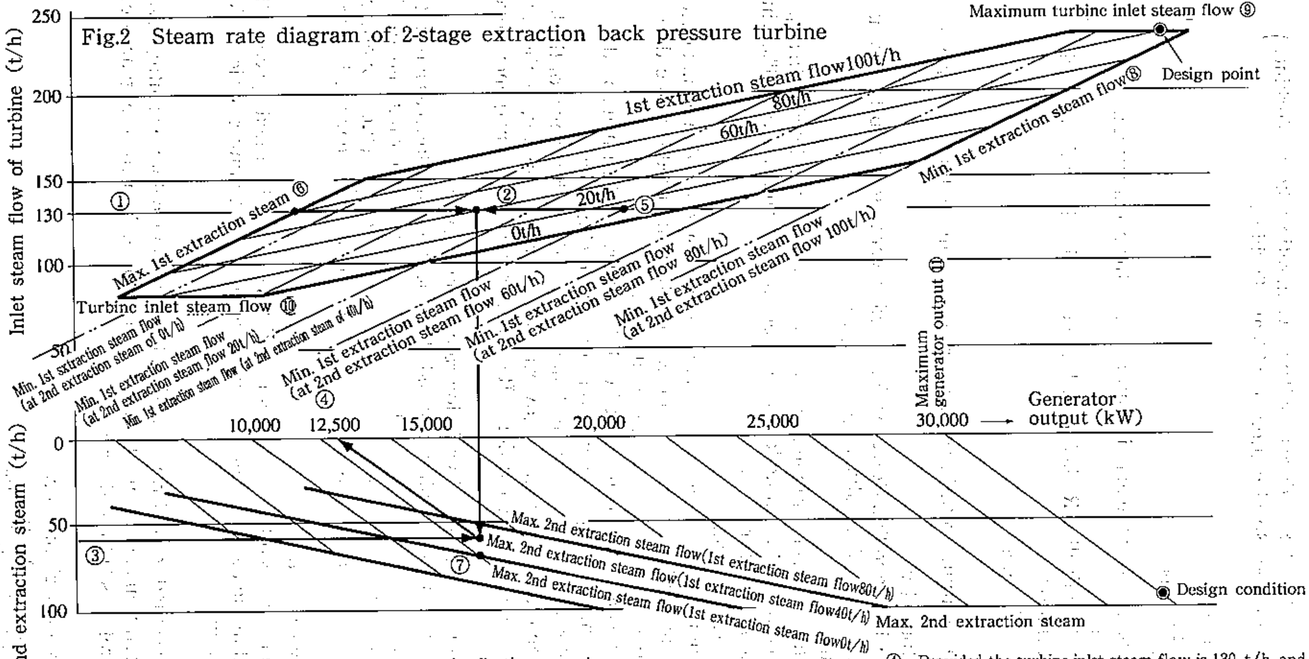


Fig.2 Steam rate diagram of 2-stage extraction back pressure turbine

Design values:
Inlet steam pressure of turbine: 11.8MPa[abs]
Inlet steam temperature of turbine: 535℃
Inlet steam flow of turbine: 235t/h
1st extraction pressure: 2.94MPa [abs]
1st extraction steam: 80t/h
2nd extraction pressure: 1.18MPa [abs]
2nd extraction steam: 95t/h
Back pressure: 0.29MPa [abs]
Exhaust quantity: 60t/h
Generator output: 30000kW max.

Application example:

① Provided the turbine inlet steam flow is 130t/h, the first extraction steam is 40 t/h and second extraction steam is 60 t/h, the generator output is 12500 kW, which is uniquely determined at the rated steam conditions.
② Provided the turbine inlet steam flow is 130 t/h and the second extraction steam is 60 t/h, the lower limit of the first extraction is 10 t/h, which is restricted by the maximum steam flow in the low pressure part of the turbine.
③ Provided the turbine inlet steam flow is 130 t/h, the upper limit of the first extraction steam is 80 t/h in order to secure the minimum steam flow in the intermediate pressure part of the turbine.
④ Provided the turbine inlet steam flow is 130 t/h and the first extraction steam is 40 t/h, the upper limit of the second extraction steam is 70 t/h in order to secure the minimum steam flow in the low pressure part of the turbine.
⑤ The lower limit of the first extraction steam is restricted by the maximum steam flow in the intermediate pressure part of the turbine.
⑥ The upper limit of the turbine inlet steam flow is 235 t/h, which is restricted by the maximum steam flow in the high pressure part of the turbine.
⑦ The lower limit of the turbine inlet steam flow is 80 t/h in order to secure the minimum steam flow in the high pressure part of the turbine.
⑧ It is shown above that the upper limit of the generator output is 30000 kW.

14-13 Terms and Definitions for Steam Turbine Control

(References: JEAC 3703-1994, Standards for Power Generating Steam Turbines
JIS B 8101-1991, Specifications for Steam Turbines)

(1) Permanent speed variation

$$R_s(\%) = \frac{n_o - n_r}{n_r} \times 100$$

where, n_o : Steady state speed after the load is shut down at the rated output. 〔s^{-1}〕
n_r : Rated speed 〔s^{-1}〕

Normally, R_s is 3 to 5%. Practically, R_s is 5% with the control value fully opened.

(2) Incremental speed variation

$$R_r(\%) = \frac{dn}{dP} \times \frac{P}{n_r} \times 100$$

where, $\frac{dn}{dP}$ = Slope of the output/rotating speed variation at any output. 〔s^{-1}/kW〕
P = Rated output (kW)

Normally, R_r is between 1.5% and 8%. However, for speed governing, Rr up to 12% is allowed near the point where successive valve begins to open.

(3) Speed regulating range

The speed regulating range means the range where the speed may be regulated with a speed governor. The turbine speed regulating at no-load operation shall be rated speed ±6%, which may be expanded to ±7% if necessary.

(4) Trip speed of emergency governor

When emergency governor tripped at the setting, maximum turbine speed must not exceed the safety limit of the turbine and the driven machine. If the turbine speed is reduced to the approximately rated speed, it shall be restored automatically.

Emergency governor trip shall operate at a speed of 111% or less of the rated speed.

(a) The maximum instantaneous speed variation rate at load shut-down

The increment ratio of revolution speed immediately after sudden shut-down of the load without changing the condition of the speed governor of a turbine running at the rated speed and rated output in the normal conditions. It should be less of the emergency governor trip speed.

(b) The maximum instantaneous speed variation rate at emergency

The maximum increment ratio of revolution speed after the load shut down as a result of emergency governor operation when, the speed governor system is abnormal and the instantaneous speed variation rate has exceeded the trip point of the emergency governor.

In general, the instantaneous maximum speed variation rate at emergency is less than 120% of the rated speed.

(5) Maximum speed in over-speed test

The maximum speed in over-speed test should not exceed 115% of the rated speed if the over-speed test is executed in the factory. The test duration should be 2 minutes or less. Test should be executed once only.

(6) Oil trip speed

Oil trip test should be executed to confirm security of the system before executing over-speed test. The oil trip operation speed must be less than the lower limit of the guaranteed continuous speed. In general, it is 96% of the rated speed.

(7) Pressure regulation

(a) Extraction pressure or back pressure

$$R_p(\%) = \frac{P_o - P}{P_r} \times 100$$

where, P_o : Stabilized pressure or instantaneously raised pressure [MPa (gage)] when the extraction or exhaust steam flow is reduced to the lowest limit from stable operation at the rated extraction or the rated exhaust steam flow, with the condition of the pressure regulation system unchanged.
P : Pressure at the rated extraction or exhaust steam flow [MPa (gage)]
P_r : Design pressure (rated) [MPa (gage)]

The target pressure regulation ratio should be 4%. The instantaneous pressure regulation ratio should be 15%.

(b) Pressure regulation ratio of turbine inlet steam (for nuclear turbine, etc.)

$$R_p(\%) = \frac{\triangle P}{P_r} \times 100$$

where, △P: Variation of inlet pressure at 100% load change [MPa]
P_r : Design pressure (rated) [MPa (gage)]

Normally, R_p is 3 to 4%.

14-14 Calculation of the Instantaneous Maximum Speed after Shut-down of Load

(1) Instantaneous Maximum Speed after Shut-down of Load

The maximum speed n_0 is found as shown below,

$$n_0 = \sqrt{\frac{7.3 \times 10^5}{GD^2} \times (E_R + \triangle E_1 + \triangle E_2 + \triangle E_3)} \quad 〔rpm〕$$

Where,

E_R : Rotating energy in rated speed [kW•s]
$\triangle E_1$: Energy flowed into the turbine during actuation delay of valve after shut-down of load [kW • s]
$\triangle E_2$: Energy flowed into the turbine during valve closing after shut-down of load [kW • s]
$\triangle E_3$: Energy stored in the turbine and steam piping and used for speed increasing after shut-down of load [kW • s]
GD^2 : Moment of inertia of rotating part of the turbine and the generator 〔kg•m²〕

$$E_R = 1.37 \times 10^{-6} \times GD^2 \times 〔n_r〕^2$$

$$\triangle E_1 = \triangle E_{1CV} + \triangle E_{1IV}$$

$$\triangle E_{1CV} = T_{dCV} \times f_1 \times P$$

$$\triangle E_{1IV} = T_{dIV} \times f_2 \times P$$

$$\triangle E_2 = \triangle E_{2CV} + \triangle E_{2IV}$$

$$\triangle E_{2CV} = T_{CCV} \times f_1 \times P \times 0.75$$

$$\triangle E_{2IV} = T_{CIV} \times f_2 \times P \times 0.83$$

$$\triangle E_3 = \{\Sigma W_1U_1 - \Sigma W_2U_2 - \Sigma (W_1 - W_2) i_e\} \times 0.8$$

n_r = Rated speed 〔rpm〕
P = Rated output at generator terminal. 〔kW〕
$\triangle E_{1CV}$ = Energy flowed into the turbine due to actuation delay of the control valve after shut-down of load [kW • s]
$\triangle E_{1IV}$ = Energy flowed into the turbine due to actuation delay of the intercept valve after shut-down of load [kW • s]
T_{dCV} = Time before the steam control valve begins to close after shut-down of load [s]
T_{dIV} = Time before the intercept valve begins to close after shut-down of load [s]
f_1 = Load sharing rate of the H.P. turbine
f_2 = Load sharing rate of the I.P. and L.P. turbines
$\triangle E_{2CV}$ = Energy stored in the turbine during the control valve closing after shut-down of load [kW • s]
$\triangle E_{2IV}$ = Energy stored in the turbine during the intercept valve closing after shut-down of load [kW • s]
T_{CCV} = Time needed during the control valve fully closed from actuated [s]

T_{CIV} = Time needed during the intercept valve fully closed from actuated from actuated [s]
W_1 = Steam stored in the turbine and piping at shut-down of load [kg]
W_2 = Steam remaining in the turbine and steam piping after completion of expansion of W_1 〔kg〕
U_1 = Internal energy of W_1 〔kJ/kg〕
U_2 = Internal energy when W_1 expands up to the condenser vacuum adiabatically 〔kJ/kg〕
i_e = Enthalpy when W_1 expands adiabatically to the turbine exhaust pressure 〔kJ/kg〕

(2) Instantaneous Maximum Speed in Emergency (when emergency governor tripping)

Maximum speed $n_E = \sqrt{\frac{7.3\times10^5}{GD^2}\times(E_E+\triangle E_{1E}+\triangle E_{2E}+\triangle E_{3E})}$ 〔rpm〕

Where, E_E = Rotating energy when the emergency governor tripped [kW•S]
ΔE_{1E} = Energy flowed into the turbine due to actuation delay of valve after shut-down of load [kW • s]
ΔE_{2E} = Energy flowed into the turbine during valve closing after shut-down of load [kW • s]
$\triangle E_{3E}$ = Same as ΔE_3
E_E = $1.37\times10^{-6}\times GD^2\times$ 〔n_E〕^{2}

$$n_E = \frac{n_t+\triangle n_\alpha+\triangle n_L}{100}\times n_r$$

$\triangle E_{1E} = \triangle E_{1EM} + \triangle E_{1ER}$
$\triangle E_{1EM} = T_{dMSV}\times f_1\times P$
$\triangle E_{1ER} = T_{dRSV}\times f_2\times P$
$\triangle E_{2E} = \triangle E_{2EM} + \triangle E_{2ER}$
$\triangle E_{2EM} = T_{CMSV}\times f_1\times P\times0.84$
$\triangle E_{2ER} = T_{CRSV}\times f_2\times P\times0.88$
$\triangle E_{3E} = \triangle E_3$ (See (1) above.)
n_E = Speed when the trip finger actuated [rpm]
n_t = Speed when the emergency governor actuated [%]
$\triangle n_\alpha$ = Speed increase until the trip finger functioned after the speed governor actuated [%]
$\triangle n_L$ = Difference between the maximum speed of the emergency governor actuated and n_t [%]

$\triangle E_{1EM}$ = Energy flowed into the turbine due to actuation delay of the main stop valve after the trip finger actuated [kW • s]
$\triangle E_{1ER}$ = Energy flowed into the turbine due to actuation delay of reheat or intercept valve after the trip finger functioned [kW • s]
$\triangle E_{2EM}$ = Energy flowed into the turbine during the main stop valve closing after the trip finger functioned [kW • s]
$\triangle E_{2ER}$ = Energy flowed into the turbine during the reheat or intercept valve closing after trip finger functioned [kW • s]
T_{dMSV} = Time needed after the trip finger functioned until the stop valve began to close [s]
T_{dRSV} = Time needed after the trip finger functioned until the reheat or intercept valve began to close [s]
T_{CMSV} = Time needed the main stop valve fully closed from actuated [s]
T_{CRSV} = Time needed the reheat stop valve fully closed from actuated [s]

(3) Example of Calculation for Instantaneous Maximum Speed after Shut-down of Load

n_r = 3,000rpm
P = 600,000kW
GD^2 = 174,000kg•m²
T_{dCV} = 0.03sec
T_{dIV} = 0.10sec

f_1 = 0.3
f_2 = 0.7
T_{CCV} = 0.05sec
T_{CIV} = 0.15sec
$E_r = 1.37\times10^{-6}\times174,000\times3,000^2=2,145,420$
$\triangle E_{1CV} = 0.03\times0.3\times600,000=5,400$
$\triangle E_{1IV} = 0.10\times0.7\times600,000=42,000$
$\triangle E_1 = 5,400+42,000=47,400$
$\triangle E_{2CV} = 0.05\times0.3\times600,000\times0.75=6,750$
$\triangle E_{2IV} = 0.15\times0.7\times600,000\times0.83=52,290$
$\triangle E_2 = 6,750+52,290=59,040$
Total steam in turbine and extraction pipes W1 = 334 kg
W_2 = 0 kg (assumption)
Steam enthalpy at the inlet for each turbine U_1 $\Sigma W_1U_1=918,590$kJ
Steam enthalpy in the turbine after adiabatic expansion U_2 $\Sigma W_2U_2=0$ kJ
i_e = 2,621kJ/kg
$\Sigma(W_1\text{-}W_2)i_e=(334\text{-}0)\times2,621=875,414$
$\triangle E_3=(918,590\text{-}0\text{-}875,414)\times0.8=34,541$

$$n_0=\sqrt{\{(7.3\times10^5)\times(2,145,420+47,400+59,040+34,541)/174,000\}}$$
$$=3097\text{rpm}$$

14-15 Mechanical-Hydraulic Control and Electric (Electronic) -Hydraulic Control

A turbine control system consisting of mechanical mechanisms and hydraulic units is called the mechanical-hydraulic control. A turbine control system consisting of electric (or electronic) device and hydraulic units is called the electric (or electronic)-hydraulic control.

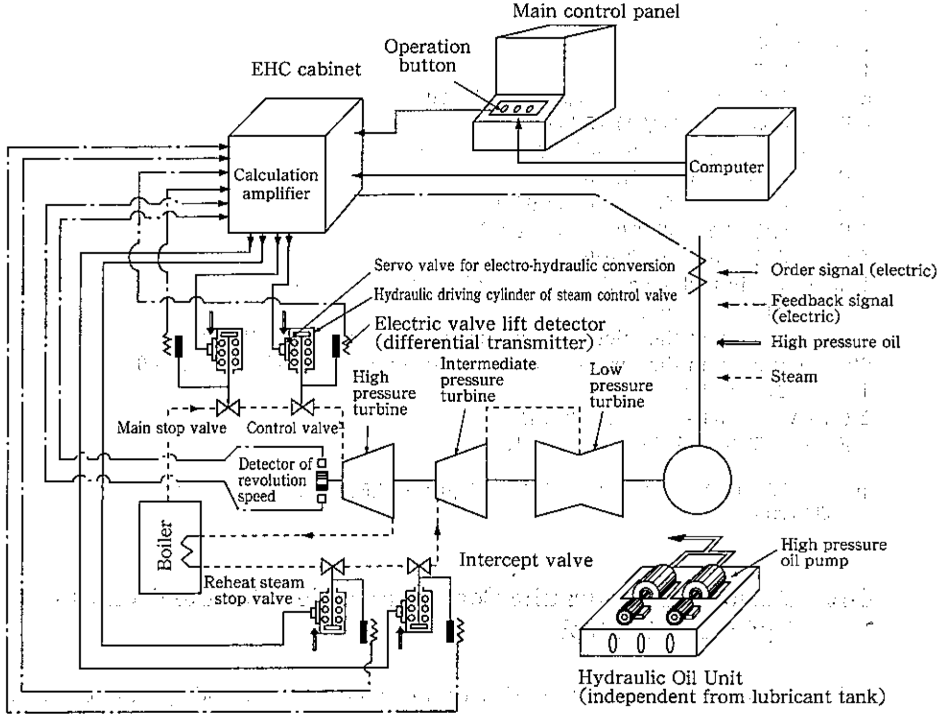
The electric-hydraulic control system has superior control performances and is suitable to automatization.

The below shows the component units of the mechanical-hydraulic control and the electric-hydraulic control systems according to their control functions.

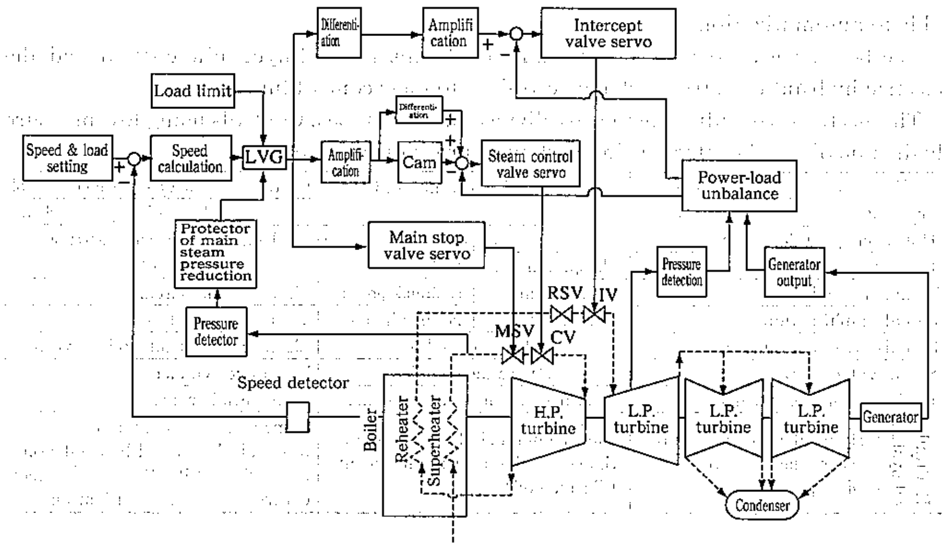
The electric-hydraulic controls are divided into two types: Controls using low pressure hydraulic oil, and controls using high pressure cydraulic oil.

Type Function	Mechanical-hydraulic control		Electric (electronic) -hydraulic control	
			Low pressure oil type	High pressure oil type
Rotation speed detection	Centrifugal fly weight type	Centrifugal hydraulic type	Electromagnetic pulse detection	
Rotating signal	Displacement	Hydraulic pressure	Pulse voltage	
Signal transmission	Lever link	Hydraulic pressure	Electric signal circuit	
Signal amplification	Hydraulic relay and lever link	Hydraulic relay	Solid-state amplifier	
Signal-power conversion	Hydraulic pilot		Electricity-hydraulic oil converter	
Steam valve operating	Hydraulic cylinder		Hydraulic cylinder	
Feed back of steam valve stroke	Hydraulic pilot and lever link		Differential trans.	
Hydraulic oil system Hydraulic pressure source Hydraulic pressure Oil type	Turbine main shaft drive pump Same as the bearing lubricant. (Turbine oil)		Same as the mechanical-hydraulic control.	Power unit Rated hydraulic oil: 10MPa[gauge] or more Fire retardant oil

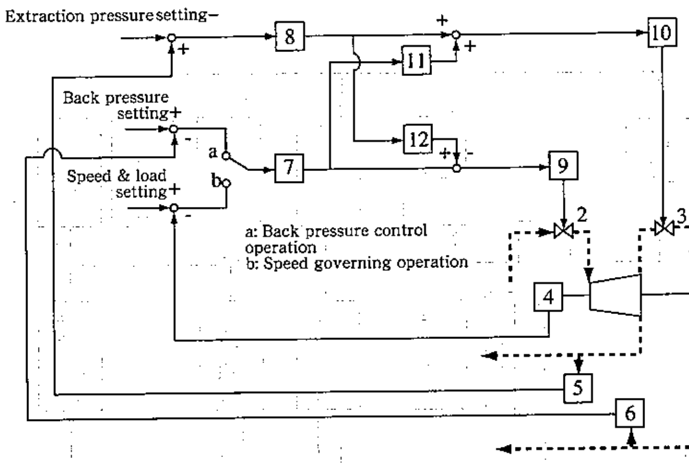
Typical constitution of electric (electronic)-hydraulic control



14-16 Control Block Diagram of Reheat Steam Turbines



14-17 Control Block Diagram of Extraction-Back Pressure Turbines

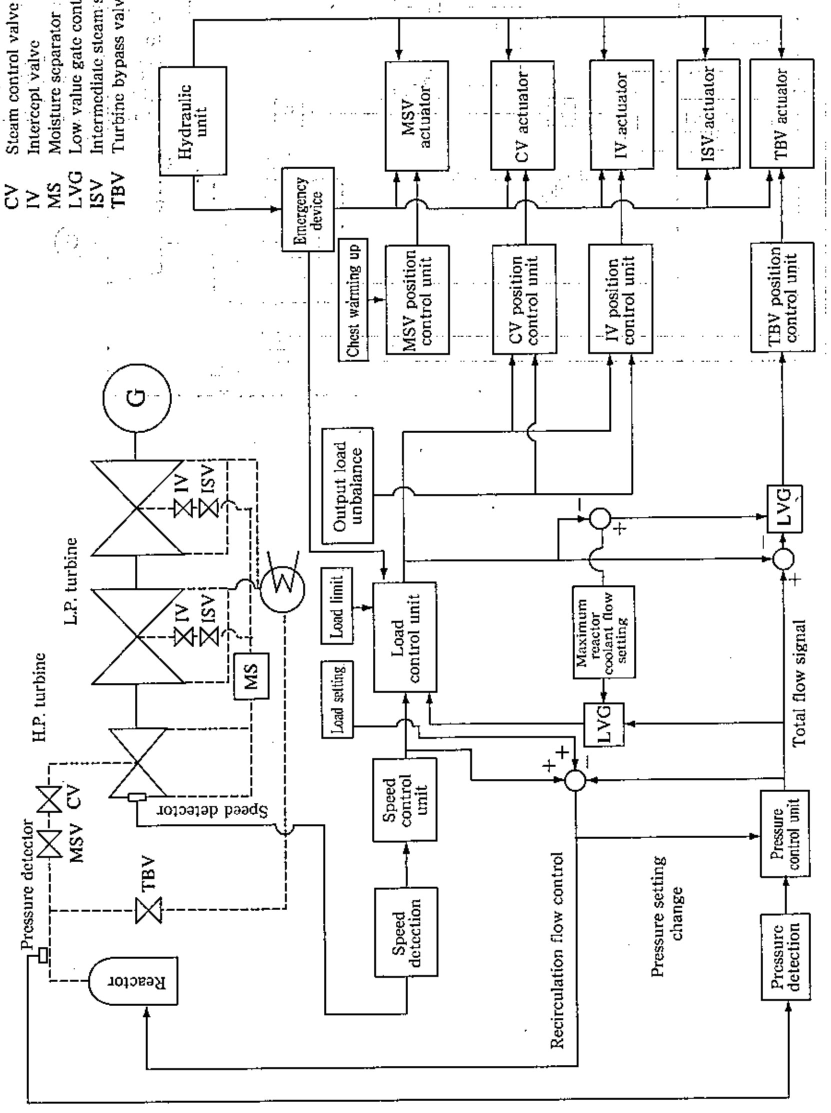


1. Steam turbine generator
2. Steam control valve
3. Extraction steam control valve
4. Speed detector
5. Extraction pressure detector
6. Back pressure detector
7.8. Primary amplifiers
9.10. Secondary amplifiers
11.12. Division constants

14-18 Control Block Diagram of Nuclear Power Plant Turbines

(1) Control of BWR

MSV	Main stop valve
CV	Steam control valve
IV	Intercept valve
MS	Moisture separator
LVG	Low value gate control
ISV	Intermediate steam stop valve
TBV	Turbine bypass valve



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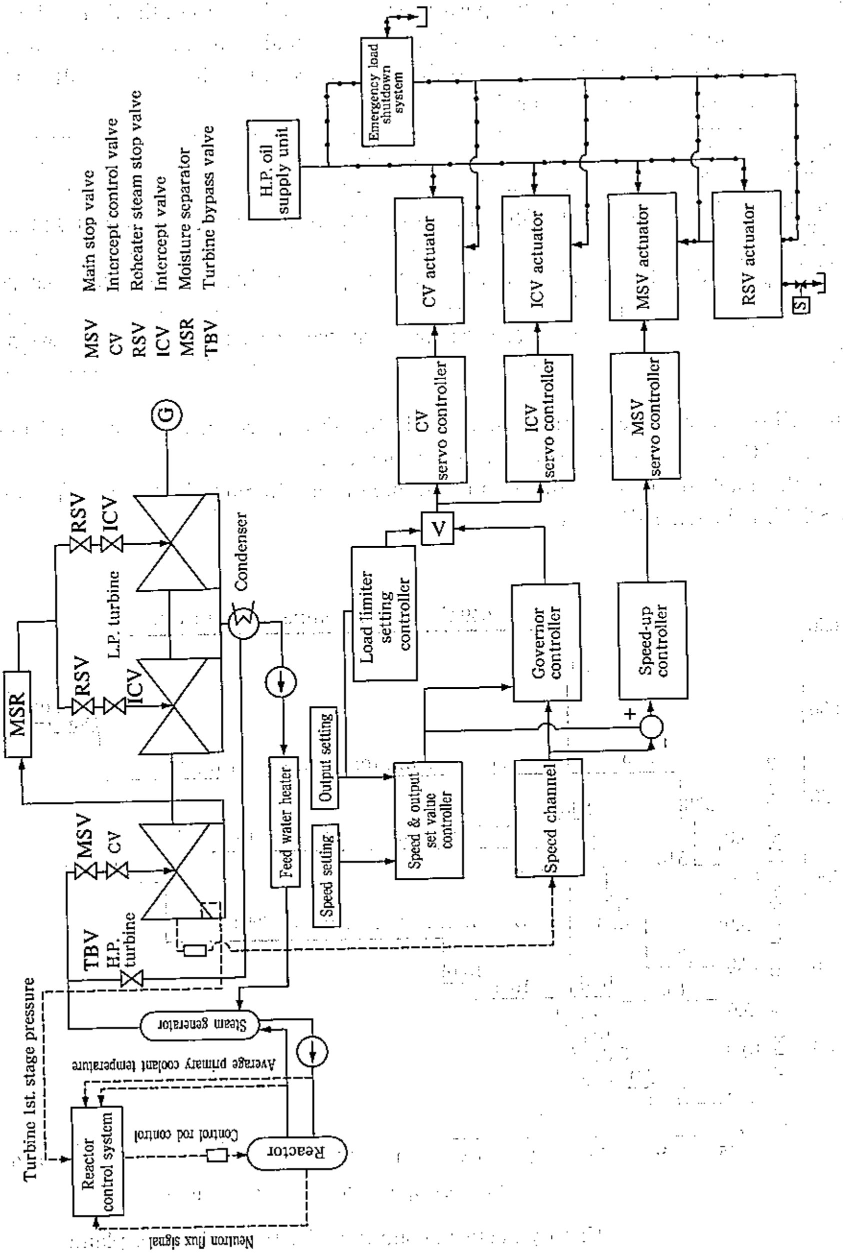
(2) Control of PWR

MSV	Main stop valve
CV	Intercept control valve
RSV	Reheater steam stop valve
ICV	Intercept valve
MSR	Moisture separator
TBV	Turbine bypass valve



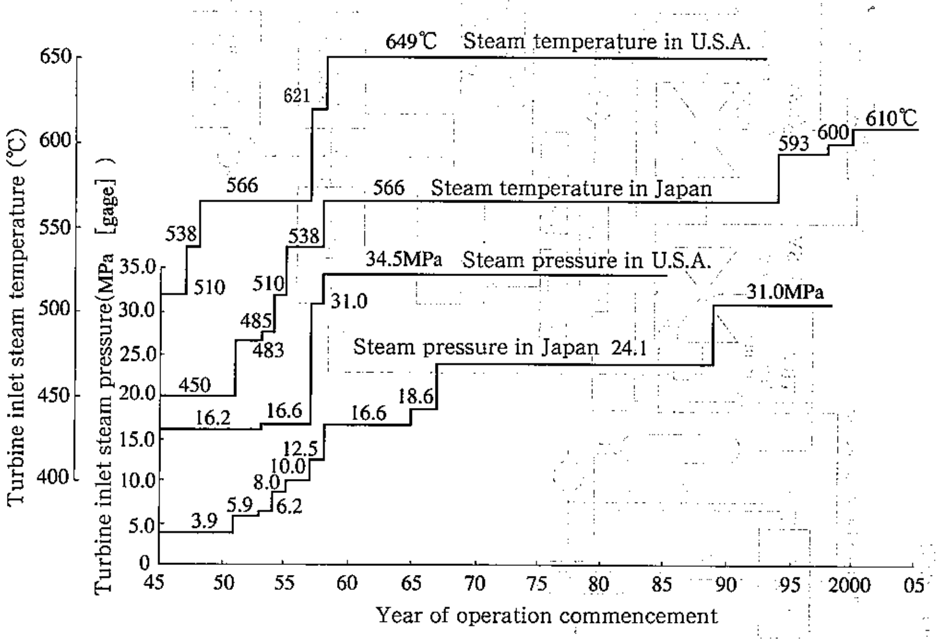
14-19 Steam Coditions of Turbines

The main steam pressure and temperature (steam conditions) of the thermal plant turbine depends upon type of turbine, combination of conditions and purpose of application, etc. No special standards are established concerning them. The followings are typical and usual conditions as reference;

Steam conditions	Type / Units	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	⑮	⑯
Main steam pressure	MPa [gage]	5.9	8.6	10.0	10.0	12.5	16.6	16.6	18.6	24.1	24.1	24.1	31.0	24.1	24.1	24.0	25.0
Main steam temperature	℃	485	510	538	538	538	566	566	538	538	538	538	566	538	566	593	600
Reheat steam temperature	℃	—	—	—	538	538	538	566	538	538	566	552/566	566/566	593	593	593	610

Note: All of the steam conditions included in the above, pressure of ±5% and temperature of ±5℃ (9°F) may be regarded as conformity.

For the nuclear turbine, the saturated steam at 4.9~6.9 MPa [gage] (moisture 0.25~0.45%) is generally used.



History in steam conditions for thermal power plants

14-20 Major Materials for Turbines

Items	Turbines for thermal	Turbines for nuclear
Casing	Cast steel, steel plate, Mo cast steel, Cr-Mo steel, Cr-Mo-V steel	Cast steel, steel plate
Main valves (Stop valves)	Same as casing.	Cast steel
Bolts	Carbon steel, Cr-Mo steel, Cr-Mo-V steel, Cr-Mo-W-V steel, Ni-Cr-Co-Ti-Mo steel	Carbon steel, Cr-Mo steel, Cr-Mo-V steel
Rotors	Carbon steel, Cr-Mo steel, Cr-Mo-V steel, Ni-Cr-Mo-V steel, 12Cr steel	Cr-Mo-V steel, Ni-Cr-Mo-V steel
Blades	12Cr steel, Ni-Cr steel, Ti, Cr-Mo-W-V steel, Cr-Mo-Nb-V steel, Ni-Cr-Co-Ti-Mo steel	12Cr steel, Ni-Cr steel, Cr-Nb steel
Nozzles and static blades	12Cr steel, 13Cr steel, Cr-Mo-Nb-V steel, Cr-Mo-W-V steel	12Cr steel, Ni-Cr steel
Diaphragms	Same as casing.	Cr Cast steel, Cr-Mo steel, Cr steel, cast steel alloy

Examples of Applicable Materials for Turbine Hot Parts

Steam condition Main steam pressure Main steam temperature Reheat steam temperature	24.1MPa 538℃ 566℃	24.1MPa 566℃ 593℃	24.1MPa 593℃ 593℃
Rotor (high pressure)	Cr-Mo-V Forged steel		12Cr Forged steel
1st stage bucket (high pressure)	12Cr Forged steel		Improved 12Cr forged steel
Nozzle box (high pressure)	Cr-Mo-V Cast steel		12Cr Cast steel or Cr-rich forged steel
Outer casing (high pressure)	Cr-Mo-V Cast steel		12Cr Cast steel
Inner casing (high pressure)	Cr-Mo-V Cast steel		12Cr Cast steel
Rotor (intermediate pressure)	12Cr Forged steel	Improved 12Cr Forged steel	
1st stage bucket (intermediate pressure)	12Cr Forged steel	Improved 12Cr Forged steel	
Outer casing (intermediate pressure)	Cr-Mo-V Cast steel		
Inner casing (intermediate pressure)	Cr-Mo-V Cast steel	12Cr Cast steel	
Main steam stop valve and control valve	Cr-Mo-V Cast steel or Cr-Mo-V Forged steel	Cr-Mo-V Forged steel	12Cr Cast steel
Reheat steam stop valve	Cr-Mo-V Cast steel	12Cr Cast steel	

[Source: Thermal and Nuclear Power Generation, Vol. 45, No.10]

14-21 General Specification for Steam Turbines

(Cited from JIS B8101-1991.)

1. Scope

This general specification covers the steam turbines for electric power plants. It may be applied to steam turbines designed for other applications.

2. Term and Definition

The major terms are defined in JIS B 0127, B 0130 and B 8102.

(d) Maximum continuous output

The maximum continuous output denotes the guaranteed maximum continuous output at the generator terminal achieved when the turbine is operated in the specified conditions. It is also called the rated output or rated load.

(f) Economical output: The output at which heat rate or steam rate may be minimized.

3. Guarantee

3.2 Guarantee of heat or steam rate

(1) Heat or steam rate may be guaranteed for 1 or more load.

(2) The basic guarantee conditions shall be specified if the feed water pumps or feed water heaters are under separate contact or the supplier does not show the pressure rise and efficiency of the pump.

3.5 Steam table

The steam table used for guarantee and test result computation shall comply with the International Skeleton Steam Table published in 1963, shall be agreed between the supplier and user, and shall be specified in the contract specification.

3.6 Tolerance

The guarantee to tolerance for guarantee is not specified in particular. If required, it shall be determined by the supplier and user.

4. Speed Regulation

4.1 Speed governor

4.1.5 The governor and operation device for the steam control valve must regulate the turbine speed not to reach the tripping speed even if the rated output is shut down instantaneously.

4.2 Speed and load control

4.2.1 The turbine speed must be controlled as shown below during no-load operation.

(1) When the turbine drives a generator, the adjusting range of the turbine speed should be within ±6% of the rated speed, at least.

4.3 Speed governing characteristics

Table: Characteristics of the speed governor regarding to speed variation and dead band

Speed govenor type		Mechanical			Electric-hydraulic type		
Rated output kW		Less than 20000	20,000~150,000	More than 150000	Less than 20000	20,000~150,000	More than 150000
Permanent speed variation %		3~5					
Incremental speed variation %	(a) 0 to 90% of rated output	Maximum value: Not restricted.				2~10	
	(b) 90 to 100% of rated output	Minimum value: 40% of permanent speed variation				12 or less	
Average incremental speed variation at 90 to 100% of rated output (1) %		15 or less				10 or less	
Dead band %		0.4	0.20	0.10	0.15	0.10	0.06

Note: (1) The average incremental speed variation of a partial admission of nozzle governing turbine at 90~100% rated output must not exceed three times as high as the permanent speed variation.

4.5 Emergency speed governor

4.5.1 In addition to a speed governor, a turbine should be equipped with an independent emergency speed governor in order to prevent the speed from being increased abnormally. The emergency speed governor must be tripped at 11% or less of the rated speed.

5. Operation and Maintenance

5.2 Permissible limitation in operation

Item / Operating conditions	Steam pressure (at turbine inlet)		Steam temperature (main steam and reheat steam at turbine inlets)	
Normal operation	Average	Maximum	Average	Maximum
	Not more than the rated pressure (in any 12 months)	Not more than 110% of the rated pressure	Not more than the rated temperature(in any 12 month)	Not more than +8℃ of the rated temperature
Abnormal operation	(1) Maximum pressure rise up to 120% of the rated pressure provided the aggregate duration of such abnormal time over any twelve months shall not exceed 12h.		(1) Permissible duration operating with temperature rise more than 8~14℃ of the rated temperature is less than 400 hours aggregated in any 12 month. (2) Permissible duration operating with temperature rise more than 14~28℃ of the rated temperature is less than 80 hours aggregated in any 12 month.	
Others	A device is needed to hold the turbine exhaust pressure before the reheater lower than 120% of the pressure defined at the rated power operation.		In the case turbine steam is supplied at the same point by two or more parallel pipes, differential temperature between these steam is required to be less than 17℃. (less than 28℃ within 15 minutes)	

(5) Rotating speed

A turbine must be capable of operation at 98 to 101% of the rated speed without any restrictions upon the time and output unless otherwise specified. It must not operate at any speed remarkably less or more than the rated speed without any agreement.

6. Specification of Components

6.4 Rotors

6.4. 2 The combined critical speed of turbine and driven machine should be sufficiently apart from the rated speed in order to keep unconditional operation in the range from 94% of the rated speed to the speed which is reached when the load is cut off completely under the condition of the speed governor not functioning.

In case manufacturer of turbine and generator are different, the shared responsibility for the combined critical speed of the turbine and the driven machine must be determined upon cooperation between both manufacturers.

6.4. 3 Overspeed test of a turbine rotor should desirably be executed by manufacturer's factory. The testing speed should desirably be 115% or less of the rated speed. Even if the test speed exceeds 115% of the rated speed, it must not exceed 120% of the rated speed.

The testing duration should be 2 minutes or less. The turbine rotor must be tested only once.

7. Foundation and Building

8. Feed Pump Drive Unit

9. Auxiliary Equipment of Turbines

9.1 Lubrication system

The lubrication system shall comply with the following.

(1) A turbine shall be equipped with the lubrication system shown below.

(a) Main oil tank

(b) Oil cooler

(c) Oil strainer

(d) Main and auxiliary oil pumps and their drive units

(e) As for a 10000 kW or more turbine, emergency oil pump (including the drive unit) or manual oil pump for stopping the turbine safely in case the main and auxiliary oil pumps go out of order

(f) Lubrication equipment, and valves, oil pipes and water pipes in its system (If the purchaser installs the oil cooler apart from the turbine, the connection pipes between them may be omitted.)

(g) A device for stopping the oil pump in an emergency

(h) Oil purifier

(10) The turbine manufacturer shall specify the recommended lubricant.

(11) The lubricant system shall be so designed that the temperatures of discharged oil of

each main bearing in the normal operation will not exceed 77℃. Temperature up to 85℃ is allowed for a small capacity turbine.

10. Turbine Instruments

10.2 Standard instruments

The standard instruments are as shown below.

(1) Pressure gauges
  Pressure gauges before the main stop valve
  Pressure gauges before the reheat stop valve
  Extraction pressure (for an extraction turbine)
  Extraction pressure to the feed water heater
  Turbine exhaust pressure
  Bearing oil pressure
  Hydraulic oil pressure
(2) Thermometers
  Main steam temperature
  Reheat steam temperature
  Exhaust temperature
  Extraction temperature to the feed water heater
  Oil temperature at oil cooler outlet
  Bearing oil temperature or bearing metal temperature
(3) Oil level gauges
  Oil level in the main oil tank
  Oil level of the hydraulic oil tank

10.3 The supervisory Instruments are as shown below.

(1) Turbine tachometer
(2) Wattmeter
(3) Differential expansion indicator and expansion indicator
  (a) These indicators are used to measure the relative axial displacement of the rotor with respect to the casing or bearing pedestal on the opposite side of the thrust bearing.
  (b) They are used to measure the relative axial displacement of the bearing pedestal with respect to the turbine foundation.
(4) Relative axial positions of the thrust collar and bearing pedestal (or wear of the thrust bearing)
(5) Vibration meter
  The vibration meter is used to measure vibrations of the bearing pedestal or rotor. Measurement of eccentricity and phase may be required.
(6) Metal thermometer (for measuring the thermal stress)
  The metal thermometer is used to measure the metal temperature or the steam temperature after the first stage and the steam temperature in the reheat inlet chamber, which are necessary to evaluate the thermal stresses on the turbine casing wall and rotor surface and to determine the safe start-up speed rate and load changing rate.
(7) Valve position meter
  Unless otherwise specified by the user and supplier, all main steam and reheat steam valves shall be equipped with an position meter. The reheat stop valves may have FULL OPEN and FULL CLOSE indications only.
(8) Moisture separator and level gauge of heater drain tank
  The water levels in the separator-reheater drain tank shall be measured.
(9) Alarm and trip transmitter
  The alarm and trip transmitter shown in section 11 of this chapter shall be provided.

10.4 Additional instruments

Additional Instruments may be specified by the user or recommended by the supplier. The following show the typical additional instruments for large capacity turbine units.

(1) Condenser cooling water temperature
(2) Pressures and levels in various tanks

(3) Steam and feed water temperatures at the inlets and outlets of the feed water heaters and heat exchangers
(4) Suction and discharge pressure of the feed water pump
(5) Condensate, feed water and main steam flows
(6) Pressure after the 1st stage

11. Protective Equipment

11.2 Tripping equipment

11.2.4 A trip system must contain the following equipment.

However, provision of (5) and (6) may be agreed upon deliberation between the user and manufacturer.

(1) Emergency speed governor
(2) Manual trip device at local
(3) Local and remote electromagnetic emergency trip equipment.
(4) Vacuum tripping equipment
(5) Thrust failure protective equipment
(6) Trip equipment for main steam pressure drop
(7) Trip equipment for bearing oil pressure drop
(8) Electric speed governor trip device in case of governor trouble
(9) Trip equipment for generator trouble
(10) Trip equipment for electric system trouble

11.3 Alarm devices

Alarm devices for the abnormalities shown below shall be provided. Necessity of tripping may be agreed upon deliberation between the user and the manufacturer.

(1) Wear or the thrust bearing pads
(2) High exhaust temperature from low pressure cylinder
(3) High bearing temperature (Discharge oil or metal temperature)
(4) Excessive vibrations

11.4 Other protective equipment

11.4.1 Protector against pressure rise at the exhaust of low: The exhaust of the low pressure cylinder or condenser shell shall be equipped with relief valves or atmosphere relief diaphragms having sufficient capacities to suppress the pressure within the allowable value in order to protect against abnormal pressure rise.

11.4.2 Protector against reverse flow of water from feed water heater system

11.4.3 Protector against abnormal pressure rise at the moisture separator-reheater: Containment shell of the moisture separator-reheater shall have proper-capacity relief valves or atmosphere relief diaphragms to protect against excess pressure.

11.4.4 If necessary, a turbine must be equipped with a device which closes the steam control valve and reduces the turbine load to the balanced output as fast as possible when the main steam pressure reduces to the specified pressure.

12. Vibrations

Vibrations of a turbine may be measured on the shaft or bearing pedestal. The vibration alarm values of the turbine and generator shall be not more than the values shown below.

Table: Double amplitude of vibration

Rated speed (rpm)	Double amplitude of vibration (mm)	
	shaft	Bearing
Less than 2500	0.175	0.067
2500 to 4000	0.125	0.062
4000 to 6000	0.100	0.050
6000 to 10000	0.075	0.037
10000 or more	0.062	0.031

Note: If the vibration amplitude exceeds the value twice as large as the value shown above, the turbine and generator should desirably be shut down automatically. An industrial small capacity turbine may be stopped manually.

13. Noises

13.1 Noises of equipment

Noise of each equipment shall be measured at a height of 1.2 meters from the floor, corridor or accessible foothold on a virtual plane 1 meter apart from the equipment surface.

13.2 Noises of power plant

14. Testing

14.2 Hydraulic pressure test

As for parts exposed to steam pressure over the atmospheric pressure, hydraulic pressure test shall be executed at a pressure not less than 1.5 times as high as the rated operation pressure.

If the parts may be broken at such a high testing pressure, the hydraulic pressure test shall be determined by the user and supplier.

If hydraulic pressure test is impossible, test shall be executed as specified.

15. Delivery and Installation

16. Design Conditions Shown by Purchaser of Equipment

17. Design Conditions Shown by Supplier of Equipment

18. Conditions of Feed Water Heater

14-22 Precautions for Testing of Heat (or Steam) Rate

(Refer to JIS B 8102-1995 Steam turbines–acceptance test)

3. Basic Plan of the Testing

3.1 Plan Needed in Advance of the Testing

Both parties of conducting the test and accepting the test result according to this standard should make agreement in advance on the purpose and method of the test. In the agreement of the test method, it is required to confirm the system configuration and operating conditions. The both parties make agreement on accuracy of the measurement required at the testing as early as possible. Typical items to be agreed during design stage of the plant are as below.

(1) Location of flow meter and piping around the meter as basic calculation data of the testing.

(2) Number and location of valves necessary not to ignore flow important for the testing, such as bypassing or flowing in and out the component of the system.

(3) Number and location of thermometer and pressure gage necessary to obtain accurate base data.

(4) Number and location of duplicated measurement necessary to obtain accurate base data.

(5) Treatment of leak flow to avoid troubles and invasion of errors happened during testing.

(6) Method of measuring leak flow from shaft of pumps, as necessary.

(7) Method for determining enthalpy of steam superheated less than 15℃ and dryness of steam contained moisture. In item 4.7, desirable method of measuring steam wetness is shown.

3.2 Agreement and Preparation in Advance

Items necessary to be agreed and prepared in advance of testing are as below;

(1) It is required to agree in advance on schedule, purpose, measurement method, operation method for necessary adjustment, modification method of test results and comparison method with the contract conditions of the testing.

(2) It is required to agree on supplier of the instrument and measured data, maker of the instrument, location of the instrument and number of peoples for conducting and recording of the testing.

(3) It is required to agree on the method of keeping the power output and steam condition constant.

(4) It is needed to prepare spare parts of the instrument likely to be failed or damaged during testing. In case of exchanging instrument during testing, the fact is recorded in written paper.

(5) Method for determining enthalpy of steam superheated less than 15℃ and dryness of steam contained moisture is acceptable only in the case both parties have agreed in advance. It is required to record clearly the method employed in application.

(6) It is required to agree on method, time happened, name of people took action, when the instrument have been calibrated.

(7) It is acceptable to apply the method of this standard, in case the written agreement between the both parties have been established in advance of testing on the necessary instrument for conducting the test in accordance with this standard. The fact must be recorded when alternate method except defined by this standard have been applied.

3.3 Condition of the Test

3.3.1 Timing of the acceptance test It is desirable to execute the acceptance test as early as possible after the first synchronization. Except not specified in the contraction, the acceptance test is executed within the term of guarantee defined in the specification. In case both parties agreed, the test may be executed at testing device in manufacturer's factory.

3.4 Preparation of the Test

3.4.1 State of the plant Before starting the test, the steam turbine and the driven machine, also including the condenser and/or the feedwater heaters if they are included in the contraction, must satisfy to be suitable for the execution.

And no leakage in condenser, heaters, pipes and valves must be confirmed. Before the testing, there must be to have a chance for confirming the situation of the plant by the manufacturer. If necessary, it is favorable to be inspected by the manufacturer and at this moment to be adjusted the difference from the agreement. Although this standard are defined for the performance test of steam turbine-generator, all other equipment supplied under the contract of turbine-generator must be kept in normal and conventional condition for the commercial operation. In case the other auxiliaries ordered after contracted on the guaranteed performance as addition to the contract or in case agreed between the both parties on the special testing with the equipment out of service, the above requirement is not applied but recorded in detail on the test report. As an example typical for these cases, the piping and valves designed for bypassing all or part of turbine for control of the temperature during startup, which is selected as a part of contraction.

3.4.3 Condition of condenser In case the performance of the condenser depending on cooling flow and temperature is guaranteed, the condenser system must be inspected regarding on cleanliness and air leakage of the condenser. The both parties must agree on items to be inspected. The condition of the condenser will be confirmed by opening the water boxes, or by measuring cleanliness or terminal temperature difference. If something stuck is found, the purchaser must remove it prior to testing under manufacturer's requirement. Otherwise, the both parties may agree on suitable method for necessary correction of test result.

3.4.4 Isolation of the system The accuracy of test result may be strongly affected by proper isolation of systems. Flow of the system to be isolated and flow bypassing improperly the flow meter or the system component must be eliminated in order to minimize necessity of measurement. For any questionable isolation of flow during the testing, measuring device of the flow must be prepared prior to the test.

All of the connected piping not needed must be isolated. In case unable to isolate, the connected piping must have a port at proper position for periodical measurement at the exit.

The flow and component to be isolated and method for the isolation must be agreed prior to the first steaming. The system isolation must be recorded in the report.

It is required to consider the water stored in condenser hotwell, air ejector, feedwater heaters, boiler drum, moisture separator-reheater, reheater and others in the systems.

3.6 Preliminary Test The preliminary test may be executed with purpose below.

(a) Confirmation of the turbine condition suitable for execution of the acceptance test
(b) Inspection of the instrument
(c) Training of the test manual

After completion of the preliminary test, the test executed may be regarded as the acceptance test, if agreed with the both parties.

In case of incomplete preliminary test, it may be given to the manufacturer to confirm the turbine condition being suitable or not for the acceptance test, after searching the reason and inspecting the condition if necessary.

3.7.2 Maximum deviation and variation of test condition Without any other agreement between the both parties, the maximum deviation of the average value obtained by each measurement during any test from the value specified at the test condition and the maximum allowable variation of each measurement during the test must be within the value shown in the table 3.

3.7.3 Duration and measurement period of the test The necessary duration of the test depends on stability of the test condition and recording speed of measurement. Accurate and measurable water level variation of stored water in the system is a critical factor of the necessary test duration.

The test duration of the acceptance test recommended is one hour. The minimum duration is 30 minutes, even though shortening is allowed by agreement or technical reason. The duration needed to confirm the capacity is determined by agreement between both parties, but not allowed to be less than 15 minutes.

The test data recordable by the designated device and related each other must be read as fast as possible. In this case, as the data are unstable, it is difficult to avoid errors by non-continuous measurement. It is desirable to shorten period of measurement as possible in order to minimize unfavorable influence of the errors to the total performance measured.

4.2.4 Measurement of the electric output

(1) For the three phase generator of grounded neutral point type or four line type, the electric output is measured by cumulative watt-hour meter or three phase watt-hour meter.

For the three phase generator with neutral point grounded by resistance, reactance or transformer with resistance, the electric output may be measured by two phase watt-hour meter, but preferably by three phase watt-hour meter.

(2) For grade-up of accuracy, the electric output is measured preferably by multiple devices, including transformer and amplifier for instrument.

4.3 Flow Rate Measurement

4.3.1 Selection of flow rate to be measured is as below.

(1) The flow rate to be measured at the acceptance test may be defined as following two groups.

(a) Primary flow: the flow which directly affects on the guaranteed heat rate and thermal efficiency, and is required to be measured with high accuracy.
(b) Secondary flow: the flow which are important to determine the turbine inlet steam flow and reheat steam flow, and necessary to operate and control the plant.

(2) In general, the flow rate of condensate system and boiler feedwater must be measured in order to define the turbine inlet flow. But, for the plant not to be a unit-to-unit or the plant supplying great deal of steam to another unit, the steam flow may be measured directly at or around the turbine inlet.

4.3.2 Measurement of primary flow The primary flow important for definition of performance must be measured by following methods.

(a) By normal or calibrated nozzle, orifice or venturi-tube
(b) By direct measurement of mass in tank
(c) By calibrated volume tank

Measuring difference of pressure (throttle mechanism) by nozzle or orifice is utilized as general methods.

Table 3 The Maximum Permissible Deviation and Variation of Test Condition

Variables	Maximum permissible deviation of the average value from specification, during any test	Maximum permissible variation from the average value, during any test
Main steam pressure	absolute ± 5 %	absolute ± 2 %
Main steam temperature	± 8 ℃	± 6 ℃
Dryness	±0.005	
Extraction pressure	absolute± 5 %	absolute ± 2 %
Exhaust pressure		
For feedwater heater	Refer to the remark 3	
For back pressure turbine	absolute ± 5 %	absolute ± 2 %
For condensing turbine	absolute +25% absolute −10%	absolute ±5%
Extraction steam flow	±10%	
Reheat steam temperature	± 8 ℃	± 6 ℃
Adiabatic heat drop	± 7 %	
Output or main steam flow (corrected to rated condition)	± 5 %	± 3 %
Final feedwater temperature	±10℃	—
Rotating speed	± 2 %(Refer to remark 2)	± 1 %
Power factor	1.00~(rated −0.05)	±0.05
Voltage	± 5 %	± 2 %
Condenser(if specified in contraction)		
Cooling water flow	±10%	—
Cooling water inlet temperature	± 5 ℃	± 1 ℃

Remark: 1. Conditions to keep the deviation of heat drop less than ±7% are as follow.

Main steam pressure	absolute pressure±5%
Main steam temperature	±15℃
Extraction steam pressure	absolute pressure±5%
Exhaust pressure(Back pressure turbine)	absolute pressure±5%

2. At the turbine guaranteed technically
3. In case the deviation of extraction steam pressure to be small compared with design value, the influence on the gross performance may be ignored usually.

In case the deviation of extraction steam flow to be unreasonably large, resulted from manufacturing of feedwater heater, the influence on the gross performance would raise a problem extremely large.

Table 4 Acceptable Instrumentation for Acceptance Test and Average Uncertainties

No.	Object	Instrument	Accuracy	Range	Uncertainty	Remarks
1	Pressure	Plumb type pressure gage		$P>0.2$ MPa	±0.3 %	
2		Pressure transducer, calibrated		all pressures	±0.3~0.5 %	
3		Burdon tube pressure gage, calibrated	0.3 %	$P>0.2$ MPa	±0.3~0.6 %	
4		Burdon tube pressure gage, calibrated generally	0.6 %	$P>0.2$ MPa	±1 %	
5		Mercury manometer		$P>0.2$ MPa	±1 mm	to the column length
6		Liquid manometer		$P>0.2$ MPa	±1 mm	
7	Difference of pressure	Liquid manometer		$h>100$ mm	±1 mm	
8		Difference of pressure transducer		all differential pressures	±0.3~0.5 %	
9	Temperature	Thermo-couple, calibrated		$t\leqq300$ ℃	±1 ℃	
				$t>300$ ℃	±0.5 %	
10		Electric resistance thermometer, calibrated"		$0<t\leqq100$ ℃	±0.2 ℃	
				$t>100$ ℃	±0.5 %	
11		Mercury thermometer(0.1℃), calibrated	0.10 ℃	$t<100$ ℃	±0.1 ℃	
12	Primary Flow	Difference of pressure meter, standard			0.75~1.5%(1)	JIS Z 8762
13		Difference of pressure meter, calibrated				
14	Cooling water flow	Bhen type flow meter		$D>1\,000$		
15	Electrical Output	Double instrument method (Watt-hour orWatt meter) Instrument transformer, calibrated Instrument, calibrated at the test load	 0.3 % 0.2 %		0.1~0.3 %	
16		Triple instrument method(Watt-hour or Watt meter) Instrument transformer, calibrated Instrument, calibrated at the test load	 0.3 % 0.2 %		0.1~0.3 %	
17	Electric Current	Ampere meter	0.2 %			
18	Voltage	Voltmeter	0.2 %			
19	Mechanical Output	Dynamometer, or Energy balance method			約±2 %	
20	Rotation Speed	Stationary gyro-meter		Within calibrated	±1.0 %	
21		Handy gyro-meter		Within calibrated	±0.5 %	
22		Electronic gyro-meter		Within calibrated	±0.1 %	
23	Atmospheric Pressure	Mercury barometer, super-precision type			±0.2 hPa	

Remark :1. The measurement accuracy of the major flow is related to main part of allowable error for the performance data of the acceptance test. Consequently, the difference of pressure device must be selected on this point of view.
2. The pressure above in MPa or hPa is defined as absolute pressure. Special attention is requested for remote or automatic measurement system.

Table 5 Definition of the Output regarding on the Heat Rate

Driving Method of Boiler Feed Pump and other Auxiliaries	Definition of the Heat Rate	
	Gross Heat Rate (GHR)	Net Heat Rate (NHR)
Driven by motor	P_b	$P_b - P_a$
Driven directly by main turbine	$P_b + P_P$	P_b
Driven by turbine	$P_b + P_a$	P_b

P_b: Generator output at terminal(kW)
P_a: Power (kW) of feed pump and other auxiliaries not to be driven by turbine
P_P: Power (kW) of feed pump and other auxiliaries directly driven by main turbine

Table 6 Example of Correction Factors for Reheat and Regenerative Turbine

- Main steam pressure
- Main steam temperature
- Reheat steam temperature
- Pressure drop of reheater
- Turbine exhaust pressure, condenser cooling water temperature, cooling water flow rate
- Efficiency of moisture separator *
- Rotating speed
- Difference of temperature of feedwater heater (Terminal temperature difference) *
- Pressure drop in extraction line *
- Difference of reserved water in system, make-up water
- Enthalpy rise at condensate pump and feedwater pump
- Over-cooling of condensate in condenser (in case turbine performance guaranteed at the cooling water temperature)
- Spray water flow at boiler
- Difference of condition for system operation of feedwater heating (cut out of heater, as example)
- power factor of generator
- Voltage
- Hydrogen pressure

Correction factors for wet steam operation :

- Wetness of main steam
- Wetness at exit steam of moisture separator
- Difference of temperature at terminal of reheater
- Pressure drop of moisture separator and reheater

Note: * Not corrected usually for supplied by the same manufacturer as turbine itself.

Table 7 Guiding Values for Uncertainty of Test Data

	measuring uncertainty of data (relative value)
Back pressure turbine	1.5~2.0 %
Back pressure and extraction turbine	1.7~2.5 %
Condenser turbine	1.0~1.7 %
Condensing and extraction turbine	1.3~2.0 %
Reheat and condensing turbine	0.9~1.2 %
Wet steam and condensing turbine	1.1~1.6 %

Remark: The allowable range above may be reduced improving accuracy of the primary flow.

14-23 Turbine Troubles and Possible Causes

I. Vibration

1. Eccentricity:
   Improper centering,
   Eccentricity of coupling,
   Unequal dipping / deformation of turbine foundation,
   Wear of bearing,
   Deformation of casing
2. Unbalanced force:
   Imperfect balancing,
   Bending of rotor,
   Lack of rotor material homogeneity,
   Damage, erosion, wear of rotating part,
   Adhesion of scale,
   Liquid stored in center bore,
   Shift of balancing weight,
   Improper sliding of claw coupling,
   Electric unbalanced force
3. Contact between rotating part and stationary part, Uneven expansion of rotating part and stationary part, Deformation or damage of stationary part(such as cylinder, diaphragm, etc.), Damage of thrust bearing, Admission of steam containing air and water, Deformation/movement of casing due to reaction force of piping and difference of expansion of casing
4. Foreign matters
   Damage in turbine,
   Improper cleaning at the assembly including admission of drain, etc.
5. Critical speed
   Resonance of foundation included
6. Instability of oil film in bearings
7. Low oil temperature in bearings
8. Quick change or inappropriateness of load, speed or steam conditions
9. Unstable sliding of cylinder legs
10. Improper sliding of bearing peadestal

II. Rise of bearing temperature

1. Shortage of lubricant oil,
   Failure of oil pump,
   Trouble of oil piping (such as clogging, etc.)
2. Trouble of oil cooler,
   Holding of air/foreign matters, Dirtiness of cooling pipe, Damage of cooling tube, Insufficient cooling water, Rise of cooling water temperature
3. Defect or deterioration of lubricant, Mixing of steam or water, Improper conditioning of lubricant, Mixing of defective lubricant, Overheat of lubricant
4. Deformation of bearings due to heat, etc.
5. Increase of rotor shaft thrust, Adhesion of scale, Wear of seal fin, Improper sliding of claw coupling
6. Increase of surface pressure, Miss alignment of shaft (refer to I-1)
7. Looseness, cracks or deformation of bearing white metal
8. Improper adjustment and abnormal wear of thrust bearing
9. Thermal conduction from gland steam
10. Electric erosion of bearing metal

III. Troubles of speed governor

1. Trouble of speed governor
2. Trouble of speed governor mechanism
3. Trouble of signal detector on speed governor
4. Malfunctioning of control valve, Adhesion of scale, Thermal deformation, Improper assembly and adjustment (such as improper gap, fitting or the like) and break of valve stem
5. Deterioration and deficiency of operating oil

IV. Overspeed of turbine

1. Defect of overspeed emergency governor, Dislocation of component parts, Increase of wear, Malfunctioning due to wear
2. Malfunctioning of steam valve, Dislocation of parts, Increase of friction wear, Thermal deformation, Adhesion of scale
3. Increase of leak steam bypassing steam valve

V. Trouble of blades

1. Improper design or machining
2. Improper selection of material
3. Flaws in material
4. Contact with stationary parts
5. Adhesion of scale or admission of foreign matters or drain
6. Admission of corrosive substances
7. Resonance with turbulent steam flow
8. Improper operation conditions
9. Quick change of operation conditions

VI. Troubles of shaft seal packing

1. Contact wear due to deformation of cylinder, pdiaphragm, brand case, etc.
2. Damage due to foreign matters
3. Corrosion by steam or water admission
4. Improper material
5. Deterioration of retaining spring for seal packing
6. Improper adjustment of gland steam

VII. Crack of shaft

1. Deterioration of material due to long-period operation
2. Repetition of operations subject to quick temperature change
3. Improper design or material

VIII. Cracks in casting or welding parts

1. Deterioration of material due to long-period operation
2. Repetition of operations subject to quick temperature change
3. Improper design or material
4. Improper thermal insulation

IX. Steam Leakage

1. Deformation of casing (cylinder)
2. Improper finishing or deformation of joint surface
3. Insufficient strength of joints and bolts
5. Defects of gasket

X. Erosion and corrosion of parts

1. Improper material selection
2. Improper draining method
3. Long-term operation at low steam temperature
4. Difference in elongation of joints and bolts
4. Steam leak into cylinder during stoppage
5. Penetration of corrosive gas
6. Improper feed water
7. Wear due to scale mixed in system
8. Speed and eddy of steam or water

XI. Efficiency down

1. Increase of clearances
2. Internal leakage from joint surface due to deformation of cylinder, nozzle, diaphragm, etc.
3. Adhesion of scale onto nozzle and blades
4. Corrosion or breakage of nozzle or blades
5. Abnormalities in steam conditions, vacuum, extraction, etc.

14-24 Vibration of Turbine Generators

1. Vibration monitor

Normally, double amplitude of the turbine shaft at a position close to each bearing of the turbine generator or on each bearing pedestal is measured.

In any case, recorder of vibration must be prepared and be capable to record any change of amplitude. It is recommended that the same vibration recorder as used in shop test of the turbine should be used for measurement at the site.

To locate the cause of vibrations, a vibration meter capable of measuring amplitude, frequency, phase, etc. is used.

2. Vibration amplitudes

The allowable value of the vibration amplitude at the rated speed differs with turbine manufacturers. Refer to the operation guide or manual. If the vibration amplitude exceeds the allowable limit, the cause shown in the following section must be checked to correct vibrations.

[Reference] (Cited from IEC* Standard "Specification for Steam Turbines IEC45-1 (1991)")

Rated speed of turbine	rpm	1,000	1,500	1,800	3,000	3,600	6,000	12,000
Double amplitude of bearing vibration	mm	0.075	0.050	0.042	0.025	0.021	0.012	0.006

Note:
These allowable values apply to well-balanced turbines.

The acceptable shaft vibration is considered normally more than twice as large as the bearing vibration above. But, the shaft vibration is not included as the evaluation criteria.

* International Electrotechnical Commission.

A steam turbine of 400000 kW or more shall be equipped with an alarm device, which gives an alarm when the maximum double amplitude of vibrations of the major bearing or the shaft close to it exceeds the value shown below.

(Article 15 of the ministry guide for technical standard of thermal power generating facilities), (Article 24 of the applicable understanding for technical standard of thermal power generating facilities)

Measurement points	Rated speed	Alarm value	
		Speed less than rated speed	Speed not less than rated speed
Bearing pedestal	3000 or 3600 rpm	0.075mm	0.062mm
	1500 or 1800 rpm	0.105mm	0.087mm
Shaft	3000 or 3600 rpm	0.15mm	0.125mm
	1500 or 1800 rpm	0.21mm	0.175mm

3. Causes of vibration (Also refer to 14-23, Turbine Troubles and Possible Causes.)

A. Contact between rotating part and stationary part

When a rotating part is in slight contact with a stationary part, the high spot of the rotor is heated locally and the shaft may be bent temporarily, resulting in unbalance.

B. Off-centering

Off-centering causes the following phenomena:

(1) Oil whip

(2) Unstable vibrations

(3) Change in the critical speed or critical speed range

C. Oil whip

(1) Vibration frequency is 1/2 of the rated speed. (2) The amplitude is quite great.

D. Unstable vibrations

(1) Uneven bending of the rotor material (2) Oil or water in the center bore

(3) Looseness of the rotor (4) Short circuit of the generator exciting coil

(5) Wear of claw coupling teeth (6) Looseness of foundation bolts

E. Vibrations at frequency twice as high as speed

Such vibrations may occur in a 2-pole generator.

F. Vibrations at frequency three times as high as speed

Such vibrations may occur in a generator collector or around it.

G. Vibrations of generator stator

The stator vibrates at the frequency twice as high as the speed.

H. Unbalance

The frequency is the same as the rotating speed and is not influenced by the magnitude of the load.

(1) Failure of the blades

(2) Bending of the shaft

I. Resonance of foundation, etc.

4. Abnormal speed operation of turbine and service life of blades

Normally, the turbine blades may operate free from troubles in the range from 2 to 3% below the rated frequency to 1% above the rated speed. The range differs with turbines. Refer to the operation guide, etc. The following shows examples of reduced service lives of the blades or blade groups (normally, the blades of the last stage and the next to last stage) when a turbine runs at lower frequency.

Conditions (1) Rated operation frequency: 60Hz

(2) Allowable operation frequency: Rated frequency−1%

Results: (1) No influences are made upon the service life of the blades in operation at the rated frequency-1% (i.e., 59.4Hz).

(2) The blades are damaged in approx. 90 minutes* in operation at the rated frequency-2% (i.e., 58.8Hz).

(3) The blades are damaged in 10 to 15 minutes* in operation at the rated frequency-3% (i.e., 58.2Hz).

(4) The blades are damaged in approx. 1 minute* in operation at the rated frequency-4% (i.e., 57.6Hz).

Note: The values marked with asterisks, *, denote the total safety running time in the service life. Damages to the blades include damages to the tie wires and shrouds.

14-25 Precautions for Turbine Operation

1. Precautions for Operation

The turbine manufacturer shows the precautions for operation and operation procedures including start up, shut down, load variation, etc. of the turbine. The user must follow its guide/manual. This clause describes the general precautions for turbine operation.

The user must always pay attention to these items and shall refer to 14-23 "Turbine Troubles and Possible Causes" "and 14-24 "Vibration of Turbine Generators" and should check the cause and take proper countermeasures when some troubles or changes are found.

Item	Precautions
1. Vibration	Pay attention to whether vibration enlarging or not, rate of increment and location of vibration.
2. Lubricant system	(1) Maintain the lubricant system clean. Use oil purifier in order to remove the involved water whenever necessary. (2) Pay attention to the bearing temperature. The temperature of lubricant cooled by the oil cooler should desirably be 40℃ to 45℃ at the cooler outlet or 60℃ to 65℃ at the bearing outlet. (3) The temperature difference between the oil inlet and outlet of bearings must not exceed 35℃. (4) Check that no oil leaks from the piping system, oil seal rings of the bearings, hydraulic mechanisms, etc. Note that an oil leak is not only unacceptable but it may cause a fire near a place locating hot steam piping. (5) Pay attention to variation of the oil pressure.

	(6) Check that the auxiliary oil pump starts up automatically and smoothly. It is recommended that the pump startup test be conducted periodically using the pressure switch testing valve even while the turbine is operated.
3. Control system	(1) Check if the controller functions satisfactorily. (2) Check if the overspeed trip mechanism functions properly. Check its functioning once a month or so if possible. If it is tested with the turbine overspeed, the rotor should be heated up sufficiently. (For example, run the rotor for 3 hours or more at least with a load not less than 1/4 of the rated output.) (3) Check if the main stop valve and control valve function properly once a day or so if possible. For a reheat turbine, also check if the interceptor valve and reheat stop valve function properly. (4) Pay attention to the change of the oil pressure of the control system.
4. Steam leakage	Check with care that no steam leaks from the gland, cylinder joint or valve stem.
5. Precautions during stoppage	(1) No steam be flowed in turbine while the rotor is stopping. (2) Open the drain valve between the main stop valve and control valve. (3) Never withdraw air from the gland while the rotor is stopping. Never operate the vacuum unit without feeding gland steam or sealing water to the gland. (4) Be sure to carry out turning while the turbine is stopping.

Note: For the startup precautions, see the clause "Minimum Load Operation and Quick Start of Steam Power Plants."

2. Inspection Procedures of Turbine in Service

The table below shows the general criteria for daily inspection of turbine for detecting abnormality or determining necessity of repair. (Refer to the report of Maintenance and Repair Committee for thermal power plant, July 1996, Thermal Power Generation Vol. 118, Thermal Power Engineering Society) Daily operation includes startup, shutdown and short-time stoppage. The inspection procedures shown below do not include the operation procedures.

Equipment	Check points	Check interval			Remarks
		Every duty	Daily	On occasion	
1. Cylinder, Rotor	1. Abnormal noises and vibrations	○			
	2. Eccentricity, shaft position, elongation, and differential elongation	○			Particular attention in startup operation.
	3. Temperature at various points of cylinder	○			Pay special attention to the temperature difference between various positions.
	4. Steam temperature and pressure at inlet and some stages	○			Pay attention to the change.
	5. Exhaust temperature	○			Pay special attention to the change when starting or stopping operation and during light load operation.
	6. Leakage and abnormality	○			
	7. Shaft current protector	○			
	8. Vibration monitor			○	
2. Bearings (including thrust bearings)	1. Abnormal noises and vibrations	○			
	2. Metal temperature	○			
	3. Lubricant pressure and temperature	○			
	4. Lubricant color and flow	○			
	5. Oil leak				
	6. Vibration monitor			○	
3. Gland steam regulator	1. Functioning of gland steam regulator	○			Pay attention to sudden change of load
	2. Vacuum in gland leakage steam condenser	○			
	3. Operating condition of Fan	○			
	4. Sealing water pressure and outlet temperature	○			
	5. Leakage	○			
4. Turning gear	1. Coupled and discoupled conditions			○	Pay attention to the manual lever position and the hook.
	2. Lubricant pressure			○	Pay special attention to abnormal noises and current.
	3. Operating conditions			○	
5. Speed governor	1. Functioning	○			Pay attention to the relationship between the oil pressure, valve opening, load and main steam pressure.
	2. Oil pressure	○			
6. Pre-emergency governor	1. Functioning	○			
	2. Oil pressure	○			
7. Emergency governor				○	Compare with the previous test values.
8. Turbine trip mechanism	1. Oil trip test in operation			○	Compare with the previous test values.
	2. Thrust protector test			○	Check the set values.
	3. Vacuum trip test			○	
	4. Solenoid trip test			○	
	5. Oil pressure low trip test			○	Check the set value.
9. Tank, valve, and piping	1. Oil level	○			
	2. Leakage	○			
	3. Vacuum in oil tank	○			
	4. Abnormal noises and vibration of exhaust pump and bearing temperature	○			
	5. Function check of oil level alarm			○	Check the alarm point.
	6. Lubricant quality			○	Analyze the lubricant.
	7. Drain the water in oil tank			○	
10. Oil pump	1. Outlet pressure	○			
	2. Abnormal noises, vibrations and temperature of bearings	○			
	3. Leakage	○			
	4. Vibration measurement			○	
	5. Automatic startup of auxiliary oil pump			○	Check the set value.
11. Oil cooler	1. Oil and cooling water temperatures at inlets and outlets	○			
	2. Leakage	○			
	3. Opening and closing of cooling water control valve	○			
12 Centrifugal oil purifier	1. Separated water and impurities	○			
	2. Abnormal noises and vibrations of pump and bearing temperature	○			
	3. Belt conditions	○			
13. Bauser type oil purifier	1. Oil level	○			
	2. Pressure and abnormal noises at oil feed pump outlet	○			
	3. Abnormal noises and vibrations of exhaust pump and bearing temperature	○			
	4. Leakage	○			
	5. Blowing of separated water	○			
	6. Differential pressure before and after cartridge filter	○			
14. Main stop valve, reheat stop valve, extraction check valve, and intercept valve	1. Steam and oil leak and abnormal noises	○			Pay attention to sticking, hunting, etc.
	2. Functioning	○			
	3. Valve opening	○			
	4. Open/close test		○		
15. Other valves	1. Leakage	○			
	2. Opening and closing of valves	○			
	3. Valve opening/closing mechanisms	○			
	4. Sealing water	○			
	5. Steam trap			○	
16. Piping	1. Leakage	○			Pay attention to abnormal noises.
	2. Hammering	○			
	3. Pipe supporting			○	Check the hanger travel position.
	4. Expansion or contraction of piping			○	
17. Instrument of vibrations, eccentricity, expansion, differential expansion, shaft position, cam position, speed, etc.	1. Functioning	○			Check the alarm points on occasion.
	2. Relationship among indications	○			
	3. Calibration of indications			○	Check vibration with a portable vibration tester.
	4. Electronic tube sensitivity			○	
18. Opening indicator	Comparing with indications of transmitter and gauge			○	

14-26 Precautions for Repairing Turbine

This clause describes the general precautions for periodical inspection. These precautions also apply to provisional inspection.

1. Before periodical inspection, look into the records of the previous inspection and the operation records to check abnormalities and repaired positions. Also look into the repair records after the previous inspection to check abnormalities found after the previous inspection, operating hour, number of start and stopp. Test the performances, measure vibrations, or check functioning if necessary. Judge the necessity of overhaul and repair works from these and make an inspection plan.
2. Precautions for maintenance and repair work
   (1) When overhauling or inspecting a turbine, put work wear designed to prevent from dropping your carriages. In addition, put on shoes with soft rubber soles in order not to make scar on surface of equipment or not to slip.
   (2) During overhaul work, use great care to the metal temperature and its drop speed in order to prevent the turbine casing or rotor from being damaged.
   (3) Before lifting the cylninder, rotor or other heavy components, pay attention to such details including safety loading capacity of the rope, and lifting angle in advance.
   (4) When opening the turbine, use great care to minimize damages to the thermal insulation material.
   (5) In order to check the condition of the dismantled turbine as is, be careful not to soil or flaw any part of the turbine when disassembling.
   (6) Close the turbine cylinder, oil piping, etc. with temporary covers after opening the turbine in order to prevent any objects from entering the openings.
   (7) For work inside of or on the turbine, bring as few objects as possible. Tie them with a string or other material so as not to drop or leave them in the turbine.
   (8) Place dismantled parts and tools in a certain place or in a container and put marks and names on them in order not to lose them.
3. Cleaning after dismantle
   (1) Remove attachment and deposit with a wire brush, scrubbing brush, liquid abrasive or aly ash. Then, clean with a vacuum cleaner or by blowing compressed air.
   (2) Clean the flange and machined surfaces with fine emery cloth, and a scraper.
   (3) Polish the fiting parts, journals and other precision machined parts with an oil stone.
   (4) Clean threads of bolts with a wire brush.
4. Inspection
   [Inspection immediately after overhaul]
   (1) Adhesive matter and deposit (Position, color, amount, and composition)
   (2) Discoloration and rust
   (3) Foreign matters
   (4) Breakage, dents, deformation and bend
   (5) Contact between rotating parts and stationary parts
   (6) Corrosion and erosion
   (7) Wear
   (8) Steam leak (from flange etc.)
   (9) Looseness of bolts
   (10) Measure relative positions of the components of the assembled turbine with and without the upper cylinder.
   Centering, relative position of rotor and casing in the axial direction, and clearances between the components (such as thrust bearings, other bearings, moving blades, stationary blades, diaphragm, tip clearances of the moving blades, gland and dummy seals, oil buffle, and oil seal)
   [Inspection after cleaning]
   (1) Cracks (in the welded parts, mounting flanges of the drain pipes and pressure gauges, steam inlet, gland, flanges, bolt holes, ribs, extraction pipe base, extraction chamber, disks, diaphragm and inner casing, and threads of bolts)
   (2) Deterioration of bolts and nuts
   (3) Conditions of expanding and sliding parts
   (4) Change of levelness and height
5. After finish of work
   (1) Record the details of inspection results, and compare them with the tolerances and the values in the previous inspection or installation. The recorded data should be used as the material for the next inspection.
   (2) Before assembly, make sure that no foreign matters or objects are left in the turbine. In order to prevent silica pollution, in particular, remove sand and ash with great care. In hard-to-check parts, use a reflective mirror for careful check.
   (3) Apply specified compound to the flange surfaces and threads used in parts exposed to high temperature.
   (4) After in operation, be sure to retighten or unscrew the bolts which must be retightened or unscrewed due to temperature change.
6. Others
   (1) Check carafully. For precision inspection, carry out liquid penetrant test, magnetic particle test, ultrasonic test, eddy-current test, hardness test, macrostructure examination, microstructure test, tensile test, hardness distribution test, creep rupture test and chemical analysis.
   (2) Remove minute cracks with a grinder, if possible. If some cracks are to be left, put marks close to them with a punch for further monitoring. Also make crack prevention holes.
   (3) To measure bend of a spindle or valve rod, attach it on a triangular base or lathe and measure with a dial gauge.
   (4) For centering or wiring of an outdoor type turbine, prevent the turbine from being exposed to the direct sunlight.
   (5) As for stud bolts or parts not to be disassembled, group the same type of parts used in the same conditions, disassembly or take out one of them periodically, and inspect it carefully to presume deterioration of other parts.

14-27 Precautions for Installing Turbine

In order to maintain a turbine in good operating condition, have better understanding about the structures and functions of the turbine and install and assemble the turbine properly. For that purpose, you should always refer to the assembly drawings and instruction manual of the turbine. In addition, you should be familiar with the basic precautions for installation shown below.

(1) When installing a component onto the foundation, fix it so that it is and will be free from any internal stresses and strains.
(2) Bolt all components in clean condition to avoid from distortion and loosening
(3) Make sure that all components move freely when the temperature changes and that the center lines are maintained properly when the components move.
(4) Ajust the centering of the shaft properly so that excessive stress be caused to the shaft and coupling flanges and proper load is supplied to the bearings.The shaft must be centered properly in compliance with the material concerning bearing alignment submitted by the turbine manufacturer.
(5) The clearance of the bearing metal, glands, nozzle partition plates and rotor must be adjusted in compliance with the clearance dimension list submitted by the turbine manufacturer. For the clearances, see 14-28 Examples of Clearances in Turbines and Center Adjustment.
(6) Connect the condenser with the turbine carefully so that an external force or moment greater than that specified by the turbine manufacturer will not applied to the turbine in any case.

(7) When lifting the rotor, use the lifting beam and guide to hoist it by maintaining the shaft level horizontally. Use great care not to bring the blades or diaphragm in contact with the stationary part to avoid any damage.

(8) Use great care to avoid distortion in the turbine due to improper design, manufacturing or installation of the piping.
Also use care to prevent from limiting the movement due to thermal expansion in operation. The piping should have sufficient vibration resistance and flexibility to maintain stresses below the tolerances by using sufficiently long loops or perpendicular bending, spring hangers or rollers. Always pay attention during installation to check whether the piping is proper in shape and has proper fixing and support points.

(9) Use gaskets of proper materials and sizes for all piping systems. The mating faces should be in parallel with each other and be bolted evenly and firmly.

(10) Provide the turbine with drain pipes in proper positions to prevent drain from being collected in any parts and from flowing reversely.

(11) During installation and assembly, use great care not to allow any foreign matters to enter the inside of the turbine cylinder and piping. Before assembly, clean all components completely. In particular, clean pipes having been stored outdoors with great care.

(12) After completion of assembly, feed oil to the oil system to remove minute foreign matters which could not be removed during assembly (oil flashing). The oil circulating speed should desirably be as high as possible. The oil temperature should desirably be between 65℃ and 70℃ at the beginning and between 25℃ and 35℃ at the end. It is effective to hit the pipes with a hammer while flowing oil through the pipes.

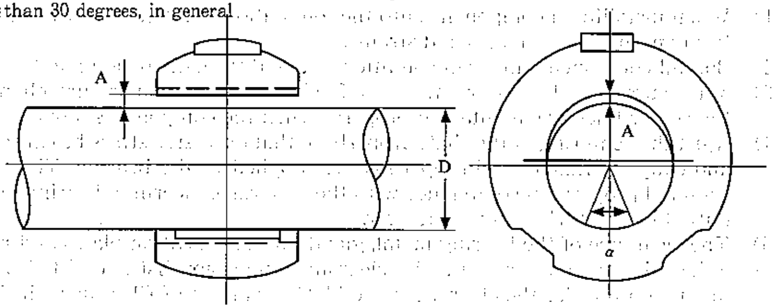
(13) Adjust all controllers and safety devices accurately. Make sure that they function properly.

(14) The turbine may become out of center after starting operation due to sinkage of the foundation and other installation conditions. Therefore, after trial running of the turbine, check variance in the level of the turbine occasionally. If the variance becomes larger than the value specified by manufacturer, re-correct centering of the unit. Carry out level variance measurement until measurements will not change any more.

(15) Make a record of all important matters in installation and assembly. Make a correct record of all pressures, temperatures, thermal expansions, etc. during trial running.

14-28 Examples of Clearances in Turbines and Center Adjustment

A: Vertical gap
D: Journal diameter (in units of mm)
α: Contact angle between journal and lower half of bearing, which is less than 30 degrees, in general

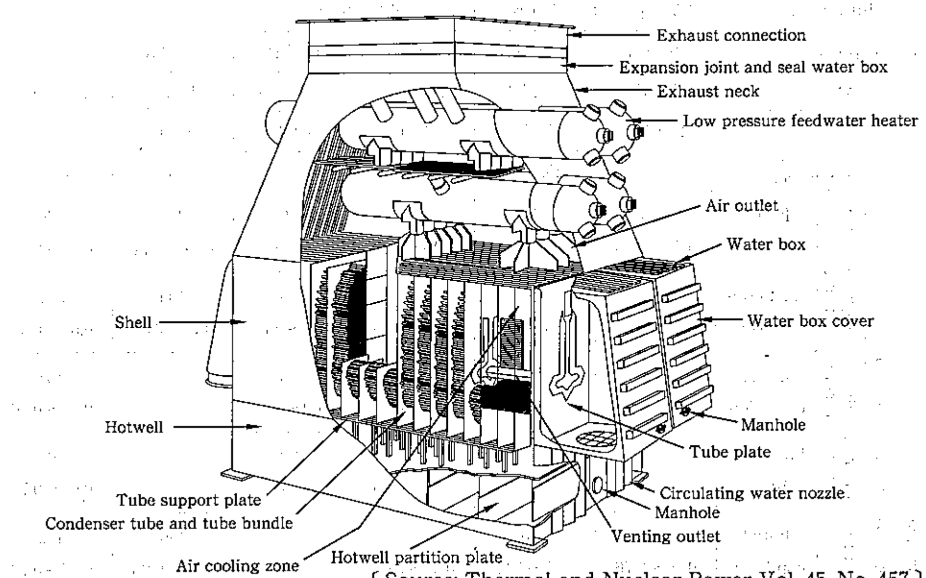


(Unit: mm)

Revolution speed				1,500rpm	1,800rpm	※3,000rpm		3,600rpm	
Rated power				1,100MW	1,175MW	600MW	1,000MW	600MW	700MW
Steam condition	Main steam	Pressure		6.55MPa	5.89MPa	24.1MPa	24.1MPa	24.1MPa	24.1MPa
		Temperature		282.4℃	275.5℃	538℃	538℃	538℃	538℃
	Reheat	Steam condition		–	259.9℃	566℃	566℃	538℃	566℃
Radial clearance	Journal diameter (D) and vertical gap (A)	High pressure turbine	Initial condition	558 0.50～0.60	455 0.80～0.90	305 0.40～0.50	406 0.53～0.63	355 0.61～0.71	330 0.43～0.53
			Last condition	558 0.50～0.60	455 0.80～0.90	381 0.50～0.60	508 0.66～0.76	405 0.71～0.81	381 0.56～0.66
		Intermediate pressure turbine	Initial condition	—	—	305 0.40～0.50	533 0.69～0.79	—	431 0.56～0.66
			Last condition	—	—	381 0.50～0.60	533 0.69～0.79	—	508 0.66～0.76
		Low pressure turbine	Initial condition	736 0.66～0.76	610 1.07～1.17	432 0.56～0.66	686 0.89～0.99	430 0.86～0.96	482 0.63～0.73
			Last condition	787 0.71～0.81	610 1.07～1.17	508 0.66～0.76	737 0.96～1.06	455 0.91～1.01	508 0.66～0.76
		Standard value		$\frac{1.0}{1000}D$	$\frac{1.75 \sim 2.0}{1000}D$	$\frac{1.3}{1000}D$	$\frac{1.3}{1000}D$	$\frac{2.0 \sim 2.3}{1000}D$	$\frac{1.3}{1000}D$
		Allowable value		$\frac{2.0}{1000}D$	—	—	—	—	$\frac{2.5}{1000}D$
	Minimum clearance between the stationary and the moving blade			1.50～3.00	As radius 0.85～0.95	1.27	1.27	As radius 0.85～0.95	1.00～2.00
	Gland, high-low pressure			0.65～1.00	As radius 0.50～0.75	0.38～0.64	0.64～0.89	As radius 0.50～0.75	0.40～0.65
Axial clearance	Thrust Bearing (total of front and rear)			0.31～0.36	0.25～0.38	0.46～0.51	0.30～0.36 0.46～0.51	0.25～0.38	0.41～0.51
	Minimum clearance between the stationary and the moving blade			1.8	8.7	2.3	2.5	6.3	3.4
Shaft leveling	Allowable errors			$\frac{2.5}{100}$	$\frac{2.5}{100}$	$\frac{2}{100}$	$\frac{2.5}{100}$	$\frac{2.5}{100}$	$\frac{2.5}{100}$

Note: ※Cross−compound turbine with 3000rpm for high／intermediate pressure and 1500rpm for low pressure.

15-1 Condenser Structure



〔Source: Thermal and Nuclear Power Vol. 45, No. 457〕

15-2 Overall Heat Transfer Coefficient of Condensers

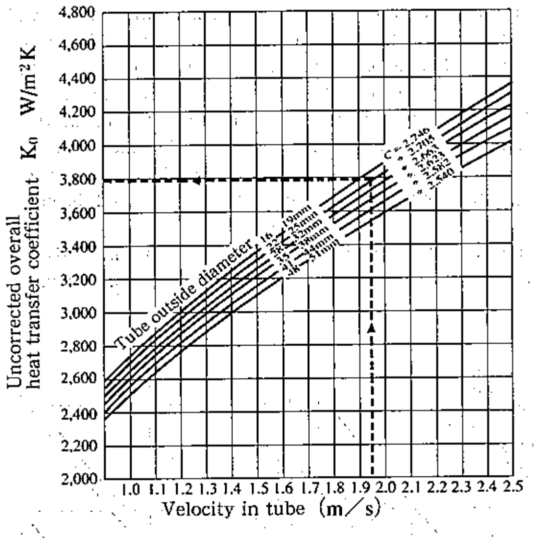
(H E I Standards for Steam Surface Condensers. 8th Ed.(1984),
8th addendum-1 (1989), 9th (1995))

(1) Corrction factor C_1 according to tube material and thickness

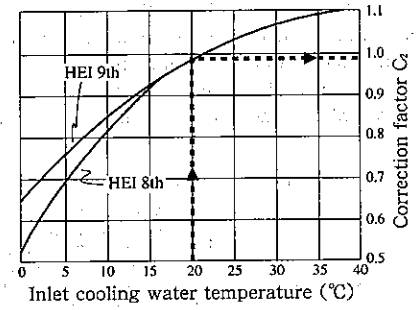
Tube material	ASTM		JIS		Thickess (BWG/mm)							Note
	Numbers	Codes	Numbers	Codes	24 0.56	22 0.71	20 0.89	18 1.24	16 1.65	14 2.11	12 2.77	(HEI)
Admiralty metal	B111-93	C44300 C44400 C44500	H3300(1992)	C4430	1.06	1.04	1.02	1.00	0.96	0.92	0.87	8th edition
					1.03	1.02	1.01	1.00	0.98	0.96	0.93	9th edition
Aluminum brass	B111-93	C68700	H3300(1992)	C6870 C6871 C6872	1.03	1.02	1.00	0.97	0.94	0.90	0.84	8th edition
					1.02	1.02	1.01	0.99	0.97	0.95	0.92	9th edition
90-10 copper nickel	B111-93	C70600	H3300(1992)	C7060	0.99	0.97	0.94	0.90	0.85	0.80	0.74	8th edition
					0.99	0.98	0.96	0.93	0.89	0.85	0.80	9th edition
70-30 copper nickel	B111-93	C71500	H3300(1992)	C7150	0.93	0.90	0.87	0.82	0.77	0.71	0.64	8th edition
					0.97	0.95	0.92	0.88	0.83	0.78	0.71	9th edition
Carbon steel	A179M-90a		G3461(1988)	STB340	1.00	0.98	0.95	0.91	0.86	0.80	0.74	8th edition
					1.00	0.98	0.97	0.93	0.89	0.85	0.80	9th edition
Stainless steel	A249M-94a A249M-94a	TP304 TP316	G3463(1994)	SUS304TB SUS316TB	0.83	0.79	0.75	0.69	0.63	0.56	0.49	8th edition
					0.91	0.87	0.83	0.76	0.70	0.63	0.55	8th edition, appendix
					0.90	0.86	0.82	0.75	0.69	0.62	0.54	9th edition
Titanium	B338-94	Gr1 Gr2	H4631(1994)	TTH270 TTH340	0.85	0.81	0.77	0.71	—	—	—	8th edition
					0.91	0.87	0.83	0.76	0.70	0.63	0.55	8th edition, appendix
					0.94	0.91	0.88	0.82	0.77	0.71	0.63	9th edition

(Note) Applicable editions shall be decided by the concerned parties, as these latest editions are not always applied in practice.

(2) Uncorrected overall heat transfer coefficient



(3) Correction factor C_2 for the cooling water temperature



Uncorrected overall heat transfer coefficient

$K_0 = C\sqrt{v}$ (W/m^2K)

C : Coefficient

v : Velocity in tube (m/s)

Design overall heat transfer coefficient

$K = K_0 \cdot C_1 \cdot C_2 \cdot C_3$ (W/m^2K)

C_1 : Correction factor for tube material and thickness

C_2 : Inlet water temperature correction factor

C_3 : Correction factor for cleanliness (Used 0.9 for titanium and 0.85 for others)

〔Calculation example〕

Cooling tube material : Aluminum brass

Cooling tube dimensions: 25ϕdia. 1.24 thick

Velocity in piping: 1.95m/s

Cooling water inlet temperature: 20℃

Uncorrected overall heat transfer coefficient

$K_0 = 3{,}776W/m^2K$

Correction factors C_1: $=0.97$, $C_2 = 0.985$, $C_3 = 0.85$

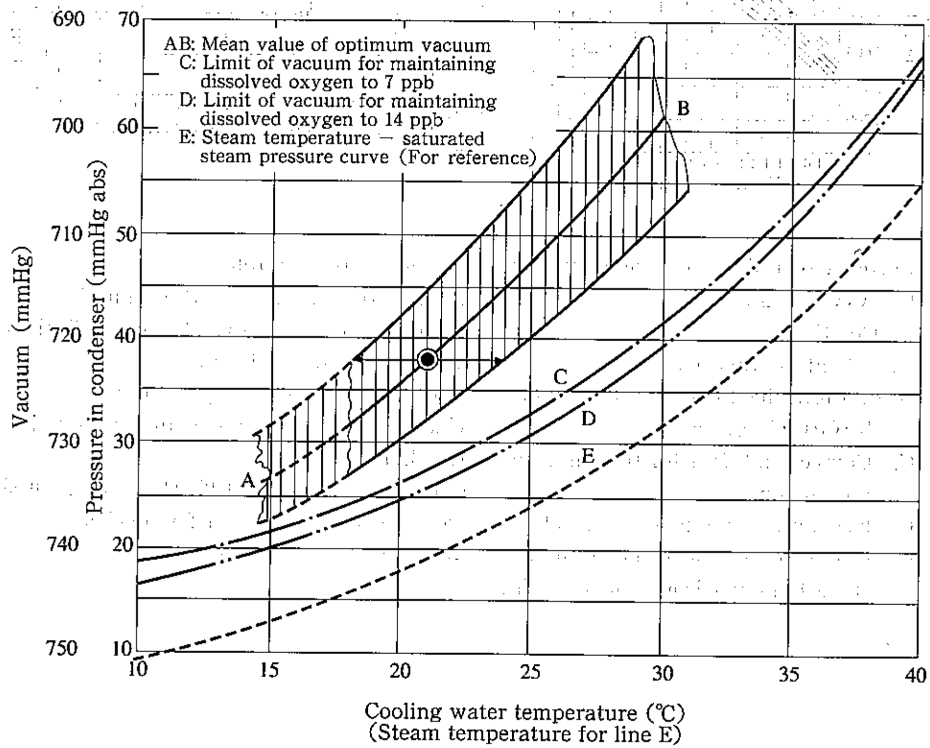
Design overall heat transfer coefficient

$K = K_0 \cdot C_1 \cdot C_2 \cdot C_3 = 3{,}066W/m^2K$

15-3 Cooling Water Temperature and Optimum Vacuum for Condensers

The design temperature of cooling water depends on the accurate annual average temperature of the available water source and the operating time at the water source temperature. In general, it is 21°C in the central part of the Pacific Ocean side, 18°C in Tohoku and Hokkaido, and 24°C in Kyushu. It is considered that the optimum vacuum corresponds to the saturated steam pressure attemperatures 9 to 15°C higher than the water source temperatures. However, the design vacuum of turbines is frequently set to 722mmHg in these regions. Thus, the cooling water quantity and cooling surface is adjusted with the condenser for economical design. Viewed from the condenser side, it is desirable that the most economical vacuum and cooling surface be determined from the basic cooling water temperature, cooling water quantity, and the power of the cooling water circulation pump.

The vacuums adopted in Japan are covered in the shaded portion shown below. The center line A-B may be regarded as the typical design target. 722mmHg (◉) at 21°C is the most typical vacuum in Japan.

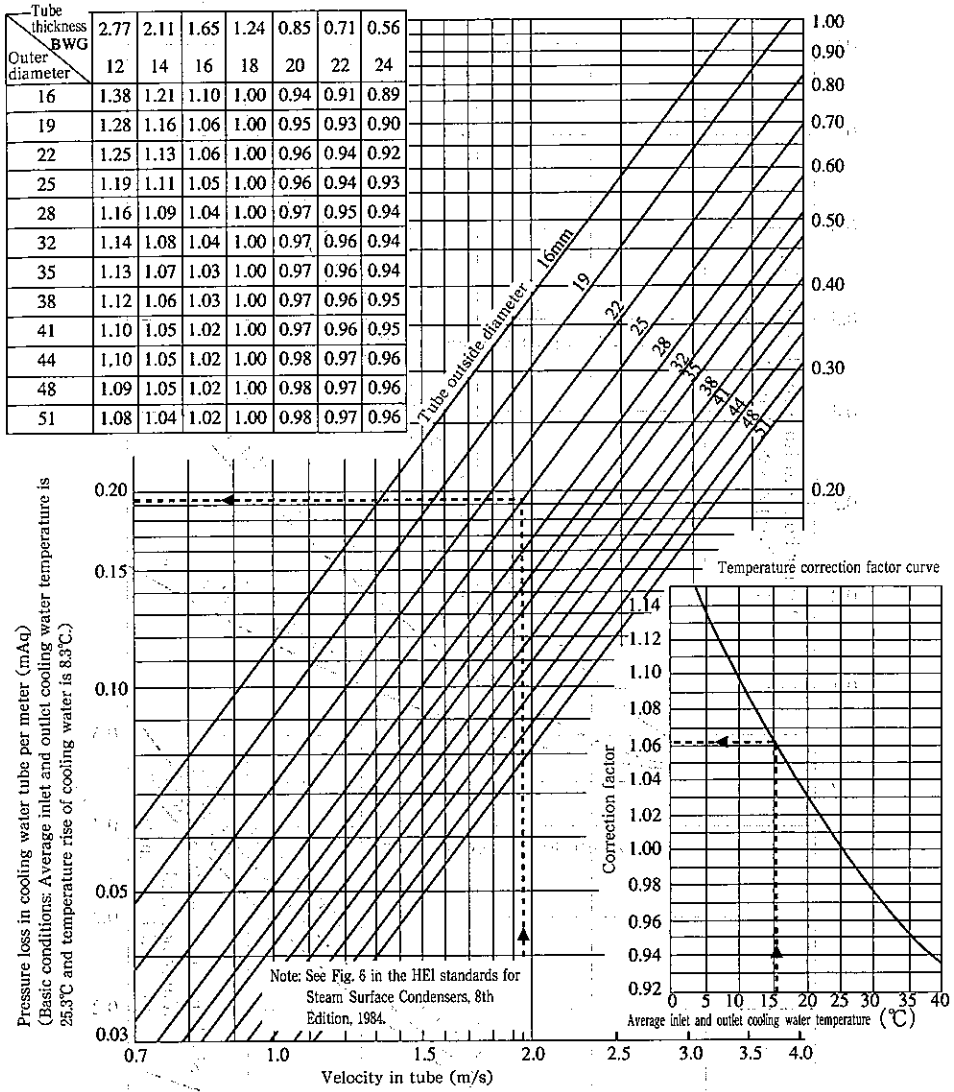


15-4 Pressure (Head) Losses of Condenser Cooling Water

(1) Pressure loss in cooling tubes

Correction factor for tube thickness

Tube thickness / BWG / Outer diameter	2.77 12	2.11 14	1.65 16	1.24 18	0.85 20	0.71 22	0.56 24
16	1.38	1.21	1.10	1.00	0.94	0.91	0.89
19	1.28	1.16	1.06	1.00	0.95	0.93	0.90
22	1.25	1.13	1.06	1.00	0.96	0.94	0.92
25	1.19	1.11	1.05	1.00	0.96	0.94	0.93
28	1.16	1.09	1.04	1.00	0.97	0.95	0.94
32	1.14	1.08	1.04	1.00	0.97	0.96	0.94
35	1.13	1.07	1.03	1.00	0.97	0.96	0.94
38	1.12	1.06	1.03	1.00	0.97	0.96	0.95
41	1.10	1.05	1.02	1.00	0.97	0.96	0.95
44	1.10	1.05	1.02	1.00	0.98	0.97	0.96
48	1.09	1.05	1.02	1.00	0.98	0.97	0.96
51	1.08	1.04	1.02	1.00	0.98	0.97	0.96

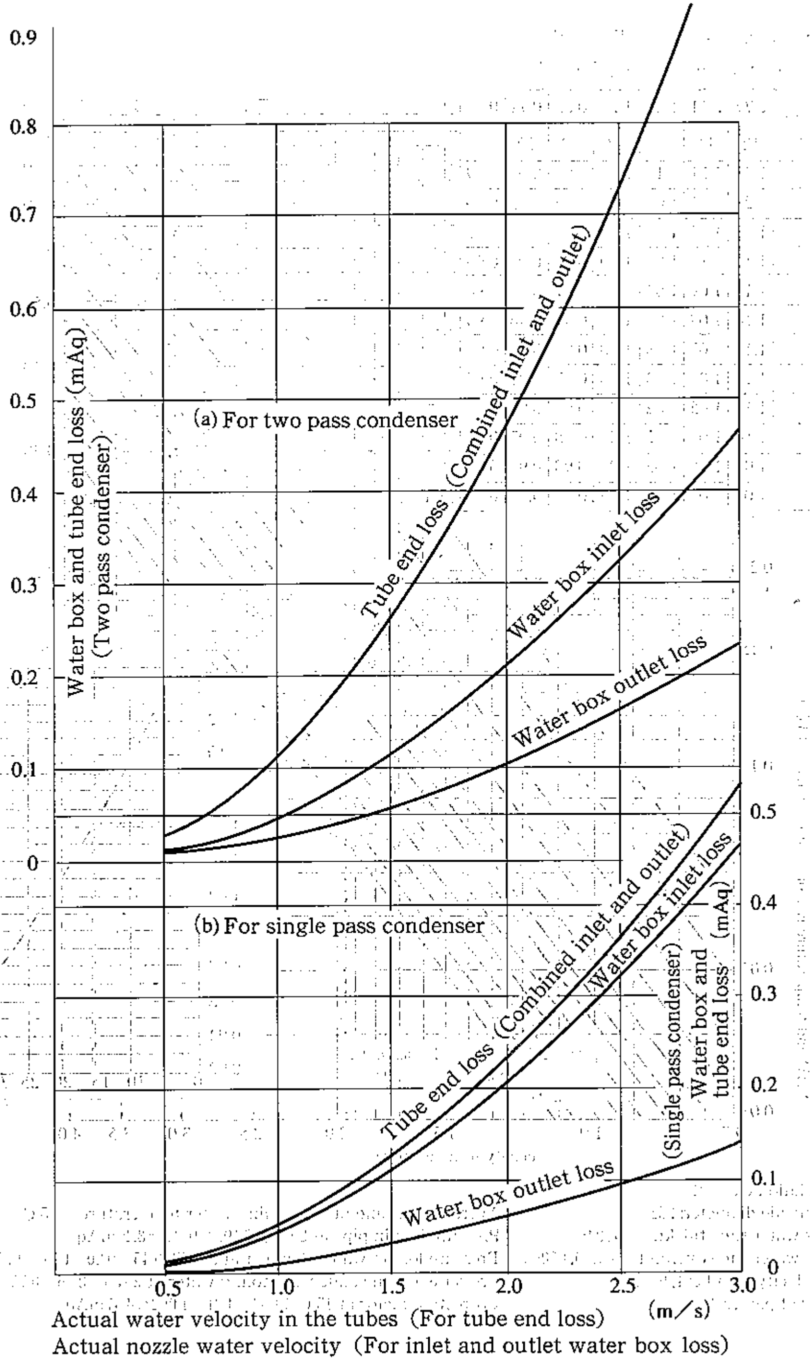


〔Calculation example〕

Tube outside diameter: 25㎜
Cooling water tube thickness: 1. 24㎜
Cooling water tube overall length: 9, 000㎜
Flow velocity in tube: 1. 95m/s
Number of passes: 2

Average inlet and outlet cooling water temperature 15℃
Pressure loss in pipe at 25.3℃: 0.192×9×2=3.46mAq
Pressure loss in water chamber at 25.3℃: 0.45+0.20+095→0.75mAq
Pressure loss in condenser cooling water at 25.3℃: 3.46+0.75=4.21mAq
Correction factor at 15℃: 1.062 4.21×1.062≒4.47mAq

(2) Water box and tube end losses



15-5 Thermal Load and Circulating Water Quantity of Condensers

(1) Thermal load of condenser

The approximate thermal load of the condenser is found as shown below.

(Thermal load of condensers)(kJ/h) ≒ (Electric output(kW)) × (Heat rate of turbines (kJ/kWh) −3600)

≒ (Input heat from steam generator(kJ/h))−3600× (Electric output(kW))

(2) Circulating water quantity of condenser

(Circulating water quantity of condenser) = (Thermal load of condenser)/ {(Circulating water temperature rise) × (Specific heat) × (Density)}

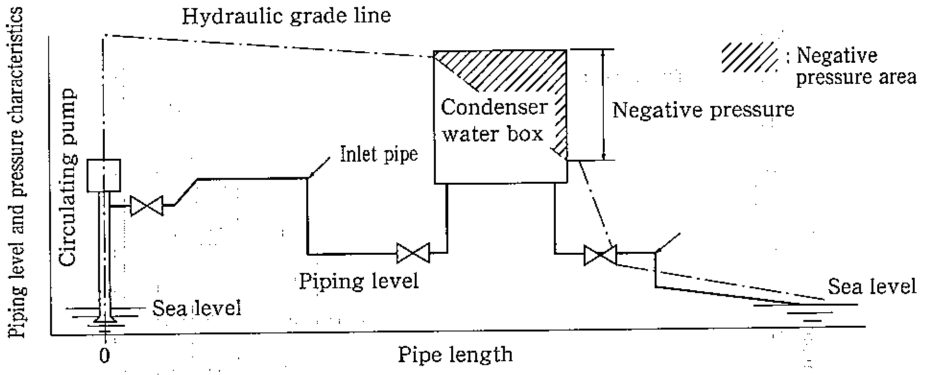
For the data of the specific heat and density, refer to ASME PTC 12-2.

15-6 Siphon Effects of Condenser Cooling Water Systems

The cooling water system of the condenser forms a siphon. It is important how much degree of siphon effects are considered for design of a cooling water system.

Since the water box of the condenser is located upper the sea level in general, it is operated at a negative pressure. If the negative pressure becomes greater, water separations are generated in the cooling water and the pressure loss increases quickly, disabling siphon effect operation. Thus, the negative pressure must be maintained below the specified value (i.e., siphon limit value).

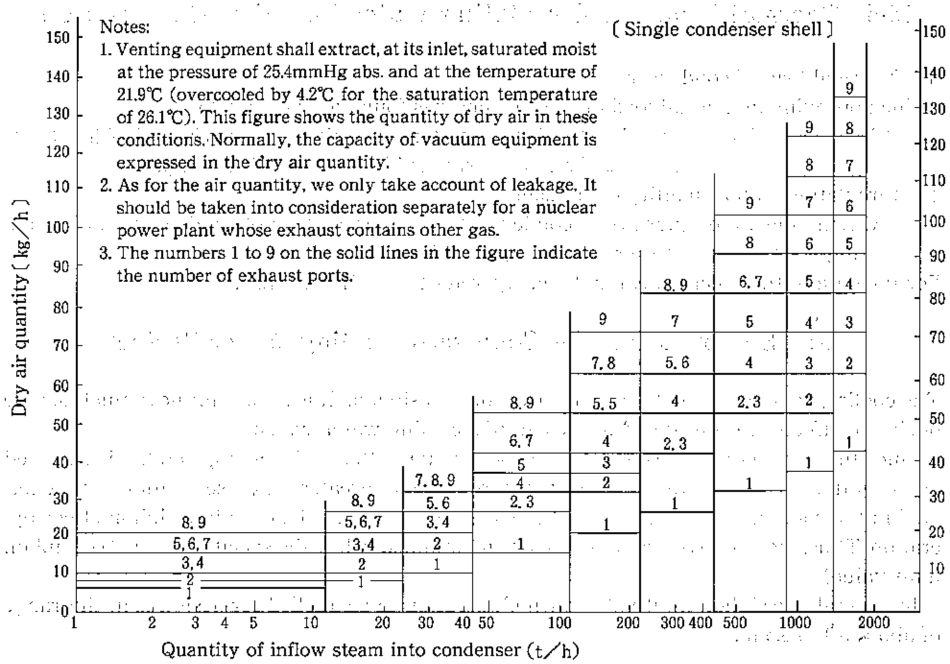
In general, the siphon limit value during operation to be applied for design is in the range of about 8.0 to 8.5 m.



15-7 Standard Capacity of Vacuum Equipment

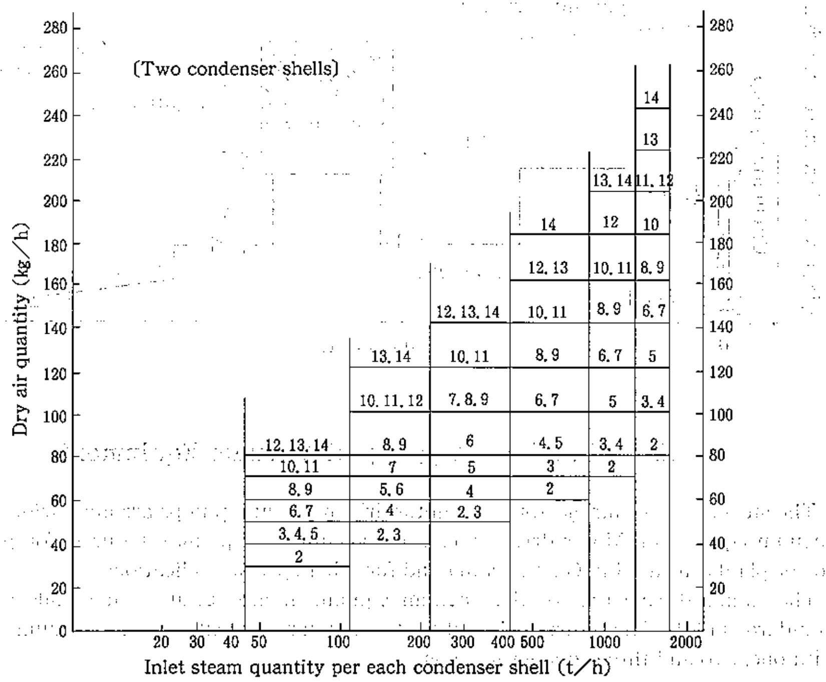
The steam jet type air ejectors and motor driven vacuum pumps are most widely used for vacuum equipment. Motor driven reciprocal vacuum pumps may be used for geothermal power plants (as used in Odake Plant) and for other special applications.

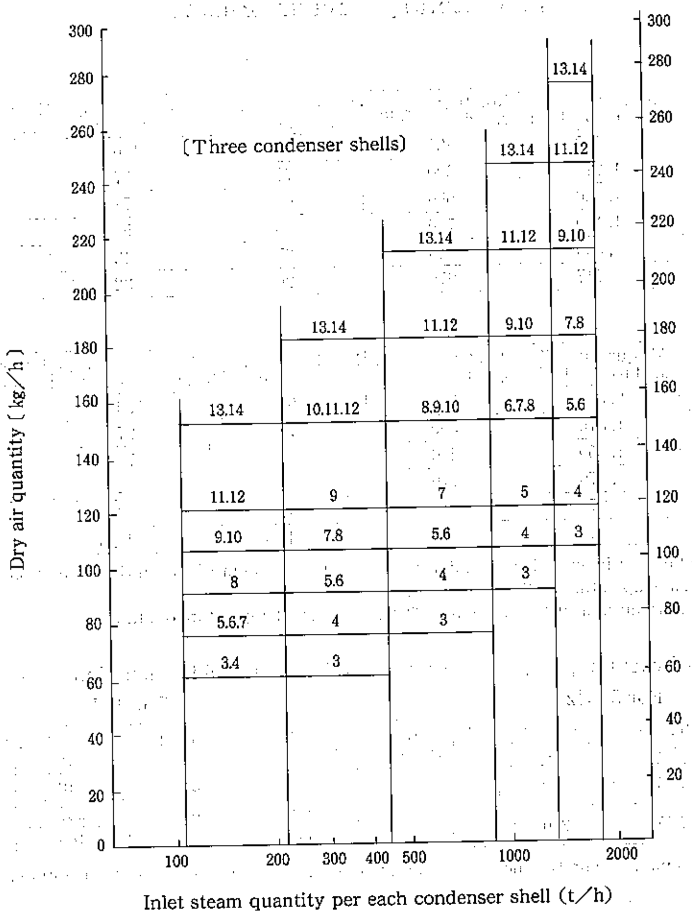
The standard capacities of the vacuum equipment are specified in details in the HEI Standards (1984). The figures below show the standard capacities of the vacuum equipment with one, two and three condenser shells.



Notes:

1. Venting equipment shall extract, at its inlet, saturated moist at the pressure of 25.4mmHg abs. and at the temperature of 21.9℃ (overcooled by 4.2℃ for the saturation temperature of 26.1℃). This figure shows the quantity of dry air in these conditions. Normally, the capacity of vacuum equipment is expressed in the dry air quantity.
2. As for the air quantity, we only take account of leakage. It should be taken into consideration separately for a nuclear power plant whose exhaust contains other gas.
3. The numbers 1 to 9 on the solid lines in the figure indicate the number of exhaust ports.





Normally, the allowable oxygen content in the condensate is 42ppb (0.03cc/ℓ). Practically, however, it may be reduced to 14ppb (0.01cc/ℓ) or 7ppb (0.005cc/ℓ) in the conditions shown below if the condenser is provided with a proper de-aerating mechanism and is operated properly.

(1) The condenser vacuum should be higher than the curve C or D shown in "15-3 Cooling Water Temperature and Optimum Vacuum for Condensers".

(2) The ratio g_2/g_1 of the design quantity of dry air g_1 to the actual quantity of dry air g_2 is restricted according to the allowable oxygen content in the condensate as shown in the table. For example, the vacuum equipment designed with the actual air quantity of 40.8kg/h must be 25% (10.2kg/h) of leak air quantity in order to limit the oxygen content in the condensate below 7ppb.

Design quantity of dry air g_1 (kg/h)	Allowable oxygen content (ppb)	Actual quantity of dry air g_2 (kg/h)	
		g_2/g_1 (%)	g_2 (kg/h)
40.8 or less	42	50	—
	14	35	—
	7	25	—
40.9~81.6	42	50	—
	14	25	—
	7	15	—
81.7 or more	42	—	40.8
	14	—	20.4
	7	—	12.3

15-8 Rotary Vacuum Pumps

(1) For 50Hz

Extraction air 1) quantity (kg/h)	Air quantity 2) at startup (kg/h)	Rotating speed (rpm)	Normal brake horsepower (kW)	Maximum brake horsepower (kW)	Rated output of standard motor (kW)
49.0	2, 570	495	88	116	132
30.6	1, 870	590	72	87	90
25.5	1, 650	590	60	71	75
20.4	1, 120	740	43	54	55
16.3	1, 000	740	37	43	45
10.2	517	970	26	32	37

(2) For 60Hz

Extraction air 1) quantity (kg/h)	Air quantity 2) at startup (kg/h)	Rotating speed (rpm)	Normal brake horsepower (kW)	Maximum brake horsepower (kW)	Rated output of standard motor (kW)
49.0	2, 650	510	91	120	132
30.6	1, 870	590	72	87	90
25.5	1, 650	590	60	71	75
20.4	1, 070	710	42	52	55
16.3	970	710	36	42	45
10.2	428	880	18.4	21. 3	22

Note: 1. Quantity of dry air in air and steam mixture at a suction vacuum of 735mmHg (saturation temperature: 25.8℃) and a temperature of 21.6℃ (4.2℃ overcooled)
2. Quantity of dry air at a suction vacuum of 380mmHg and a temperature of 21.1℃

(3) Examples of vacuum pumps for Nuclear (BWR) (For rapid evacuation)

For 50 Hz

Extraction air flow 3) (m^3/min)	Rotating speed (rpm)	Maximum brake horsepower (kW)	Rated output of standard motor (kW)
235	365	320	380
175	365	240	260

For 60 Hz

Extraction air flow 3) (m^3/min)	Rotating speed (rpm)	Maximum brake horsepower (kW)	Rated output of standard motor (kW)
225	355	310	380
170	355	230	260
113	395	160	170

Note: 3. Suction vacuum is 380mmHg, suction air temperature is 20℃, and sealing water temperature is 15℃.

15-9 Comparison of Steam Jet Air Ejector and Rotary Vacuum Pump

Steam jet ejector	Rotary pump
(1) Construction cost is low, since two sets of nozzles and diffusers (including a spare set of nozzle and diffuser) require a single cooler (without a spare cooler).	(1) Equipment costs is large since two rotary pumps must be installed. One pump is a spare if the air leakage is small.
(2) No rotary parts. Almost trouble free and easy maintenance.	(2) Disadvantageous in operation and maintenance due to wear of the rotary parts in comparison with the steam jet type.
(3) Requires a separate starting ejector and complicated piping and valve system. Disadvantageous for central control system in comparison with the rotary pump.	(3) Easy operation from the central control room from start-up to 100% load operation. Suitable for the central control system.
(4) The ejector cannot be started up unless the drive steam source is started up.	(4) May be started up at any time whether or not the drive source is started up. Suitable to a once-through boiler.
(5) Less running cost than two rotary pumps. If one rotary vacuum pump is sufficient, the running cost of the steam jet type air ejector will be more than the rotary vacuum pump, and there are less effective result of air leakage extent.	(5) Requires less running costs than the steam jet type ejector if a single rotary pump is sufficient due to small air leakage. However, there will be a great difference in the allow generator power, etc. since the standard type is adopted. It is hard to compare the economic efficiency easily.

15-10 Capacities of Starting Ejectors

A condenser system using a steam jet type air ejector requires a starting ejector, which reduces the condenser pressure from the atmospheric pressure down near to 500 mmHg vacuum for approx. 30 minutes before starting a turbine.

Total condensate flow/ (See note below.) (t/h)	Extraction dry air (at design suction vacuum of 506 mmHg)		Total condensate flow/ (See note below.) (t/h)	Extraction dry air (at design suction vacuum of 506 mmHg)	
	(m^3/h)	(kg/h)		(m^3/h)	(kg/h)
0 ~ 45.4	85	102	1,814.5~2,268.0	2,975	3,570
45.5~ 113.4	170	204	2,268.1~2,721.5	3,565	4,278
113.5~ 226.8	340	408	2,721.6~3,175.1	4,160	4,992
226.9~ 453.6	595	714	3,175.2~3,628.7	4,755	5,706
453.7~ 907.2	1,190	1,428	3,628.8~4,082.3	5,350	6,420
907.3~1, 360.8	1,785	2,142	4,082.4~4,535.9	5,945	7,134
1, 360.9~1, 814.4	2,380	2,856			

Note: For the condensate flow over 226.9t/h, the above table shows the capacities for extracting air from the condenser and low pressure turbine is 1.623m^3 per condensate flow of 1t/h.

15-11 Causes of Low Vacuum in Condensers and Check Points

1. Preliminary check points before investigating causes of low vacuum
   - (1) Instrumental errors (including atmospheric pressure correction)
   - (2) Increase of the turbine exhaust quantity
   - (3) Changes in the cooling water temperature and measuring accuracy
   - (4) Comparison with the cooling performance curves
   - (5) Comparing the heat transfer coefficient or cleanliness factor immediately after installation or cleaning the cooling tubes
   - (6) Changing with time in the terminal temperature difference
2. Relationship between cleanliness factor and condenser vacuum (See the following figures.)

Application example: How to find the cleanliness factor of a condenser whose design circulating inlet temperature is 21℃ and design cleanliness is 85%, provided the circulating inlet temperature is 25℃ and vacuum difference$^{(Note)}$ is −4mmHg,

The correction factor for the circulating inlet temperature of 25℃ is 1.14, which is found from the correction factor curve c (design circulating inlet temperature is 21℃ and design cleanliness factor is 85%) according to the inlet temperature of the circulating water.

The vacuum difference at 21℃ is found from this correction factor as follows: $(-4) \div 1.14 = -3.5$. Since the vacuum difference at 21℃ is − 3.5mmHg vac., the cleanliness factor is approx. 72%, which is found from the curve c representing the relationship between the cleanliness factor and condenser vacuum difference.

Note: Vacuum difference V: Measured vacuum value at certain circulating inlet temperature minus design value at the circulating inlet temperature

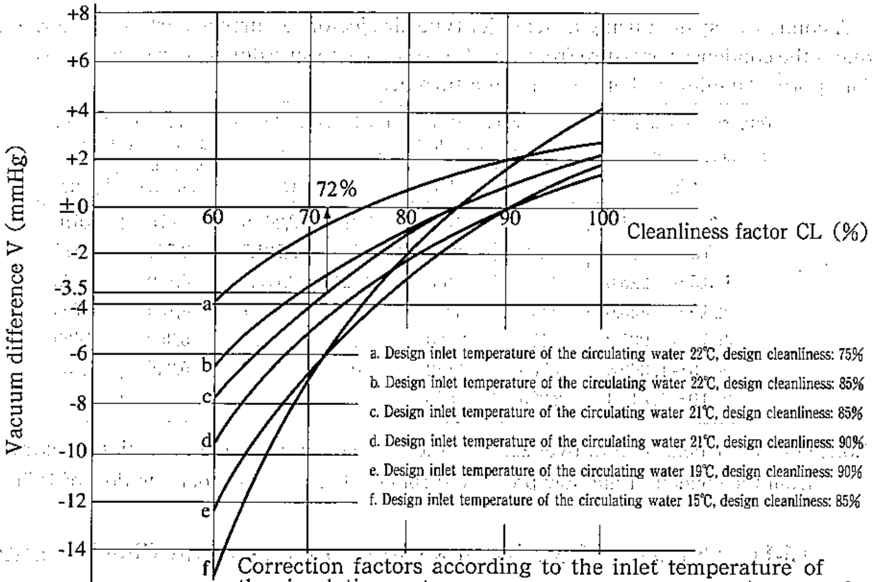
Example: Provided the seawater inlet temperature is 25℃, design vacuum is 713mmHg and actual vaccum is 709mmHg, the vacuum difference $V=709-713=-4$mmHg.

Applied conditions:

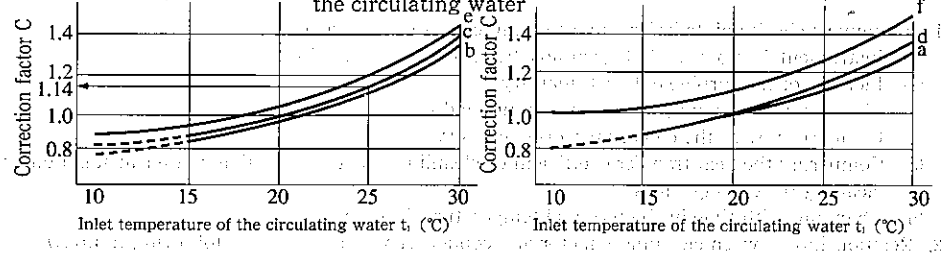
(1) The condenser should run in the rated conditions (including the load, cooling water quantity and so forth).

(2) The dotted lines in the figures below show the values used for air ejector. Values for vacuum pumps should be determined for each plant.

Relationship between cleanliness and condenser vacuum difference



Correction factors according to the inlet temperature of the circulating water

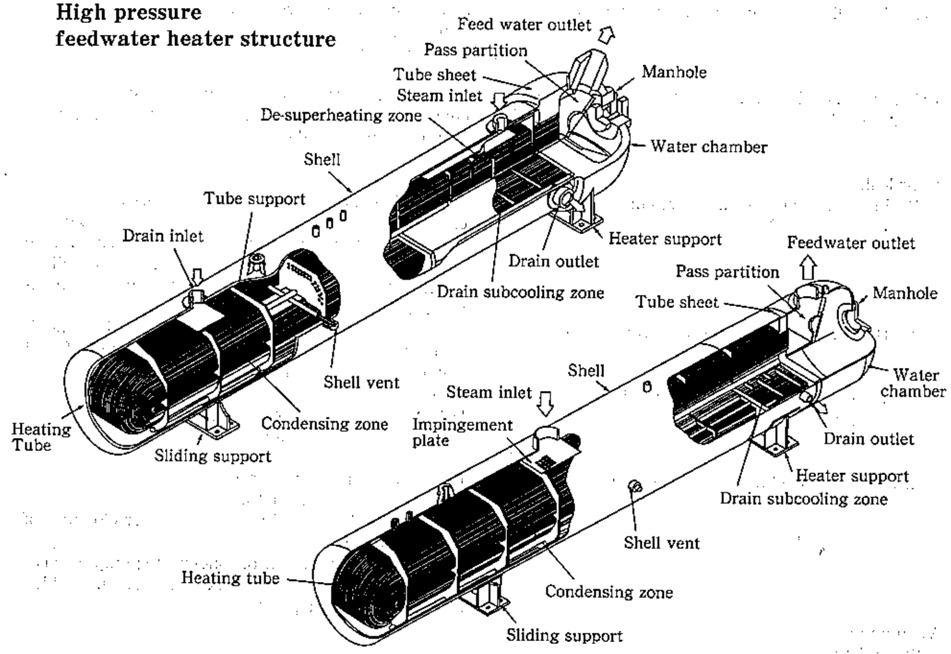


3. Causes of vacuum drop and check points

Causes or phenomena	Check points
CONDENSER 1. Dirtiness of cooling water tube	(a) Inspection of the inner surface of the cooling water tubes — (1), (2) & (3)
(1) Gradual drop of vacuum (2) Increase of pressure loss	(b) Analyze contents of adherent matters.—(1), (2) & (3)
(3) Increase of terminal temperature difference	(c) Changing of pressure loss and terminal temperature difference with time (from the daily report, etc.) — (2) & (3) (d) Backward calculation of heat transfer coefficient or cleanliness factor — (1)
2. Decrease of cooling water	
(1) Large cooling water temperature difference at the inlet and the outlet	(a) Check the water flow quantity from performance curve. (1)(2)(3)
(2) Large cooling water temperature difference at the inlet and the outlet	(b) Clogging of cooling water tube inlet. — (2)
(3) Small cooling water temperature difference at the inlet and the outlet	(c) Deterioration of water circulating pump performance, lowering of electric frequency, etc. — (3)

Causes or phenomena	Check points
(4) Air collected in upper part of water box	(d) Clogging of cooling water channel, screens, strainers, or other attachments—(2) (e) Re-examine air discharge valves and water level gauge at top—(4) (f) Examine siphon effects.—(4)
3. Changes in cooling water inlet temperature and water quality	(a) Compare temperature and quality of waste water discharged from neighboring factories with normal data. (b) Relationship with tide
4. Air leak (1) Increase of air flow meter reading	(a) Finding looseness or damages of joint between turbine exhaust port and condenser (including expansion joint), extraction pipe joint, etc. in the vacuum zone (using Freon gas sensor or the like). Leakage will be found in the horizontal coupling of the turbine chamber in some occasions.
(2) Delay in vacuum-up in the turbine start-up	(b) Looseness of couplings, valve seats and packing holders of steam trap pipes, valves and level gauge of feed water heaters in vacuum zone.
(3) Increase of vaccum down speed when stopping turbine	(c) Leak of gland steam (d) Defects of atmosphere discharge unit. (e) Conduct leak test by filling water.
5. Rise of water level in condensate reservoir	(a) Deterioration pump performance (b) Check water level regulator. (c) Abnormal indications due to leak from or clogging of waterlevel gauge (d) Accidents on suction side of condensate pump (such as corrosion of impellers, air leak from packing holder, clogging of balance pipe)
Vacuum pump 1. Steam jet type (1) Insufficiency of steam pressure and steam flow	(a) Check valve opening and pressure gauge.—(1)
(2) Increase of leak air quantity	(b) Clogging of nozzle or strainer—(1) & (3)
(3) Insufficiency of cooling water (condensate) flow	(c) Check changes during operation with air flow meter, and locate leak position with freon gas sensor.—(2)
(4) Out of sealing water in 1st stage drain pipe	(d) Check cooling water (condensate) pressure and temp erature.—(3)
(5) Incomplete discharge of 2nd stage drain	(e) Check condensate recirculating regulator of condensate pump.—(3)
(6) Increase of discharge air pressure	(f) Check level gauge, temperature and clogging of 1st stage drain U pipe.—(4)
(7) Clogging or damage of nozzle or diffuser	(g) Check clogging of 2nd stage drain pipe and functioning of trap.—(5)
(8) Reverse air flow	(h) Check valve and piping of air discharge side.—(6)
(9) Dirtness of cooling water pipe	(i) Check overhaul of nozzle and diffuser.—(7)
(10) Fluctuation of operation steam pressure	(j) Through hole in partition wall of cooler due to corrosion, damages of packing, etc.—(8) (k) Failure in closing diffuser gate valve, leak from it, etc.—(8) (l) Check inside of cooling water tube and corrosive holes of tube at drain water level.—(9) (m) Drain mixing in steam (Slight fluctuation) Check pressure gauge—(10)
2. Rotary pump (1) Insufficiency of pump operating water quantity	(a) Check water pressure and clogging of piping.—(1)
(2) Rise of pump operating water temperature	(b) Check cooling water route.—(2)
(3) Insufficiency of ejector driving air quantity	(c) Check clogging of piping and nozzle.—(3)
(4) Malfunctioning of air ejector	(d) Check defects of pressure switches.—(4)

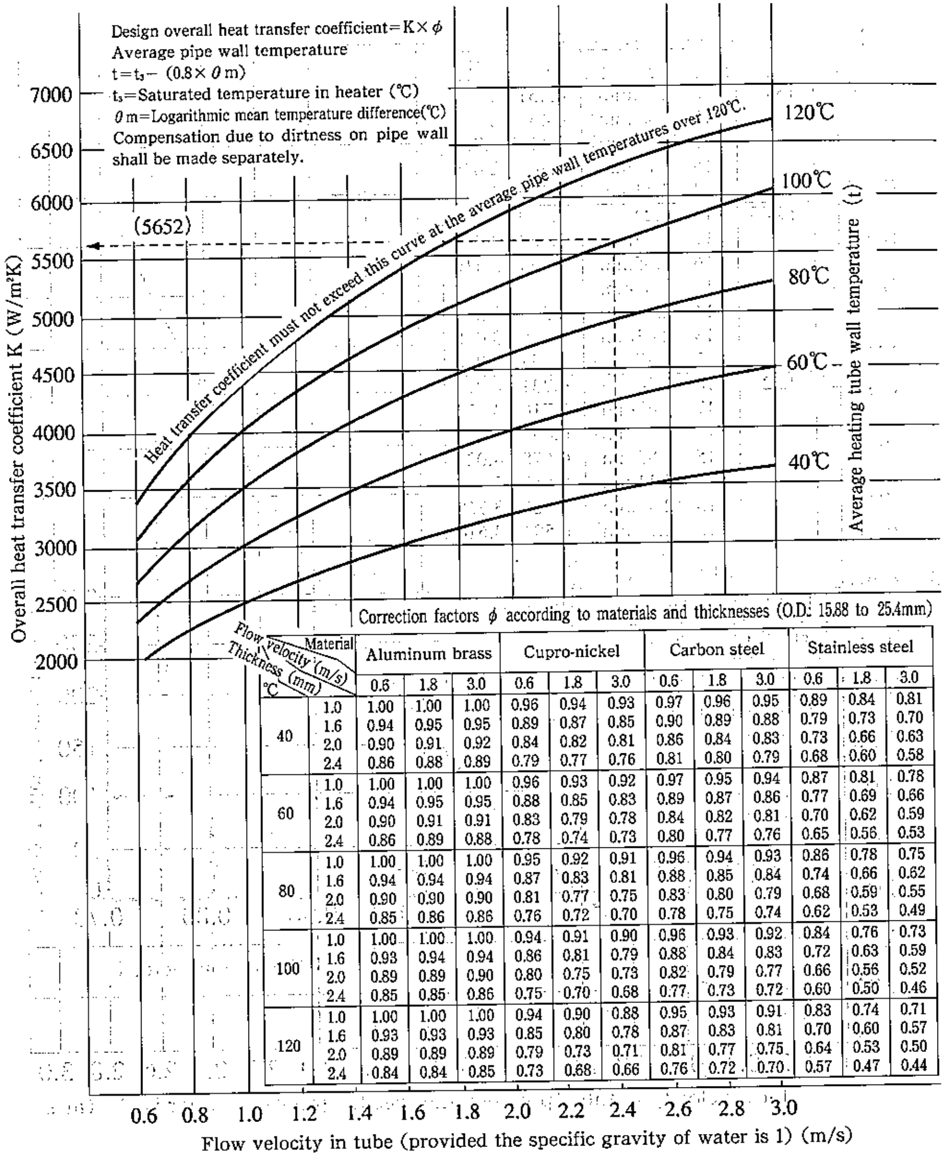
15-12 Feedwater Heater Structure



High pressure feedwater heater structure

Low pressure feedwater heater structure

15-13 Overall Heat Transfer Coefficient of Feed Water Heaters



Design overall heat transfer coefficient=K× ϕ

Average pipe wall temperature

$t=t_s-(0.8\times\theta m)$

t_s=Saturated temperature in heater (℃)

θm=Logarithmic mean temperature difference(℃)

Compensation due to dirtness on pipe wall shall be made separately.

Correction factors ϕ according to materials and thicknesses (O.D. 15.88 to 25.4mm)

℃	Thickness (mm) \ Flow velocity (m/s) \ Material	Aluminum brass			Cupro-nickel			Carbon steel			Stainless steel		
		0.6	1.8	3.0	0.6	1.8	3.0	0.6	1.8	3.0	0.6	1.8	3.0
40	1.0	1.00	1.00	1.00	0.96	0.94	0.93	0.97	0.96	0.95	0.89	0.84	0.81
	1.6	0.94	0.95	0.95	0.89	0.87	0.85	0.90	0.89	0.88	0.79	0.73	0.70
	2.0	0.90	0.91	0.92	0.84	0.82	0.81	0.86	0.84	0.83	0.73	0.66	0.63
	2.4	0.86	0.88	0.89	0.79	0.77	0.76	0.81	0.80	0.79	0.68	0.60	0.58
60	1.0	1.00	1.00	1.00	0.96	0.93	0.92	0.97	0.95	0.94	0.87	0.81	0.78
	1.6	0.94	0.95	0.95	0.88	0.85	0.83	0.89	0.87	0.86	0.77	0.69	0.66
	2.0	0.90	0.91	0.91	0.83	0.79	0.78	0.84	0.82	0.81	0.70	0.62	0.59
	2.4	0.86	0.89	0.88	0.78	0.74	0.73	0.80	0.77	0.76	0.65	0.56	0.53
80	1.0	1.00	1.00	1.00	0.95	0.92	0.91	0.96	0.94	0.93	0.86	0.78	0.75
	1.6	0.94	0.94	0.94	0.87	0.83	0.81	0.88	0.85	0.84	0.74	0.66	0.62
	2.0	0.90	0.90	0.90	0.81	0.77	0.75	0.83	0.80	0.79	0.68	0.59	0.55
	2.4	0.85	0.86	0.86	0.76	0.72	0.70	0.78	0.75	0.74	0.62	0.53	0.49
100	1.0	1.00	1.00	1.00	0.94	0.91	0.90	0.96	0.93	0.92	0.84	0.76	0.73
	1.6	0.93	0.94	0.94	0.86	0.81	0.79	0.88	0.84	0.83	0.72	0.63	0.59
	2.0	0.89	0.89	0.90	0.80	0.75	0.73	0.82	0.79	0.77	0.66	0.56	0.52
	2.4	0.85	0.85	0.86	0.75	0.70	0.68	0.77	0.73	0.72	0.60	0.50	0.46
120	1.0	1.00	1.00	1.00	0.94	0.90	0.88	0.95	0.93	0.91	0.83	0.74	0.71
	1.6	0.93	0.93	0.93	0.85	0.80	0.78	0.87	0.83	0.81	0.70	0.60	0.57
	2.0	0.89	0.89	0.89	0.79	0.73	0.71	0.81	0.77	0.75	0.64	0.53	0.50
	2.4	0.84	0.84	0.85	0.73	0.68	0.66	0.76	0.72	0.70	0.57	0.47	0.44

[Calculation example]

Heating tube material: Stainless steel

Heating tube thickness: 1.0mm

Flow velocity in heating tube 2.4m/s

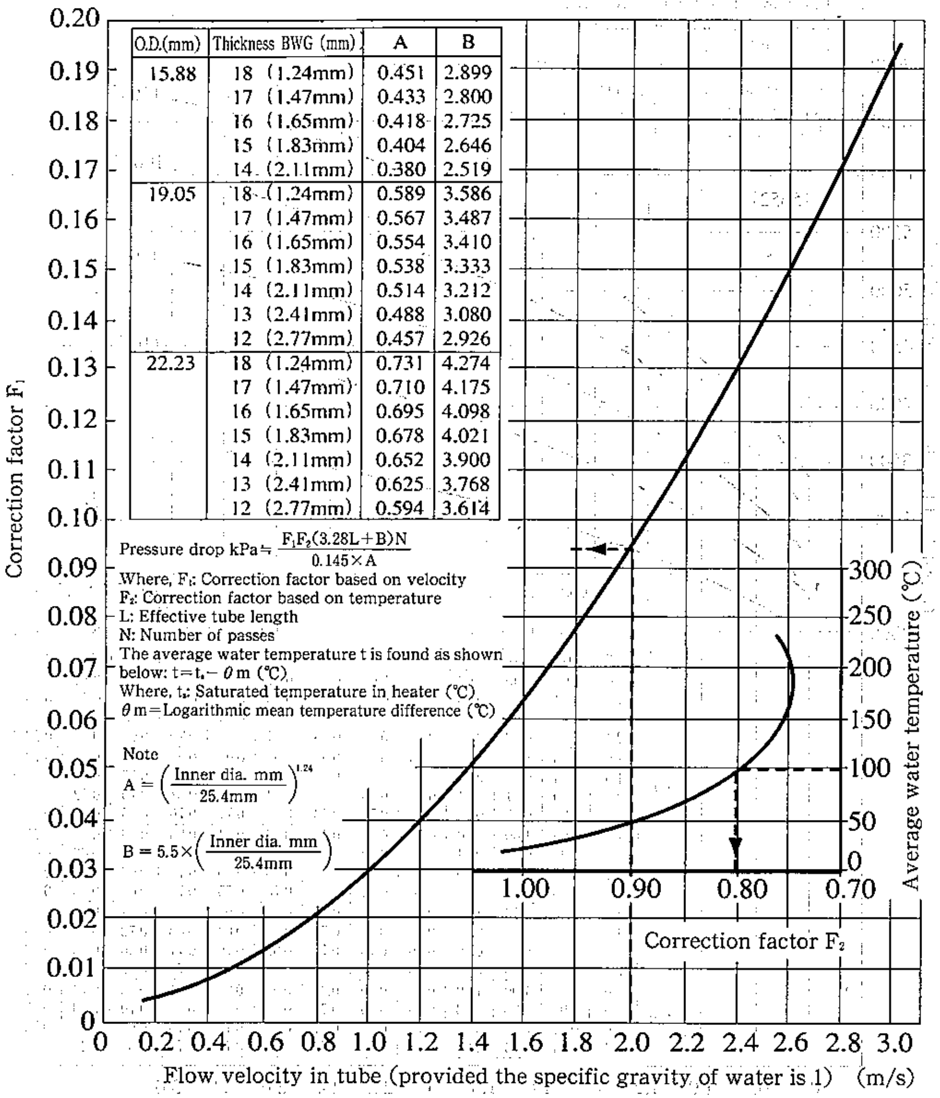
Average tube wall temperature: 100℃

Design overall heat transfer coefficient=K× ϕ =4860×0.745=3620

Where, ϕ is found by interpolation as shown below:

$$0.76+(0.73-0.76)\frac{2.4-1.8}{3.0-1.8}=0.745$$

15-14 Pressure Drop in Tube of Feed Water Heaters



O.D.(mm)	Thickness BWG (mm)	A	B
15.88	18 (1.24mm)	0.451	2.899
	17 (1.47mm)	0.433	2.800
	16 (1.65mm)	0.418	2.725
	15 (1.83mm)	0.404	2.646
	14 (2.11mm)	0.380	2.519
19.05	18 (1.24mm)	0.589	3.586
	17 (1.47mm)	0.567	3.487
	16 (1.65mm)	0.554	3.410
	15 (1.83mm)	0.538	3.333
	14 (2.11mm)	0.514	3.212
	13 (2.41mm)	0.488	3.080
	12 (2.77mm)	0.457	2.926
22.23	18 (1.24mm)	0.731	4.274
	17 (1.47mm)	0.710	4.175
	16 (1.65mm)	0.695	4.098
	15 (1.83mm)	0.678	4.021
	14 (2.11mm)	0.652	3.900
	13 (2.41mm)	0.625	3.768
	12 (2.77mm)	0.594	3.614

Pressure drop kPa $\fallingdotseq \dfrac{F_1F_2(3.28L+B)N}{0.145\times A}$

Where, F_1: Correction factor based on velocity
F_2: Correction factor based on temperature
L: Effective tube length
N: Number of passes
The average water temperature t is found as shown below: $t=t_s-\theta m$ (℃)
Where, t_s: Saturated temperature in heater (℃)
θm=Logarithmic mean temperature difference (℃)

Note

$$A=\left(\frac{\text{Inner dia. mm}}{25.4\text{mm}}\right)^{1.24}$$

$$B=5.5\times\left(\frac{\text{Inner dia. mm}}{25.4\text{mm}}\right)$$

[Calculation example]

Heating tube outer diameter and thickness: 15.88×1.65
Flow velocity in heating tube: 2.0m/s
Average water temperature: 100℃
Effective length L of heating tube: 6.5m
Number of passes N: 2

F_1=0.095, F_2=0.805, B=2.725
A =0.418

$$\text{Pressure drop}=\frac{0.095\times0.805\times(3.28\times6.5+2.725)\times2}{0.145\times0.418}$$

=61kPa

(The found pressure drop includes the pressure drop at the tube inlet and outlet.)

15-15 Tube Materials and Allowable Temperature of Feed Water Heaters

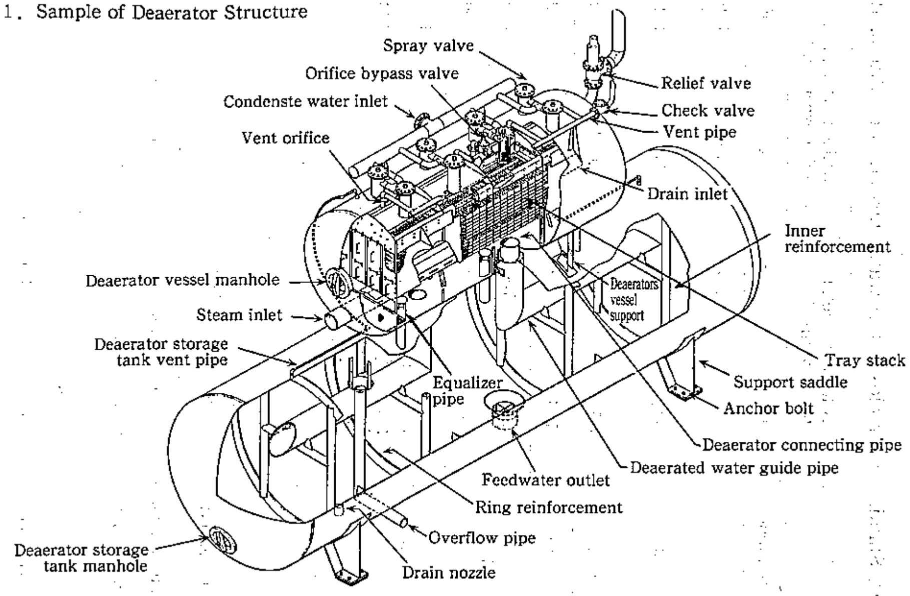
(HEL Standards for closed feedwater heaters 6th edition, 1998.)

Code	Tube meterial		ASTM		JIS		Allowable metal temperature 1)		Allowable coupling temperature for roller expansion 2)	
			Number	Symbol	Number	Symbol	℃	°F	℃	°F
1	Copper with arsenic		B111-93	C14200	—	—	204.4	400	176.7	350
2	Admiralty metal		B111-93	C44300 C44400 C44500	H3300 (1992)	C4430	232.2	450	176.7	350
3	90-10 cupro-nickel		B111-93	C70600	H3300 (1992)	C7060	315.6	600	204.4	400
4	80-20 cupro-nickel		B111-93	C71000	H3300 (1992)	C7100	371.1	700	232.2	450
5	70-30 cupro-nickel	Annealed	B111-93	C71500	H3300 (1992)	C7150	371.1	700	260	500
6		Stress relieved					426.7	800	260	500
7	70-30 monel metal	Annealed	B163-93	—	H4552 (1991)	NCuT	482.2	900	287.8	550
8		Stress-relieved					426.7	800	287.8	550
9	Carbon steel		A179-90 4) A210-91 A556-90 A557-90	—	G3461 (1988) —	STB410 KA-STB480	426.7	800	343.3	650
10	Stainless steel		A213-94 5) A249-94 A688-91	TP304 3)	G3463 (1994)	3) SUS304TB	426.7	800	260	500

Note:
1) The maximum design temperature (metal temperature) of a tube shall be the saturated temperature corresponding to the maximum design pressure of the shell. If there is a de-superheater zone, the temperature shall be 19.4℃ higher.
2) These values indicate the maximum temperatures for tube fit to steel tube plates by means of roller expansion only. The feed water outlet temperature shall apply to the coupling temperature.
3) The table above only shows the typical values widely used. Select a proper value with consideration of the design conditions and applicable standards.
4) A179 indicates cold drawn low carbon steel. A556 indicates seamless cold drawn steel for the feed water heater. A557 indicates an electric welded tube for the same application as A556.
5) A213 indicates a tube for the boiler superheater or heat exchangers. It includes seamless ferrite and austenite stainless steel. A249 is the austenite automatic-welding pipe of the same intended use. A688 is an austenite system welded pipe for feed water heaters.

15-16 Performances and Approximate Dimensions of Deaerators

1. Sample of Deaerator Structure



2. Performance

(1) Dissolved oxygen in inlet feedwater

a. In the case of condensing turbines The expected oxygen content at the condenser outlet should be taken account of air penetration from the low pressure feed water heater and the drain pump in vacuum conditions, and the flanges and valves of pipes for the attached air and drain systems. Pay special attention to refill from an open tank.

b. In the case of back pressure turbines Find the oxygen contents from the solubility of oxygen the feed water temperature.

(2) Dissolved oxygen at the outlet of deaerators Based on the feed water standards of JIS B 8223 (1999).

Boiler type	Boiler maximum operating pressure 〔MPa[gauge]〕	Dissolved oxygen 〔 μgO/ℓ 〕	
Water tube boiler	Equal or less than 1	keep low	
	Over 1 and 2 or less	500 or less	
	Over 2 and 3 or less	100 or less	
	Over 3 and 5 or less	30 or less	
	Over 5	7 or less	
	Over 5 and oxygenated	From 20 to 30	
Once-through boiler	7.5 or over	Treatment method	Dissolved oxygen
		Volatile treatment	7 or less
		Oxygenation	20～200

Note: As for oxygenation, it shall be the value suitable for making the concentration of iron and copper, etc. of the feed water minimum in this range.

3. Standard Capacity and Approximate Dimensions of Deaerators

Power (MW)	Deaerator tank storage capacity (m³)	Tank dimension (mm)		Weight (Main frame + tank) (t)		
		Inside diameter	Length	Assembly		Full water
				Main frame	Tank	Main frame + tank
50 ≀ 75	50～60	3,300	About 8,000	7	16	110
100 ≀ 125	70～80	3,300	About 10,500	11	21	160
156 ≀ 600	80～100	3,500	About 14,000	26	33	240
700 ≀ 1000	135～160	3,800	About 19,000	46	54	400

Note: This table shows the capacities and dimensions derived from accumulation of actual data widely used.

16-1 Structure of Turbine Generators

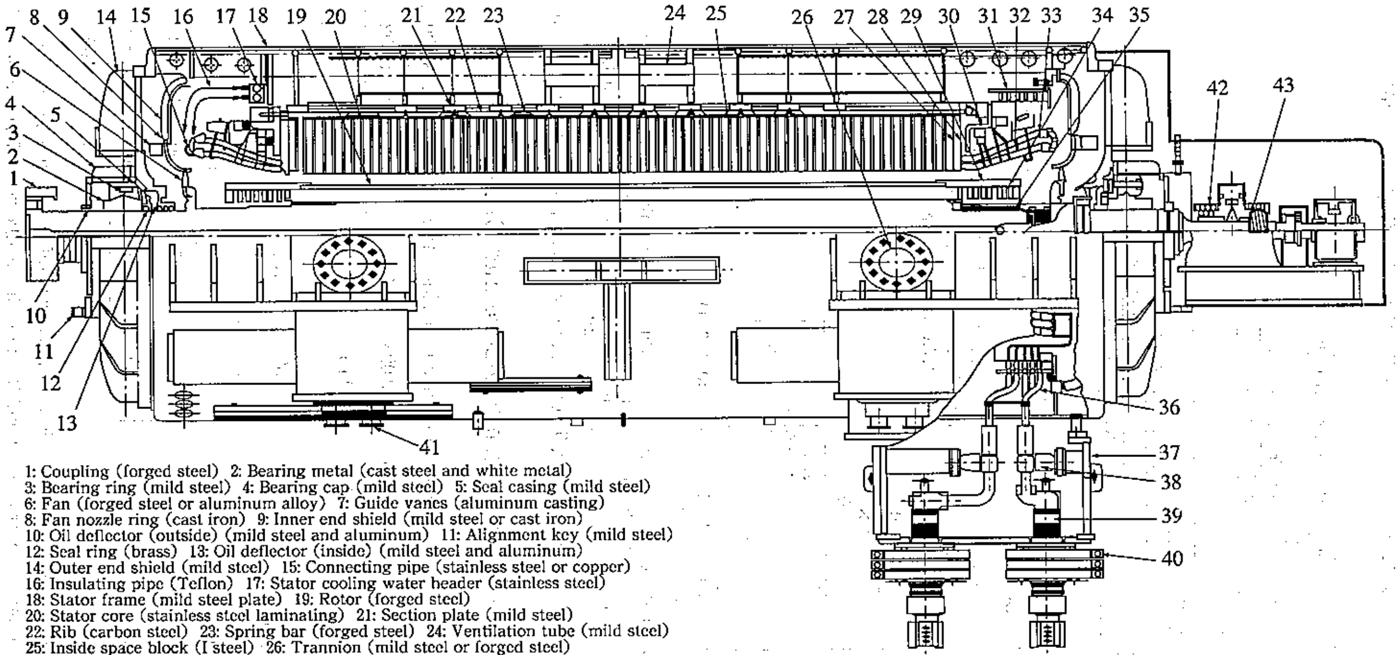
Most of the turbine generators for thermal power is the high-speed machine of two poles, and speed of revolution serves as 3,000rpm by 50Hz, and it serves as 3,600rpm by 60Hz.

The turbine generator for nuclear power is 4 poles and serves as 1,500rpm or 1,800rpm. Since the generating steam of a nuclear reactor is a large quantity, low-temperature and low pressure of steam compared with thermal power. It is because a turbine with long blades and low revolving speed is employed for nuclear power plants.

A gas turbine generator is used also as the object for emergency, or an object for peak loads appreciating its short starting time or its economical efficiency.

Moreover, generators for the combined-cycle-power-generation aiming at the improvement in efficiency by compound operation of a gas turbine and a steam turbine are also manufactured. There are one axis type and a multi-axis type.

The following figure is an example of the structure of a direct-water cooled stator winding type turbine generator, and shows the names and materials of the principal parts.

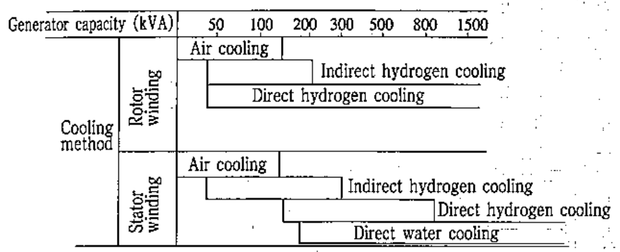


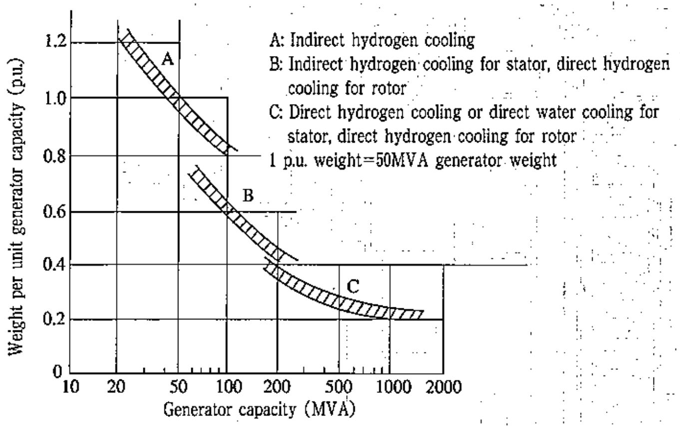
1: Coupling (forged steel) 2: Bearing metal (cast steel and white metal)
3: Bearing ring (mild steel) 4: Bearing cap (mild steel) 5: Seal casing (mild steel)
6: Fan (forged steel or aluminum alloy) 7: Guide vanes (aluminum casting)
8: Fan nozzle ring (cast iron) 9: Inner end shield (mild steel or cast iron)
10: Oil deflector (outside) (mild steel and aluminum) 11: Alignment key (mild steel)
12: Seal ring (brass) 13: Oil deflector (inside) (mild steel and aluminum)
14: Outer end shield (mild steel) 15: Connecting pipe (stainless steel or copper)
16: Insulating pipe (Teflon) 17: Stator cooling water header (stainless steel)
18: Stator frame (mild steel plate) 19: Rotor (forged steel)
20: Stator core (stainless steel laminating) 21: Section plate (mild steel)
22: Rib (carbon steel) 23: Spring bar (forged steel) 24: Ventilation tube (mild steel)
25: Inside space block (I steel) 26: Trannion (mild steel or forged steel)
27: Outside space block (non-magnetic steel)
28: Stator frame flange (mild steel, cast iron or non-magnetic cast iron)
29: Retaining ring (forged steel or non-magnetic steel) 30: Facing or copper facing (copper)
31: Stator connection support (insulator) 32: End winding support (insulator)
33: Stator coil (copper wire and insulator) 34: Rotor coil (copper wire and insulator)
35: Lead conductor (copper) 36: Stator connection lead (copper)
37: Terminal box (mild steel) 38: Lead support (porcelain)
39: High voltage bushing (porcelain and copper)
40: Bushing current transformer (copper, insulator and steel plate)
41: Hydrogen gas cooler (copper alloy, aluminum alloy and mild steel, cast iron)
42: Brush (carbon) 43: Slip ring (forged steel)

Section Drawing of Turbine Generator (Stator Coil Direct Water Cooling Type)

〔Source: Electrical Engineering Handbook (1988), The Institute of Electrical Engineers of Japan〕

16-2 Capacities of Turbine Generator and Cooling Systems





Note: Indirect cooling: The system which cools exothermic parts, such as conductor, through insulator, core, etc., indirectly.
Direct cooling: The system which cools exothermic parts, such as conductor, directly by coolant.

〔Source: Toshiyuki Ooshima and others, Thermal and Nuclear Power, No.291, (1980)〕

16-3 Example of Hydrogen Pressure and Output

Allowable output for each operating hydrogen pressure (provided the rated output is 100%)

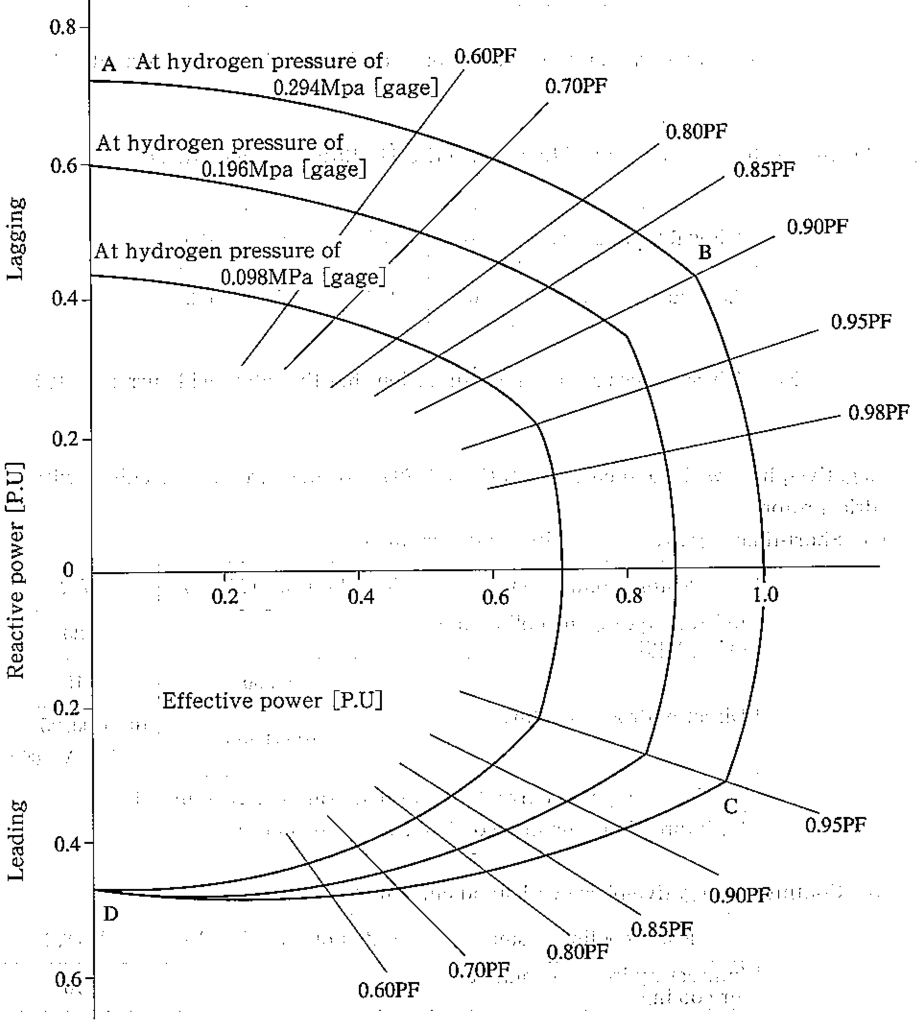
Hydrogen pressure [MPa]		0.005	0.098	0.196	0.294	0.392
Cooling system	Normal cooling	100	115	125	—	—
	Rotor: Direct cooling Stator: Normal cooling	35	60	100	—	—
	Rotor: ┐ Direct cooling	—	—	87	100	—
	Stator: ┘ (with hydrogen)	—	—	87	100	100
	Rotor: Direct cooling	—	55	91	100	—
	Stator: Liquid cooling	—	—	74	88	100

Note: The above values are based on actual examples. However, they will differ with design margin.

〔Source: Ryouichi Takeuchi and others superintend, Hand Book of Thermal Power, 1970, Ohmsha, Ltd.〕

16-4 Example of Possible Output Curves of Turbine Generators

[Note] Curve AB: Restricted by field coil
Curve BC: Restricted by armature coil
Curve CD: Restricted by overheat at stator core end and stability limit.
PF: Power factor



16-5 Short-Time Overload Withstand Capability of Turbine Generators

1. Short-time allowable current of armature coils (JEC-114-1979 an explanation)

Allowable time (sec.)	10	30	60	120
Armature current (%)	226	154	130	116

Note: These values are on the assumption that the rated armature current is 100%.

2. Short-time allowable current of field coils (JEC-114-1979 an explanation)

Allowable time (sec.)	10	30	60	120
Field current (%)	208	146	125	112

Note: These values are on the assumption that the rated field current is 100%.

3. Negative-phase withstand current (JEC-114-1979): For synchronous machines with cylindrical rotors

(a) Short-time negative-phase withstand current I_2^2t

Rotor cooling system	Rated output (MVA)	I_2^2t
Indirect hydrogen cooling and air cooling	—	30
Direct hydrogen cooling	~800	10
	801~1,600	10−0.00625 ×(MVA−800)

I_2 : Negative-phase current when rated armature current is 1

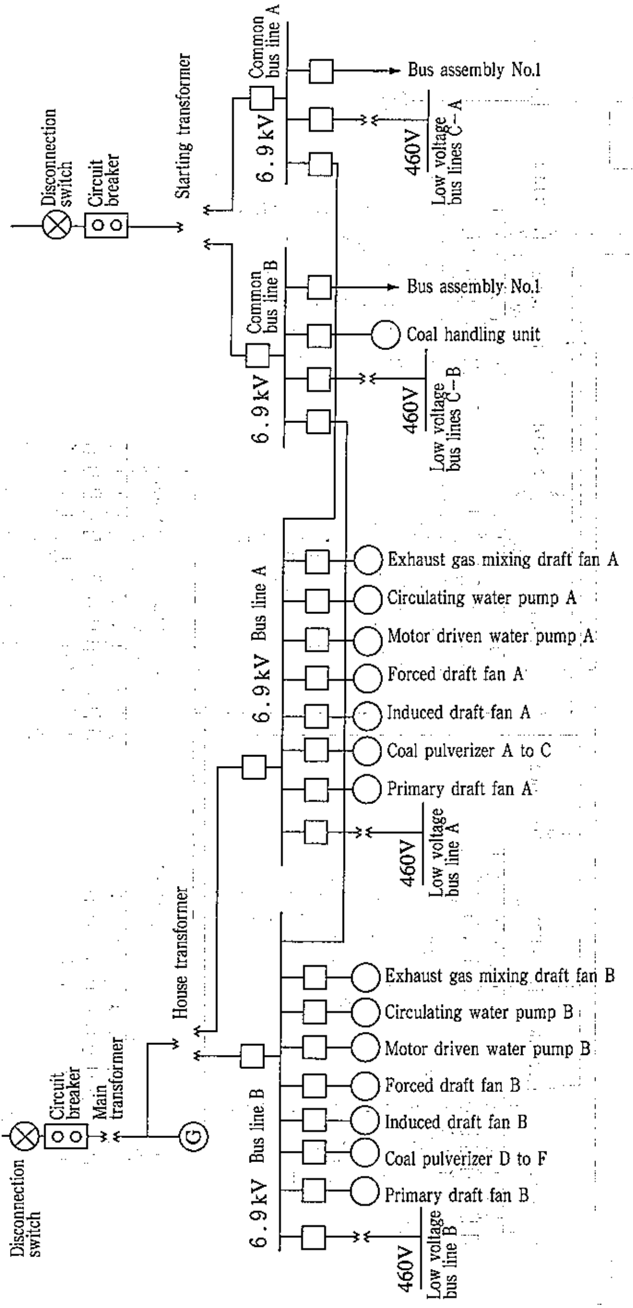
t : Impression time in seconds (120 seconds max.)

(b) Continuous negative-phase withstand current I_2

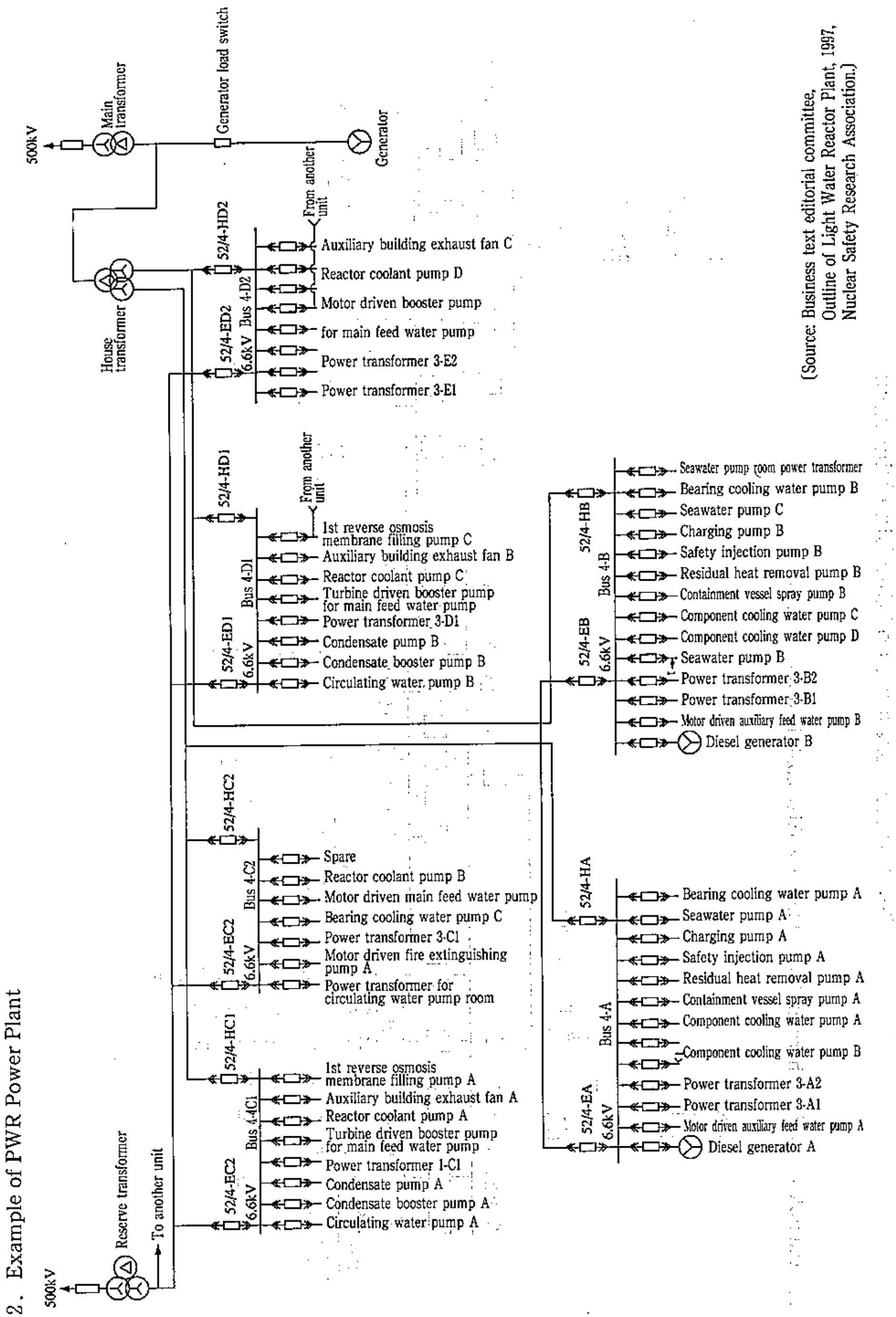
Rotor cooling system	Rated output (MVA)	I_2 (%)
Indirect hydrogen cooling and air cooling	—	10
Direct hydrogen cooling	~960	8
	961~1,200	6
	1,201~1,500	5

16-6 Typical Examples of One-Line Diagrams

1. Example of Utility Thermal Power Plant (600MW coal fired power plant)



2. Example of PWR Power Plant



(Source: Business text editorial committee, Outline of Light Water Reactor Plant, 1997, Nuclear Safety Research Association.)

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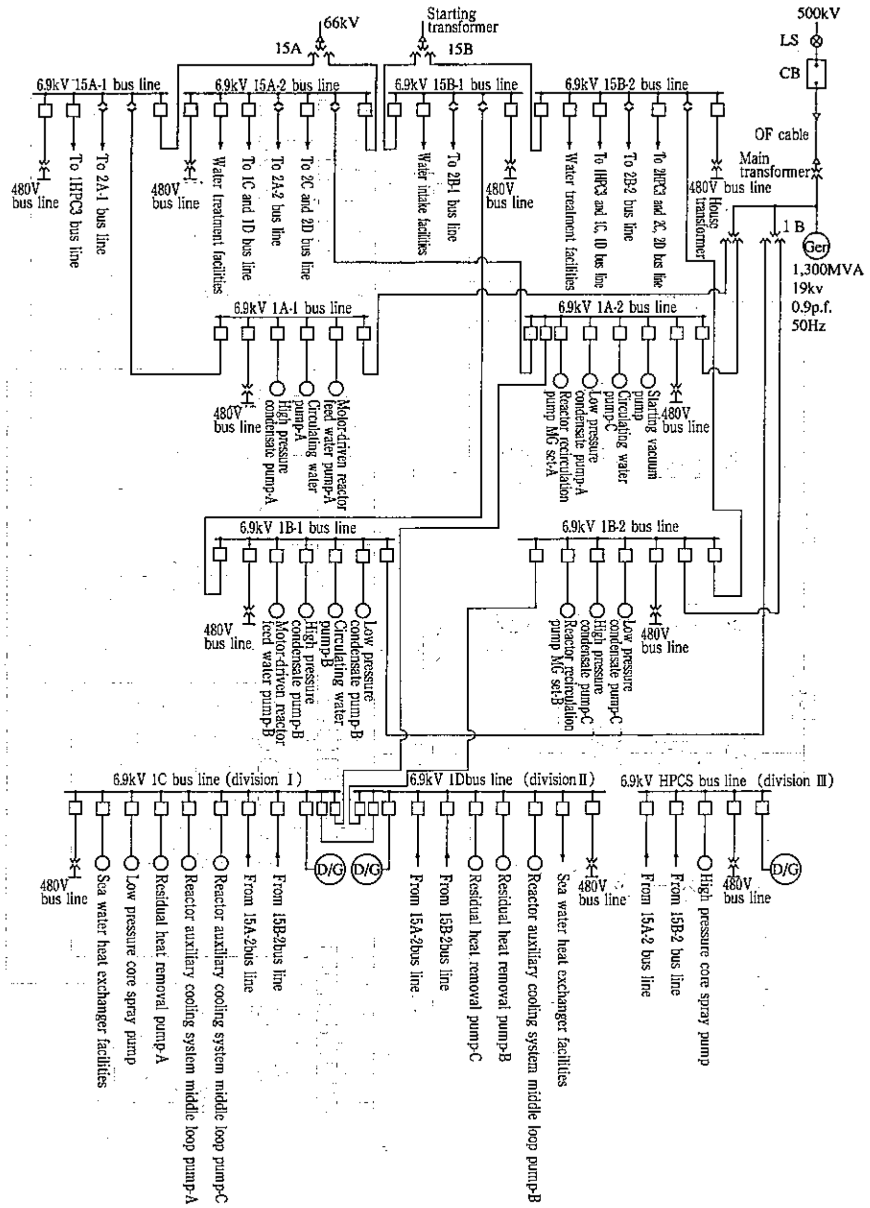
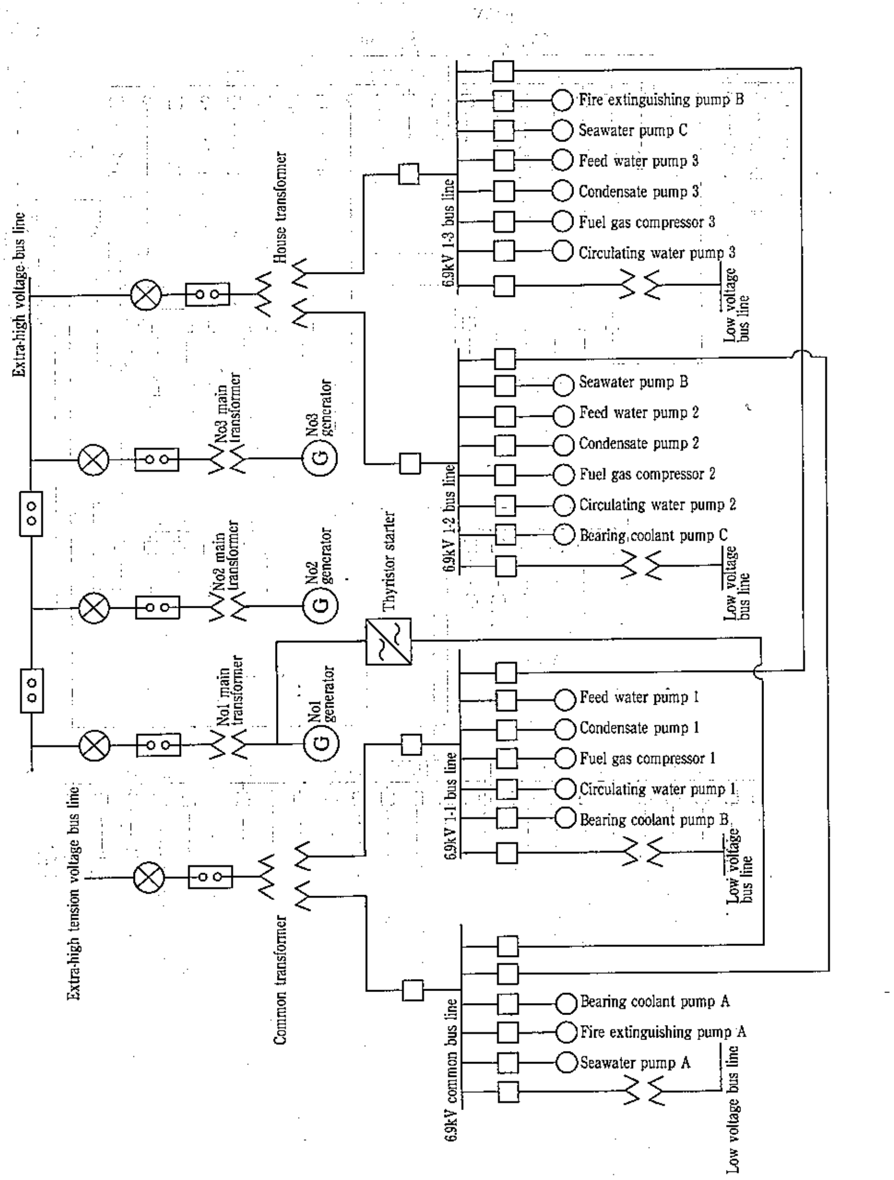
3. Example of BWR Power Plant (1100MWe class plant)



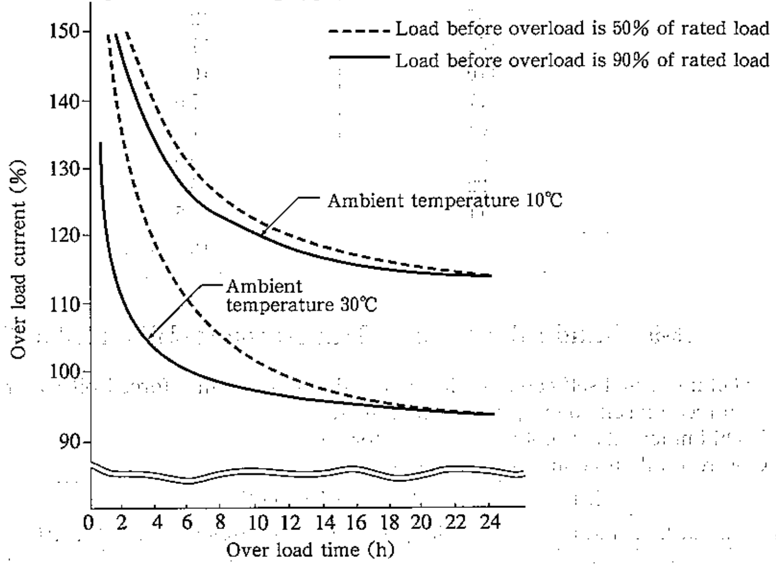


4. Example of Combined Thermal Power Plant (1200MWe class plant)

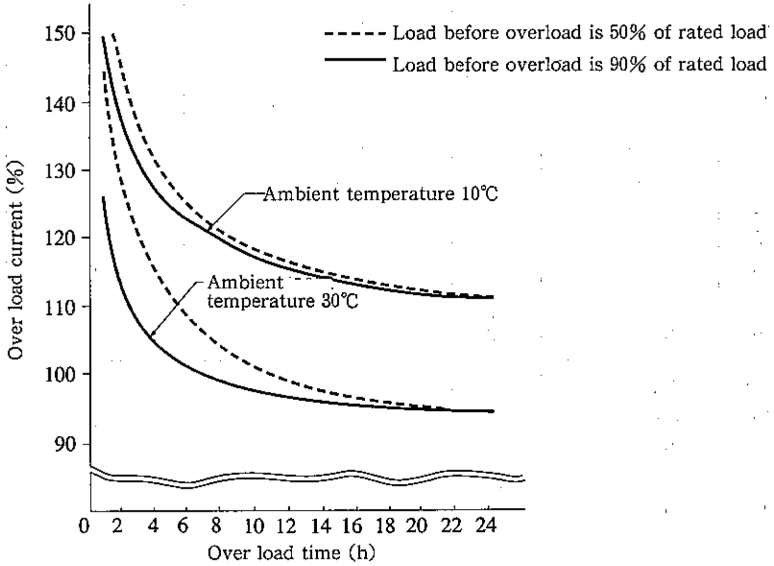
16-7 Short-Time Overload Operation of Oil Immersed Transformers

〔Source: Technical Report of The Institute of Electrical Engineers of Japan Section (I) No143 (Nov.1986), Transformer Reliability Investigation Technical Committee, Oil Immersed Transformer Operating Guide〕

1. Example of self cooling type transformer



2. Example of forced cooling type transformer



16-8 Impedance Voltage Standard Value of Transformers

Nominal voltage (kV)	Impedance voltage (%)
500	14
275	14
220	13
187	12
154	11
110	10
77	7.5
66	7.5
33	5.5
22	5.0
11	4.5

〔Source: Electrical Engineering Handbook, (1988), p.665, The Institute of Electrical Engineers of Japan〕

16-9 Standard Noises of Transformers (JEM 1118-1977)

A: Oil immersed self cooling, oil immersed water cooling, forced oil water cooling, and forced oil self cooling type transformers
B: Oil immersed air cooling type transformers
C: Forced oil air cooling type transformers

Equivalent capacity (double winding) (MVA)									Noise level (Phone)(A)
Isolating grade 70 or less			Isolating grade 100			Isolating grades 140 to 200			
A	B	C	A	B	C	A	B	C	
0.3									56
0.5									58
0.7									60
1									62
1.5									63
2									64
3									65
4									66
5									67
6									68
7.5									69
10	3		3						70
12.5	6		4						71
15	7.5		6						72
—	10		10	4		4			73
20	15		12.5	5		6			74
25	20	15	15	7.5		10			75
30	25	20	20	15		12.5	6		76
40	30	25	25	20	10	15	10		77
50	40	35	30	25	20	20	15	10	78
60	50	45	40	30	30	25	20	20	79
80	60	60	50	35	35	30	25	25	80
100	80	80	75	45	45	40	30	30	81
	100	100	100	60	60	50	35	35	82
			150	75	75	75	45	45	83
				100	100	100	60	60	84
				150	150	150	75	75	85
						200	100	100	86
						300	150	150	87
						450		200	88
								300	89
								450	90
								600	91

(continued)

Remark: 1. If the equivalent capacity of the transformer in use is not shown above, adopt the noise level of the most approximate and greater capacity.

2. If an oil immersed transformer has self cooling and air cooling ratings, the standard noise level for the air cooling rating shall be regarded as the noise level of the transformer.

(1) Apply an MVA value for the self cooling type to a transformer whose electrical performances are based on the self cooling operation.

(2) Apply an MVA value in column A for the air cooling type to a transformer whose electrical performances are based on the air cooling operation.

3. As for a double or triple rating transformer, apply the value shown above to the maximum capacity only.

4. The above table is not applicable to the standard noise level of a transformer with a separate cooler.

5. Three phones shall be added to any value shown above to obtain a guarantee value.

16-10 Characteristics of Low Voltage 3-Phase Squirrel Cage Induction Motors (cited from JIS C 4210-1983)

1. Rated power

The rated powers of the standard low voltage squirrel cage induction motors are as shown below: 0.2, 0.4, 0.75, 1.5, 2.2, 3.7, 5.5, 7.5, 11, 15, 18.5, 22, 30, 37 (kW)

2. Characteristics of low voltage induction motors

Type	Rated power (kW)	Poles	Synchronous speed (rpm)		Insulation type	Full load characteristic		Reference value		
			50Hz	60Hz		Efficiency η (%)	Power factor P_f (%)	No load current I_0 (Mean value of each phase) (A)	Full load current I (Mean value of each phase) (A)	Full load slip S (%)
Protection type	0.75	2	3000	3600	E	Min. 68.0	Min. 77.0	2.1	3.9	7.5
	3.7				E	Min. 80.0	Min. 82.5	6.9	15.4	6.0
	15				B	Min. 85.0	Min. 83.0	23	58	5.5
	37				F	Min. 87.0	Min. 85.0	50	138	5.0
	0.75	4	1500	1800	E	Min. 69.5	Min. 70.0	2.8	4.2	8.0
	3.7				E	Min. 81.0	Min. 78.0	9.0	16.1	6.5
	15				B	Min. 85.5	Min. 80.5	28	60	5.5
	37				F	Min. 87.0	Min. 82.0	63	143	5.5
	0.75	6	1000	1200	E	Min. 68.0	Min. 63.0	3.4	4.8	8.5
	3.7				B	Min. 80.0	Min. 73.0	10	17.4	6.5
	15				B	Min. 84.5	Min. 76.0	34	64	6.0
	37				F	Min. 86.5	Min. 78.5	74	152	5.5
Fully closed type	0.75	2	3000	3600	E	Min. 68.0	Min. 77.0	2.1	3.9	7.5
	3.7				E	Min. 80.0	Min. 82.5	6.9	15.4	6.0
	15				B	Min. 85.0	Min. 82.5	24	59	5.5
	37				F	Min. 87.0	Min. 84.5	51	139	5.0
	0.75	4	1500	1800	E	Min. 69.5	Min. 70.0	2.8	4.2	8.0
	3.7				E	Min. 81.0	Min. 78.0	9.0	16.1	6.5
	15				B	Min. 85.5	Min. 79.5	29	61	5.5
	37				F	Min. 87.5	Min. 81.5	64	143	5.5
	0.75	6	1000	1200	E	Min. 68.0	Min. 63.0	3.4	4.8	8.5
	3.7				B	Min. 80.0	Min. 73.0	10	17.4	6.5
	15				B	Min. 84.5	Min. 75.0	35	65	6.0
	37				F	Min. 86.5	Min. 78.0	74	152	5.5

Note: The full load currents and no load currents shown above apply to the rated voltage of 200V. For rated voltage of E, apply 200／E.

16-11 Characteristics of High Voltage 3-Phase Induction Motors

(JEM 1381-1993)

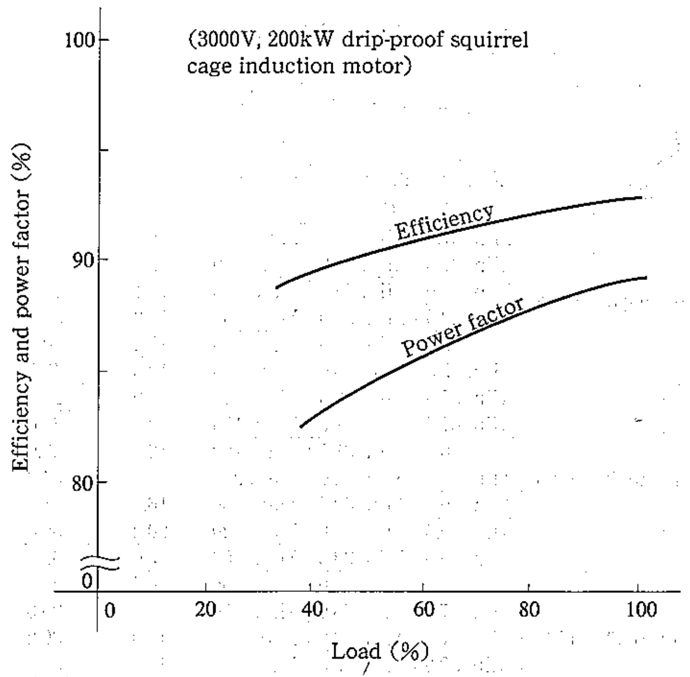
(Generally Class F Insulation)

Type	Rated power (kW)	Poles	Synchronous speed (rpm)		Full load characteristic		Starting(1) current Ist (Mean value of each phase) (A)	Reference value		
			50Hz	60Hz	Efficiency η (%)	Power factor P_f (%)		No load current I_0 (Mean value of each phase) (A)	Full load current I (Mean value of each phase) (A)	Full load slip S (%)
Open type	75	2	3000	3600	Min. 87.0	Min. 82.5	Max. 135	8.0	19.7	4.0
	90				Min. 87.5	Min. 83.0	Max. 160	9.4	23.4	4.0
	110				Min. 88.0	Min. 83.5	Max. 195	11.1	28.2	4.0
	132				Min. 88.5	Min. 84.0	Max. 235	13.0	33.6	3.5
	160				Min. 89.0	Min. 84.5	Max. 280	15.2	40.2	3.5
	200				Min. 89.5	Min. 85.0	Max. 345	18.3	49.5	3.5
	75	4	1500	1800	Min. 87.0	Min. 80.5	Max. 125	9.0	20.2	4.5
	90				Min. 87.5	Min. 81.0	Max. 150	10.4	24.0	4.0
	110				Min. 88.0	Min. 81.5	Max. 180	12.3	29.0	4.0
	132				Min. 88.5	Min. 82.0	Max. 215	14.4	34.3	4.0
	160				Min. 89.0	Min. 82.5	Max. 260	16.9	41.1	3.5
	200				Min. 89.5	Min. 83.0	Max. 320	20.2	50.8	3.5
	250				Min. 90.0	Min. 83.5	Max. 400	25.0	62.9	3.5
	75	6	1000	1200	Min. 86.5	Min. 77.0	Max. 135	10.4	21.3	4.5
	90				Min. 87.0	Min. 78.0	Max. 160	12.2	25.3	4.5
	110				Min. 87.5	Min. 79.0	Max. 190	14.0	30.2	4.0
	132				Min. 88.0	Min. 79.5	Max. 225	16.0	35.6	4.0
	160				Min. 88.5	Min. 80.0	Max. 270	19.0	42.7	4.0
	75	8	750	900	Min. 85.5	Min. 73.5	Max. 135	12.3	22.5	4.5
	90				Min. 86.0	Min. 74.5	Max. 160	14.0	26.5	4.5
	110				Min. 86.5	Min. 75.5	Max. 190	16.4	31.8	4.5
	132				Min. 87.0	Min. 76.0	Max. 225	19.2	37.7	4.5
Fully closed type	75	2	3000	3600	Min. 87.5	Min. 82.0	Max. 145	8.2	19.7	4.0
	90				Min. 88.0	Min. 82.5	Max. 175	9.6	23.4	4.0
	110				Min. 88.5	Min. 83.0	Max. 210	11.3	28.2	4.0
	132				Min. 89.0	Min. 83.5	Max. 250	13.2	33.6	3.5
	160				Min. 89.5	Min. 84.0	Max. 300	15.5	40.2	3.5
	75	4	1500	1800	Min. 87.5	Min. 80.0	Max. 130	9.1	20.2	4.5
	90				Min. 88.0	Min. 80.5	Max. 155	10.6	24.0	4.0
	110				Min. 88.5	Min. 81.0	Max. 185	12.6	29.0	4.0
	132				Min. 89.0	Min. 81.5	Max. 220	14.7	34.3	4.0
	160				Min. 89.5	Min. 82.0	Max. 265	17.3	41.1	3.5
	75	6	1000	1200	Min. 87.0	Min. 76.5	Max. 140	10.6	21.3	4.5
	90				Min. 87.5	Min. 77.5	Max. 165	12.3	25.3	4.5
	110				Min. 88.0	Min. 78.5	Max. 195	14.3	30.2	4.0
	132				Min. 88.5	Min. 79.0	Max. 230	16.6	35.6	4.0
	75	8	750	900	Min. 86.0	Min. 73.0	Max. 140	12.3	22.5	4.5
	90				Min. 86.5	Min. 74.0	Max. 165	14.1	26.5	4.5
	110				Min. 87.0	Min. 75.0	Max. 200	16.5	31.8	4.5

Note: (1) The starting currents comply with (1) Direct proportion method, 5.1 in JIS C 4207.

Remark: The full load currents, no load currents and starting currents shown above apply to the motors of 3000V rating. For motors of 3300 V rating, multiply the values shown above by 3000／3300.

16-12 Partial Load Characteristic of Induction Motors (Example)



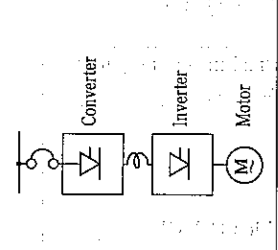
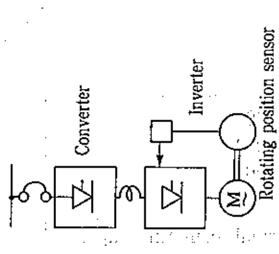
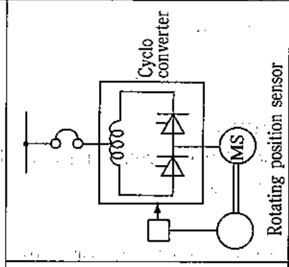
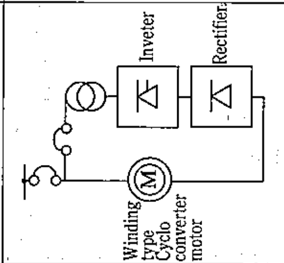
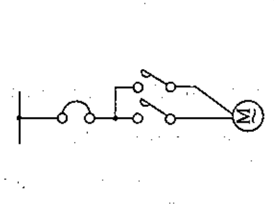
16-13 Allowable Times of Start-up for Squirrel Cage Induction Motors

Application	Allowable number of starts		Cooling time necessary for restarting (h)
	Cold	Hot	
Forced draft fan	1 to 2	1	1 to 2
Gas recirculation fan	1 to 2	1	1 to 2
Feed water pump	2 to 3	1 to 2	1 to 1.5
Circulating water pump	2 to 5	1 to 3	0.5 to 1.5
Condensate pump	2 to 5	1 to 3	0.5 to 1.0
Exciter	1 to 2	1	1 to 2

Note:
1. The above table shows the sample of main auxiliary motors for thermal power plants.
2. An induction motor, big starting current flows at the time of starting, and if starting is repeated, it may result in the damage-by-fire accident of a coil, and it is necessary to restrict the number of times of starting for generation of heat by starting current.
3. "Cold" denotes the condition where the motor temperature is the same as the ambient temperature.
4. "Hot" denotes the condition where the motor temperature is stable as in continuous operation at the rated output.
5. "Cooling time necessary for restarting" is the cooling-off period required for re-starting without detriment to a motor.

16-14 Types of Speed Control for AC Motors

Types of main control methods and comparison for AC motors speed control for energy saving by thyristors without using fluid couplings.

Control system Item	Thyristor inverter (VVVF)	Thyristor motor		Thyristor Scherbius	Pole changing control
		DC type	AC type		
Applicable motor	Squirrel cage induction motor	Synchronous motor		Winding type induction motor	Squirrel cage induction motor
Circuit system					
Operation	The converter converts input alternating current into direct current. The inverter converts it into alternating current of any intended frequency, based on which the speed is controlled.	The converter rectifies input alternating current. The inverter reversely converts rectified current into variable frequency alternating current (through load commutation), based on which the speed is controlled.	The cyclo-converter converts input alternating current into variable voltage, variable frequency alternating current, based on which the speed is controlled.	The inverter reversely converts current induced by the rotor winding into alternating current, which is returned to the power source. The amount of returned current is varied to control the speed.	The number of poles of the motor is changed to change the speed.
Features	• May be used for normal motors. (Suitable to modification of exiting motors.) • Subject to partial resonance due to torque pulsation. • For small and middle capacity motors	• Better efficiency. • Simpler conversion system than the AC type control. • Subject to partial resonance due to torque pulsation, controllability is deteriorated at low speed. • For middle and large capacity motors.	• Reverse direction operation is possible. • Torque pulsation is less than the DC type control. • Recovers by itself even if commutation fails. • The thyristor circuit is more complicated than the DC type control. • More expensive than other types of controls.	• Not economical if the operation range is expanded to low speed. • Best efficiency. • Requires proper countermeasures against instantaneous black out.	• Changes the speed step by step. • Simple mechanism. • Not suitable to frequent speed change.

16-15 Limits of Temperature Rise for Cables (JCS 168 D)

1. Basic temperature

The basic temperature differs with cable laying methods as shown below.

Basic temperature and laying methods

Laying methods	Basic temperature (℃)
Duct	25
Direct embedding	25
Air and culvert	40*
Water bottom	25
Sand filled trough with 3 exposed sides (exposed to sunlight)	43.5
Sand filled trough with exposed top (exposed to sunlight)	40
No sand trough with exposed top (exposed to sunlight)	40

*30 degrees may be regarded as the basic temperature for rubber or plastic cables mainly used for indoor wiring.

2. Maximum allowable conductor temperature

The maximum allowable conductor temperature is related to the heat resistance of the sheath. It differs with cable types as shown below.

Cable types and maximum allowable conductor temperatures

Cable type		Maximum allowable temperature (℃)
Solid cables	6600V or less	80
	11,000V	75
	22,000V	70
	33,000V	65
Low gas pressure cables		75
OF cables	Normal insulating paper	80
	Low loss paper	85
PGC & PGF cables		80
POF cables	Normal insulating paper	80
	Low loss paper	85
Butyl rubber cables (BN)		80
Ethylene propylene cables		80
Natural rubber cables		60
Polyethylene cables (EV)		75
Cross-linked polyethylene cables (CE,CV)		90
Vinyl cables (VV)		60
Cambric cables		80
Silicon rubber cables		100

3. Maximum allowable temperature in case of short circuit

Type	Maximum allowable temperature
Pipe type cables Solid cables Low gas pressure cables (POF cables not included)	220
OF cables Pipe type cables (POF only)	150
Butyl rubber cables (BN)	230
Polythylene cables (EV)	140
Cross-linked polyethylene cables (CE,CV)	230
Cambric cables	200
Vinyl cables (VV)	120
Natural rubber cables	150
Ethylene propylene cables	230
Silicon rubber cables	300

4. Current correction according to basic temperature.

If the basic temperature is different from any values shown in 1, basic temperature above, correct the allowable current at the given temperature using the correction factors shown below. (This correction applies to 11kV or less cables only.)

Current correction factors according to basic temperatures

Maximum allowable conductor temperature (℃)	60			65		70		75		80		90	
Standard basic temperature (℃) / Basic temperature ℃	25	30	40	25	40	25	40	25	40	25	40	25	40
20	1.07	1.15	1.41	1.06	1.34	1.05	1.29	1.05	1.25	1.04	1.22	1.04	1.18
25	1.00	1.08	1.32	1.00	1.26	1.00	1.22	1.00	1.20	1.00	1.17	1.00	1.14
30	0.93	1.00	1.22	0.94	1.18	0.94	1.15	0.95	1.13	0.95	1.12	0.96	1.10
35	0.85	0.91	1.12	0.87	1.10	0.88	1.08	0.89	1.07	0.90	1.06	0.92	1.05
40	0.76	0.82	1.00	0.79	1.00	0.82	1.00	0.84	1.00	0.85	1.00	0.88	1.00
45	0.65	0.71	0.87	0.71	0.89	0.75	0.91	0.77	0.93	0.80	0.94	0.83	0.95
50	0.53	0.58	0.71	0.61	0.77	0.67	0.82	0.71	0.85	0.74	0.87	0.78	0.89

16-16 Allowable Currents of Cables (JCS 168 D)

1. Allowable currents of 600V cables (with copper conductors)

Unit: A

Laying conditions / Nominal cross sections or diameters	Vinyl insulation, vinyl sheath cables (VV cables)						Cross-bridged polyethylene insulation, vinyl sheath cables (CV cables)					
	Air or culvert laying			Duct laying			Air or culvert laying			Duct laying		
	1- core	2- core	3- core	1- core	2- core	3- core	1- core	2- core	3- core	1- core	2- core	3- core
	3 cable laying S=2d	1 cable laying	1 cable laying	4 hole, 3 cable laying	4 hole, 4 cable laying	4 hole, 4 cable laying	3 cable laying S=2d	1 cable laying	1 cable laying	4 hole, 3 cable laying	4 hole, 4 cable laying	4 hole, 4 cable laying
mm												
1.0	11	10	8	—	11	9	—	—	—	—	—	—
1.2	14	12	11	—	14	11	—	—	—	—	—	—
1.6	20	18	15	—	19	16	—	—	—	—	—	—
2.0	26	23	20	—	24	20	—	—	—	—	—	—
2.6	36	32	27	—	33	28	—	—	—	—	—	—
3.2	47	42	36	—	42	35	—	—	—	—	—	—
mm^2												
2.0	20	18	15	—	19	16	31	28	23	—	25	21
3.5	28	25	21	—	26	22	44	39	33	—	35	29
5.5	37	33	28	—	34	28	58	52	44	—	45	37
8	47	42	36	—	42	35	72	65	54	—	55	46
14	66	59	50	—	57	48	100	91	76	—	75	63
22	88	78	66	—	74	62	130	120	100	—	98	81
38	120	110	93	—	100	84	190	170	140	—	130	110
60	165	145	120	—	130	105	255	225	190	—	170	140
100	230	200	165	235	170	140	355	310	260	310	225	185
150	295	255	220	300	215	175	455	400	340	390	285	235
200	350	310	260	350	250	210	545	485	410	460	330	275
250	400	355	300	395	280	230	620	560	470	520	370	305
325	470	420	355	455	320	265	725	660	555	600	425	350
400	525	—	—	510	—	—	815	—	—	670	—	—
500	590	—	—	570	—	—	920	—	—	750	—	—
600	645	—	—	620	—	—	1,005	—	—	820	—	—
800	825	—	—	755	—	—	1,285	—	—	990	—	—
1,000	940	—	—	845	—	—	1,465	—	—	1,115	—	—

Note: The allowable currents shown above are based on the following conditions.

(1) Maximum allowable conductor temperature CV: 90℃, VV: 60℃

(2) Ambient temperature Air: 40℃, duct: 25℃

(3) The distance between the centers of cables laid in a culvert or air multi-cable shall be twice as large as the cable outer diameter.

(4) Frequency: Commercial frequency

(5) For duct laying, the intrinsic thermal resistance of soil g shall be 100 (℃ cm/W) and the loss rate L_f shall be 1.0.

2. Allowable currents of 3,300 V～6,600 V cables (with copper conductors)

Unit: A

Laying conditions	Air and culvert laying			Duct laying		
Size	1- core	3- core	C V T	1- core	3- core	C V T
	S= 2d	Single cable	Single cable	4 holes, 3 cables	Single cable	Single cable
mm^2						
8	78	61		76	58	
14	105	83		100	79	
22	140	105	120	130	100	110
38	195	145	170	180	135	155
60	260	195	225	235	175	200
100	355	265	310	310	235	270
150	455	345	405	390	295	340
200	540	410	485	455	350	400
250	615	470	560	515	395	450
325	720	550	660	595	465	530
400	810		750	665		590
500	930		855	745		665
600	1,040		950	820		735
800	1,295			990		
1,000	1,480			1,105		

Note: The allowable currents shown above are based on the following conditions.

(1) Maximum allowable conductor temperature CV: 90℃

(2) Ambient temperature Air: 40℃, duct: 25℃

(3) The distance between the centers of cables laid in a culvert or air multi-cable shall be twice as large as the cable outer diameter.

(4) Frequency: Commercial line frequency

(5) For duct laying, the intrinsic thermal resistance of soil g shall be 100 (℃・cm/W) and the loss rate L_f shall be 1.0.

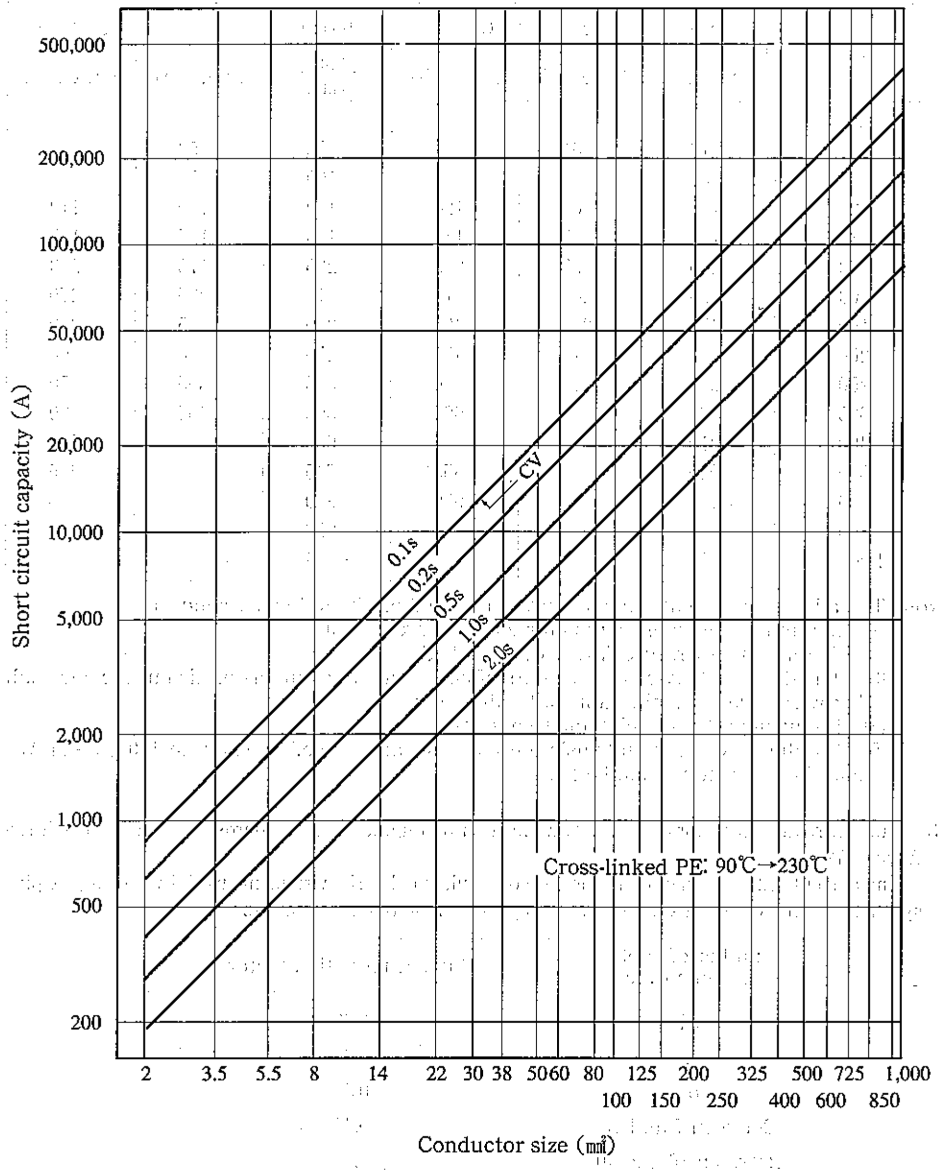
3. Current reduction factors (Nov. 1998 Exposition of Engineering Standards for Electric Facilities-Article 172)

The current reduction factors in the case of insulated electric wire being used by storing in pipe synthetic resin molding, a synthetic resin pipe, metal molding, a metal tube.

Number of cables in same tube	Current reduction factor
3 or less	0.70
4	0.63
5 or 6	0.56
Between 7 and 15	0.49
Between 16 and 40	0.43
Between 41 and 60	0.39
61 or more	0.34

16-17 Short-Time Allowable Currents of Cables (JCS 168 D)

CV (with copper conductors)



16-18 Allowable Currents of OF Cables (JCS 168 C(1973))

1. 66 to 77 kV OF cables

(a) Allowable currents of 66 to 77 kV single-core OF cables Unit: A

Laying method / Number of cables / Nominal cross section (㎟)	Duct laying				Direct embedding		Air or culvert laying	
	1 hole, 1 cable		1 hole, 3 cables					
	1	2	1	2	1	2	1	2
2,000	1,355	1,115	1,030	875	1,335	1,125	1,910	1,810
1,500	1,215	1,000	970	810	1,205	1,005	1,480	1,400
1,200	1,100	905	910	765	1,100	920	1,470	1,390
1,000	1,015	840	860	725	1,020	850	1,335	1,260
800	890	735	755	640	895	740	1,160	1,100
600	745	615	660	565	780	640	975	925
400	610	505	555	480	640	520	770	730

(b) Allowable currents of 66 to 77 kV 3-core OF cables Unit: A

Laying method / Number of cables / Nominal cross section (㎟)	Duct laying		Direct embedding		Air or culvert laying	
	1	2	1	2	1	2
500	500	440	565	480	655	620
400	460	405	520	440	585	555
325	425	370	475	405	525	500
250	375	330	420	360	455	430
200	340	300	380	325	405	385
150	295	260	330	285	345	330
100	240	215	265	230	275	260
80	210	190	235	205	240	230

2. 110 kV OF cables

(a) Allowable currents of 110 kV single-core OF cables Unit: A

Laying method / Number of cables / Nominal cross section (㎟)	Duct laying				Direct embedding		Air or culvert laying	
	1 hole, 1 cable		1 hole, 3 cables					
	1	2	1	2	1	2	1	2
2,000	1,270	1,020	945	770	1,255	1,015	1,765	1,740
1,500	1,145	925	880	720	1,135	915	1,535	1,500
1,200	1,045	850	835	690	1,040	840	1,375	1,335
1,000	960	785	795	660	965	775	1,245	1,200
800	860	700	720	600	865	695	1,115	1,070
600	725	590	635	530	760	610	945	905
400	600	495	540	455	630	505	755	720

(b) Allowable currents of 110 kV 3-core OF cables Unit: A

Laying method / Number of cables / Nominal cross section (㎟)	Duct laying		Direct embedding		Air or culvert laying	
	1	2	1	2	1	2
400	440	380	495	420	565	535
325	405	350	455	385	510	485
250	360	315	405	345	445	420
200	325	285	365	315	395	375
150	285	250	315	275	335	320
100	230	205	260	225	270	255

3. 154 kV OF cales

(a) Allowable currents of 154 kV single-core OF cables Unit: A

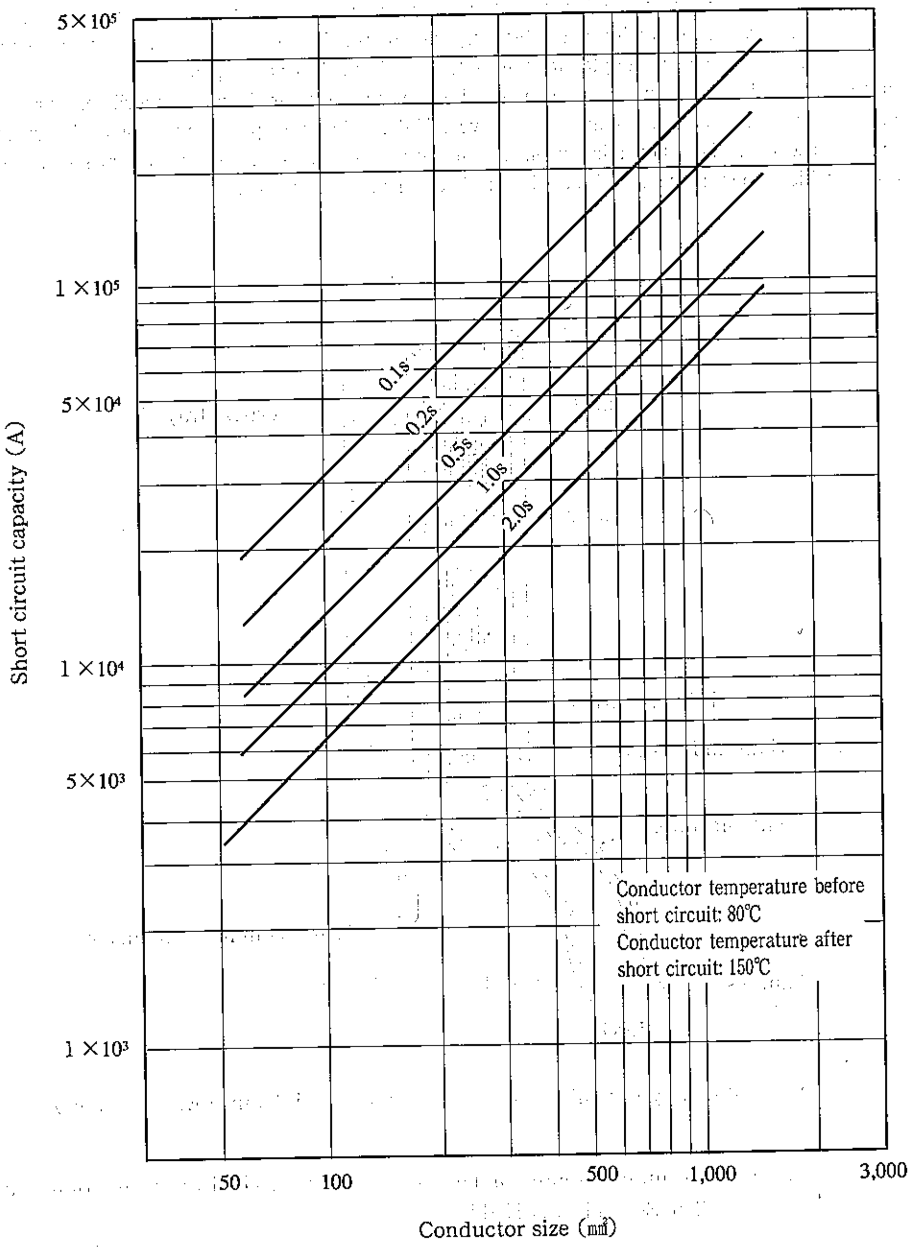
Laying method / Number of cables / Nominal cross section (㎟)	Duct laying				Direct embedding		Air or culvert laying	
	1 hole, 1 cable		1 hole, 3 cables					
	1	2	1	2	1	2	1	2
2,000	1,320	1,070	1,020	835	1,310	1,085	1,840	1,810
1,500	1,190	970	975	800	1,185	975	1,600	1,560
1,200	1,090	890	900	745	1,085	895	1,435	1,390
1,000	1,005	825	855	710	1,005	825	1,300	1,255
800	885	725	770	645	890	725	1,140	1,100
600	775	645	705	590	785	645	980	940
400	640	535	585	495	650	535	785	750

(b) Allowable currents of 154 kV 3-core OF cables Unit: A

Laying method / Number of cables / Nominal cross section (㎟)	Duct laying		Direct embedding		Air or culvert laying	
	1	2	1	2	1	2
325	440	385	480	410	550	525
250	390	345	425	365	480	455
200	350	310	385	330	430	405
150	305	275	335	290	365	350

16-19 Short Circuit Capacities of OF Cables

Short circuit capacities of 66000 and 77000 V OF cables

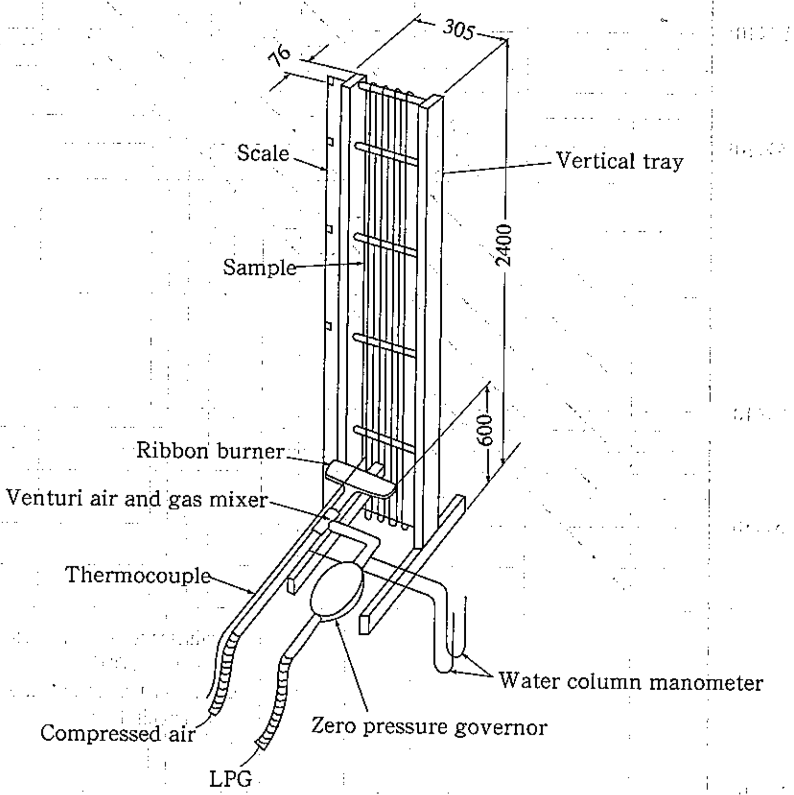


Conductor temperature before short circuit: 80℃
Conductor temperature after short circuit: 150℃

16-20 Flame Retardant Cables

The flame retardant cables is a self-extinguishing cable which is free from spreading of fire when the cable is ignited by an external or internal cause and then the fire cause is eliminated. In the United States, the IEEE Standard 383 was established in 1974 as a method of evaluating flame retardant of 1E-rated cables (for power control and instrumentation) used in nuclear power plants. In Japan, the "Method for testing flame retardant of wires and cables" reported by the Electric Society showed a recommended test method, which is widely adopted for the cables used in nuclear power plants.

In this test method, as shown below, cables laid on a vertical tray are burnt with a ribbon burner for 20 minutes, and then the ribbon burner is removed. If flame dose not spread to the top of the tray, the cables are accepted. The allowable currents, temperature rise limits and other properties of general-purpose cables shown above are also applicable to the flame retardant cables.



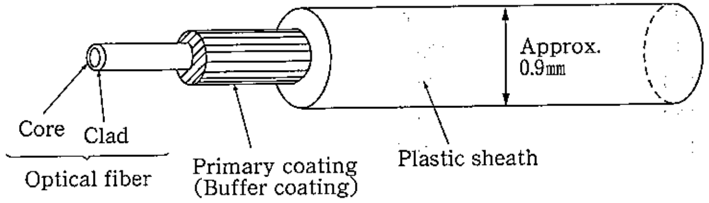
Vertical tray type combustion testing device specified in IEEE 383 (in mm)

〔Source: Technical Report of The Institute of Electrical Engineers of Japan The Second Part No145〕

16-21 Types of Optical Fiber Cables

1. Structure of cables

An optical fiber cable has the portion which it is called a core, and the portion called clad to the perimeter, and, as for the core, the refractive index is high slightly (0.5 - about several %) rather than clad. Furthermore, a primary coat and plastic covering are given for reinforcement of mechanical strength.

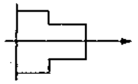
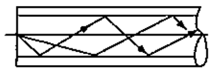
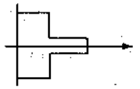
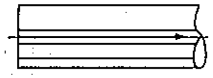
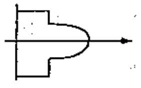
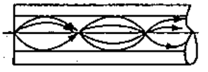


Structure of optical cable

2. Types of cables

Optical fiber cables are available in many types. They are classified according to the structures and materials.

Types (and structures) of optical fibers

Refraction rate distribution		Transmission mode		Transmission frequency bands
Step index (SI)			Multi-mode fiber	Dozens of MHz.km
			Single-mode fiber	Several GHz. km
Graded index (GI)			Multi-mode fiber	Hundreds of MHz. km

Types (and materials) of optical fibers

Type	Core	Cladding	Transmission losses
Quartz glass fiber	Quartz glass	Quartz glass	2.5 to 5 dB/km
Multicomponent glass fiber	Multicomponent glass	Multicomponent glass	5 to 20 dB/km
Polymer clad fiber	Quartz glass	Silicon polymer	3 to 5 dB/km
Plastic fiber	Plastic	Plastic	Up to hundreds of dB/km

16-22 Insulation Types of Electrical Equipment (JEC 6147-1992)

The symbol and temperature of a heatproof class of the insulating material and the insulation system in an electric product are specified as follows.

[Heatproof class]	[Temperature]
Y	90℃
A	105℃
E	120℃
B	130℃
F	155℃
H	180℃
200	200℃
220	220℃
250	250℃

16-23 Limits of Temperature Rise for Stationary Induction Equipment (JEC 2200-1995)

	Parts of transformer	Temperature measuring methods	Insulation type	Limits of temperature rise (℃)
Dry transformer	Winding	Resistance method	A	55
			E	70
			B	75
			F	95
			H	120
	Iron core surface	Thermometer method		Temperature free from damages to near insulation material

	Parts of transformer		Temperature measuring methods	Limits of temperature rise (℃)
Oil immersed transformer	Winding	Natural oil circulation	Resistance method	55
		Forced oil circulation	Resistance method	60
	Oil	If oil in tank is in direct contact with atmosphere	Thermometer method	50
		If oil tank is not in direct contact with atmosphere	Thermometer method	55
	Surface near iron core or other metallic insulating material		Thermometer method	Temperature free from damages to near insulating material

16-24 Limits of Temperature Rise for Rotating Machines (JEC 114-1979, JEC2100-1993)

The table below shows the limits of temperature rise at the basic coolant temperature. The maximum allowable temperature is the sum of the coolant temperature and the limits of temperature rise. The coolant temperature of air is basically 40℃, which shall be corrected according to the design conditions and altitude.

1. General rotating machines and air cooled synchronous generators (in ℃)

Item	Machine parts	Class A insulation			Class E insulation			Class B insulation			Class F insulation			Class H insulation		
		Thermometer method	Resistance method	Embedded thermometer method	Thermometer method	Resistance method	Embedded thermometer method	Thermometer method	Resistance method	Embedded thermometer method	Thermometer method	Resistance method	Embedded thermometer method	Thermometer method	Resistance method	Embedded thermometer method
1	Stator winding	50	60	60	65	75	75	70	80	80	85	100	100	105	125	125
2	Insulated rotor winding	50	60	–	65	75	–	70	80	–	85	100	–	105	125	–
3 A	Multi-layer field winding	50	60	–	65	75	–	70	80	–	85	100	–	105	125	–
3 B	Insulated single-layer field winding	60	60	–	75	75	–	80	80	–	100	100	–	125	125	–
3 C	Exposed single-layer field winding	65	65	–	80	80	–	90	90	–	110	110	–	135	135	–
3 D	Field winding housed in cylindrical rotor	–	–	–	–	–	–	–	90	–	–	110	–	–	125	–
4	Iron core or other mechanical part near insulated winding	60	–	–	75	–	–	80	–	–	100	–	–	125	–	–
5	Uninsulated short-circuited winding, iron core or other mechanical part not near insulated winding; brush and brush holder	Temperature causing no mechanical troubles or damages to near insulating materials														
6	Slip ring	60	–	–	70	–	–	80	–	–	90	–	–	100	–	–
7 A	Bearing (Self-cooling)	40℃ when measured on surface, 45℃ when measured with thermometer element embedded in metal, or upon deliberation by parties concerned if coolant temperature is too low or heat resistant lubricant is used														
7 B	Bearing (Water cooling)	Upon deliberation by parties concerned if bearing lubricant is cooled with water or bearings are directly cooled with water														

Note: The insulated rotor winding denotes the winding of a rotating armature, rotor winding of an induction synchronous motor, and starting winding of a salient pole synchronous induction motor.

2. Normal hydrogen cooling type synchronous machines (Unit: ℃)

Item	Machine parts	Class B insulation			Class F insulation		
		Thermometer method	Resistance method	Embedded thermometer method	Thermometer method	Resistance method	Embedded thermometer method
1	Stator winding hydrogen pressure (Gauge pressure) (In unit of Mpa)						
	0.005	–	–	80	–	–	100
	0.098	–	–	75	–	–	95
	0.196	–	–	70	–	–	90
	0.294	–	–	65	–	–	85
2	Exposed single-layer field winding	–	90	–	–	110	–
3	Field winding housed in cylindrical rotor	–	90	–	–	110	–
4	Iron core or other mechanical part near insulated winding	80	–	80	100	–	100
5	Uninsulated short-circuited winding, iron core or other mechanical part not near insulated winding; brush and brush holder	Temperature causing no mechanical troubles or damages to near insulating materials					
6	Slip ring	80	–	–	90	–	–

3. Direct cooling type synchronous machines (Unit: ℃)

Item	Machine parts	Class B insulation				
		Water cooling		Hydrogen cooling		
		Thermometer method	Embedded thermometer method	Thermometer method	Resistance method	Embedded thermometer method
1	Coolant	45	45	70	–	70
2	Stator winding	–	80	–	–	80
3	Field winding housed in cylindrical rotor	–	–	–	70	–
4	Iron core or other mechanical part near insulated winding	80	–	80	–	–
5	Uninsulated short-circuited coil, iron core or other mechanical part not near insulated winding; brush and brush holder	Temperature causing no mechanical troubles or damages to near insulating materials				
6	Slip ring	80	–	80	–	–

16-25 Dielectric Strength of Electrical Equipment

1. Test voltages for winding of rotating machines (synchronous and induction machines) (JEC 114-1979, JEC 37-1979, JEC2100-1993)

Apply test voltage shown below between the charge part of a rotating machine and ground or between charge parts for a minute to test the dielectric strength.

Item	Machine and charge part classes		Test voltages (Effective values)
1	Armature winding	(a) Less than 1 kW or 1 kVA rating	$2E+500$V (1000 V at least)
		(b) Not less than 1 kW or 1 kVA rating, less than 10000 kW or 10000 kVA	$2E+1{,}000$V (1500 V at least)
		(c) Not less than 10000 kW or 10000 kVA rating	
		(i) $E\leq 2{,}000$V	$2E+1{,}000$V (1500 V at least)
		(ii) $2{,}000<E\leq 6{,}000$V	$2.5E$
		(iii) $E>6{,}000$V	$2E+3{,}000$V
2	Field winding	(a) When not starting as an induction motor	
		(i) In the case of the system with which the field winding of a synchronous machine is excited through a thyristor rectifier	Larger one of $10E_x$ and $2E_{AC}+1{,}000$V (1,500V at least, 5,000V at most)
		(ii) In case of except (i)	$10E_x$ (1,500V at least, 5,000V at most)
		(b) When starting as an induction motor	
		(i) When starting as field winding short-circuit	$2E_t$ (1,500V at least, 5,000V at most)
		(ii) When starting as field winding open-circuit	$2E_t+1{,}000$V (1500 V at least)
3	Insulated starting winding		$2E_t+1{,}000$V (1500 V at least)

Remark: In the above table, E expresses the armature rated voltage of the main machine, E_x expresses the rated voltage of excitation equipment and E_{AC} expresses the highest voltage (effective value) of a thyristor rectifier.

2. Test voltages between the conductive parts and ground of electric machines (JEC 0102)

Nominal voltage (kV)	Test voltage (kV)		
	Lightning impulse withstand voltage test	Short time commercial frequency withstand voltage test(effective value)	Long time commercial frequency withstand voltage test(effective value)
3.3	30	10	—
	45	16	
6.6	45	16	—
	60	22	
11	75	28	—
	90		
22	100	50	—
	125		
	150		
33	150	70	—
	170		
	200		
66	350	140	—
77	400	160	—
110	550	230	—
154	750	325	—
187	650	—	170-225-170
	750		
220	750	—	200-265-200
	900		
275	950	—	250-330-250
	1,050		
500	1,300	—	475-635-475
	1,425		
	1,550		
	1,800		

Remark: 1. About application classification when two or more examination voltage values correspond to the nominal voltage, the view was shown in description 2.

2. Nominal voltage of 187kV or more is carried out for the effective grounding system.

3. About the nominal voltage of 500kV, although there are 2 cases 525kV and 550kV as the highest voltage of a system, test voltage presupposes that it is the same.

3. On-site test voltages in compliance with Engineering Standards for Electric Facilities (cited from Ordinance of Ministry of International Trade and Industry No.52 "Engineering Standards for Electric Facilities" issued in Mar. 1997

Cable runs

Article 14

(1) Low voltage cable runs

Voltage classes for cable runs		Insulation resistances
Max. 300V	If the voltage to the ground is below 150V (Voltage between the cable and ground for an earthed cable run, or voltagebetween the cables for a non-earthed cable run. This also applies to the following.)	0.1MΩ
	Others	0.2MΩ
Over 300V		0.4MΩ

(2) High voltage and extra-high tension voltage cable runs (Test voltage is applied between the cable run and ground continuously for 10 minutes.)

Cable run types	Test voltages
1 Cable runs for the maximum operation voltages not more than 7000V	Voltage 1.5 times as high as the maximum operation voltage
2 Grounded neutral cable runs for the maximum operation voltages over 7000 V and not more than 15000 V (Only cable runs having neutral lines which are grounded at plural points)	Voltage 0.92 times as high as the maximum operation voltage
3 Cable runs for the maximum operation voltages over 7000 V and not more than 60000 V (Except the cable runs shown in item 2 above)	Voltage 1.25 times as high as the maximum operation voltage (10500 V if the voltage is below 10500V)
4 Non-grounded neutral cable runs for the maximum operation voltages over 60000 V (Including cable runs using potential transformers for grounding)	Voltage 1.25 times as high as the maximum operation voltage
5 Grounded neutral cable runs for the maximum operation voltage over 60000 V (Except cable runs using potential transformers for grounding and shown in items 6 and 7)	Voltage 1.1 times as high as the maximum operation voltage (75000 V if the voltage is below 75000 V)
6 Directly grounded neutral cable runs for the maximum operation voltages over 170000 V (Except cable runs shown in item 7)	Voltage 0.72 times as high as the maximum operation voltage
7 Directly grounded neutral cable runs for the maximum operation voltages over 170000 V which belong to the power plants or equivalent facilities directly grounded with the neutral points	Voltage 0.64 times as high as the maximum operation voltage

8 Cable runs are connected to rectifier with which the maximum use voltage exceeds 60,000V	Cable runs are connected to the AC side and DC high-voltage side are the AC voltage 1.1 times of the maximum operation voltage, or the DC voltage 1.1 times of the DC voltage of operating.
	Cable runs used as the neutral point by the side of a direct current or return wire is the value calculated by the formula specified below.

The formula of the dielectric strength test voltage of low voltage direct-current side cable runs by regulation of the above 8 carries out as follows.

$E \doteqdot V \times 1/\sqrt{2} \times 0.5 \times 1.2$

Where, E : AC test voltage (in V)

V is the crest value of the abnormal voltage of the AC which appears in cable runs which serves as a neutral point or return wire at the time of inverter commutation failure. (in V)

However, test voltage in the case of using a cable for an electric wire is made one twice the direct-current voltage of E.

Article 15 Rotating machines and rectifiers

Types			Test voltages	Test methods
Rotating machines	Generators, motors, phase modifiers and other rotating machines (except rotary current transformers)	Rotating machines for the maximum operation voltages not more than 7000 V	Voltage 1.5 times as high as the maximum operation voltage (500 V if the voltage is below 500 V)	Apply test voltage between winding and ground for 10 minutes continuously.
		Rotating machines for the maximum operation voltages over 7000 V	Voltage 1.25 times as high as the maximum operation voltage(10500 V if the voltage is below 10500 V)	
	Rotary current transformers		AC voltage as high as the maximum DC operation voltage (500 V if the voltage is below 500 V)	
Rectifier		Maximum operation voltages not more than 60,000V	AC voltage as high as the maximum DC operation voltage (500 V if the voltage is below 500 V)	
		Maximum operation voltages over 60,000V	AC voltage 1.1 times of the maximum operation voltage of AC side, or the DC voltage 1.1 times of the maximum use operation voltage of DC side.	It adds between AC side and DC high-voltage side terminal and the ground for 10 minutes continuously.

Article 17 Transformer

Types	Test voltages	Test methods
1 Windings for the maximum operation voltages not more than 7000 V	Voltage 1.5 times as high as the maximum operation voltage (500 V if the voltage is below 500 V)	Apply test voltage between the test winding and other winding and between the iron core and outer case for 10 minutes continuously.
2 Windings for the maximum operation voltages over 7000 V and not more than 15000 V which are connected with grounded neutral cable runs (Only cable runs having neutral lines which are grounded at plural points)	Voltage 0.92 times as high as the maximum operation voltage	
3 Windings for the maximum operation voltages over 7000 V and not more than 60000 V (Except the windings shown in item 2 above)	Voltage 1.25 times as high as the maximum operation voltage (10500 V if the voltage is below 10500 V)	
4 Windings for the maximum operation voltages over 60000 V which are connected with non-grounded neutral cable runs (Including cable runs using potential transformers for grounding)	Voltage 1.25 times as high as the maximum operation voltage	
5 Windings for the maximum operation voltages over 60000 V (star connection and Scott connection windings only) which are connected with grounded neutral cable runs (except cable runs using potential transformers for grounding and shown in item 6) and are provided with lightning conductors at the neutral points (star connection windings) or at the junctions of the main end coils and T-shape end coils (Scott connection windings)	Voltage 1.1 times as high as the maximum operation voltage (75000 V if the voltage is below 75000 V)	Ground any terminal of the winding to be tested other than the neutral point (or junction of the T-shape end coil and main end coil or a Scott connection type winding; same in this item), any terminal of another winding (each winding if there are two or more other windings), iron core, and outer casing. Apply 3-phase AC test voltage to the terminals other than the neutral point of the winding to be tested for 10 minutes continuously. If it is difficult to apply 3-phase AC test voltage, you may apply single-phase AC test voltage between the ground and any terminal other than the neutral point of the winding to be tested and the grounded terminals for 10 minutes continuously and then apply voltage 0.64 times (or 0.96 times for Scott connection winding) as high as the maximum operation voltage between the neutral point and ground for 10 minutes continuously.

6 Windings for the maximum operation voltages over 170000 V which are connected with directly grounded neutral cable runs and have lightning conductors at the neutral points (Only applicable to star connection type windings.)	Voltage 0.72 times as high as the maximum operation voltage	Ground the neutral point terminal of the winding to be tested, any terminal of another winding (each winding if there are two or more other windings), iron core, and outer casing. Apply test voltage to any terminal other than the neutral point of the winding to be tested and ground for 10 minutes continuously. Then, apply voltage 0.3 times as high as the maximum operation voltage between the neutral point and ground for 10 minutes continuously.
7 Windings for the maximum operation voltages over 170000 V (star connection type windings only) which are connected with directly grounded neutral cable runs and directly grounded at the neutral points	Voltage 0.64 times as high as the maximum operation voltage	Ground the neutral point terminal of the winding to be tested, any terminal of another winding (each winding if there are two or more other windings), iron core and outer casing. Apply test voltage to any terminal other than the neutral point of the winding to be tested and ground for 10 minutes continuously.
8 Winding linked to rectifier with which the maximum operation voltage exceeds 60,000V.	Voltage by the side of AC of a rectifier 1.1 times the AC voltage of the maximum operation, or the voltage by the side of a D C of a rectifier 1.1 times the D C voltage of the maximum operation.	Apply test voltage to the winding to be tested, another winding, core and outer casing for 10 minutes continuously.
9 Other windings	Voltage 1.1 times as high as the maximum operation voltage (75,000V if the voltage is below 75,000V)	Apply test voltage to the winding to be tested, another winding, core and outer casing for 10 minutes continuously.

Article 18 Instruments, etc. (Apply test voltage between the live parts and ground for 10 minutes continuously)

Instrument types	Test voltages
1 Instruments for the maximum operation voltages not more than 7000 V	Voltage 1.5 times as high as the maximum operation voltage (Or, DC voltage 1.5 times as high as or AC voltage as high as the maximum operation voltage for AC parts of DC instruments; 500 V if the voltage is below 500 V)
2 Instruments for the maximum operation voltages over 7000 V and not more than 15000 V which are connected wiht grounded neutral cable runs (Only cable runs having neutral lines which are grounded at plural points)	Voltage 0.92 times as high as the maximum operation voltage
3 Instruments for the maximum operation voltages over 7000 V and not more than 60000 V (Except the cable runs shown in item 2 above)	Voltage 1.25 times as high as the maximum operation voltage (10500 V if the voltage is below 10500 V)
4 Instruments for the maximum operation voltages over 60000 V which are connected with non-grounded neutral cable runs (including cable runs using potential transformers for grounding)	Voltage 1.25 times as high as the maximum operation voltage
5 Instruments for the maximum operation voltages over 60000 V which are connected with grounded neutral cable runs (except cable runs using potential transformers for grounding) (Except those shown in items 6 and 7)	Voltage 1.1 times as high as the maximum operation voltage (75000 V if the voltage is below 75000 V)
6 Instruments for the maximum operation voltages over 170000 V which are connected with directly grounded neutral cable runs (Except those shown in item 7)	Voltage 0.72 times as high as the maximum operation voltage
7 Instruments for the maximum operation voltages over 170000 V which are connected with directly grounded neutral cable runs of the power plants, transformer stations or equivalent facilities with directly grounded neutral points	Voltage 0.64 times as high as the maximum operation voltage
8 Instruments, etc. are connected to AC side and DC side of cable runs of rectifier whose maximum operation voltage exceeds 60,000V.	Instruments, etc. are connected to the AC side and DC high-voltage side cable runs are the AC voltage 1.1 times of the maximum operation voltage, or the DC voltage 1.1 times the maximum operation voltage of DC voltage side.
	Instruments, etc. are connected to DC low voltage side cable runs are the value calculated by the formula specified to the article 14.

The following parts are not included: Transformers for grounded instruments, coupling capacitors for power transmission lines, lightning arrestors (including surge absorbers), and coupling reactors for power transmission lines.

16-26 Insulation Resistance of Rotating Machines

IEEE-43-1974 specifies the minimum insulation resistance of a rotating machine as shown below.

$$Rm = kV+1 \quad [M\Omega]$$

Where, Rm: Insulation resistance at 40℃

kV: Rated voltage of rotating machine (in kV)

Also specifies the temperature correction factor, which is roughly calculated as shown below.

$$Kt = \frac{1}{2^{(\frac{\theta}{10}-4)}}$$

Therefore, we recommend that insulation resistance at a temperature of θ℃ be determined as shown below.

$$R_{\theta} \geqq \frac{kV+1}{2^{(\frac{\theta}{10}-4)}} \quad [M\Omega]$$

Where R_{θ} : Insulation resistance at a temperature of θ℃

kV: Rated voltage of rotating machine(in kV)

θ : Winding temperature(℃) in insulation measurement

16-27 Device Numbers of Automatic Control Circuit for Thermal Power Plants (JEM 1094-1994, JEM 1090-1994)

1 Device number

Basic device number	Device number	Device title
1	1	Main controller or switch
2	2	Time limit relay for starting or closing or time delay relay for starting or closing
3	–	Control switch
	3-28 B	Control switch (for reset of bell relay)
	3-28 Z	Control switch (for reset of buzzer relay)
	3-30	Control switch (for reset of indicator)
	3-30 L	Control switch (for reset of lamp indicator)
	3-41	Control switch (for field circuit breaker)
	3-41M	Control switch (for main field circuit breaker)
	3-41 S	Control switch (for spare field circuit breaker)
	3-52	Control switch (for AC circuit breaker)
	3-66 F	Control switch (for reset of flicker relay)
	3-86	Control switch (for reset of lock-out relay)
	3-86 B	Control switch (for reset of lock-out relay for boiler)
	3-86 G	Control switch (for reset of lock-out relay for generator)
	3-86 T	Control switch (for reset of lock-out relay for turbine)
	3-88	Control switch (for contactor of auxiliary machine)
	3-89	Control switch (for disconnection switch)
	3 R	Control switch (for reset of general use)
4	4	Controller for main control circuit or relay
5	5	Stopping switch or relay
	5 B	Stopping switch or relay (for boiler)
	5 E	Emergency stopping switch
	5 P	Panic switch
	5 T	Stopping switch or relay (for turbine)
6	6	Circuit breaker for starting, switch, contactor or relay
7	–	Control switch
	7-55	Control switch (for automatic power factor regulator)
	7-65	Control switch (for regulator)
	7-70	Control switch (for field regulator of generator)
	7-70 E	Control switch (for field regulator of exciter or manual regulator of exciter)
	7-70M	Control switch (for field regulator of main exciter)
	7-70M S	Control switch (for sub-exciter field regulator of main exciter)
	7-70 S	Control switch (for field regulator of spare exciter)
	7-70 S S	Control switch (for sub-exciter field regulator of spare exciter)
	7-77	Control switch (for load regulator)
	7-90 R	Control switch (for voltage setting of automatic voltage regulator)
	7- I R	Control switch (for induction voltage regulator)
8	8	Switch of control power source
9	9	Field reversing switch, contactor or relay
10	10	Sequential switch or programmable controller
	10 P	Programmable controller
11	11	Test switch or relay
	11-41	Test switch (for field circuit breaker)
	11-52	Test switch (for circuit breaker)
	11 J	Jogging switch
	11 L	Test switch (for lamp check)
12	12	Over speed switch or relay
13	13	Synchronous speed switch or relay
14	14	Low speed switch or relay
15	–	Speed regulator
	15	Automatic speed matching equipment
	15 L	Control relay for automatic speed matching equipment (decrease)
	15 R	Control relay for automatic speed matching equipment (increase)
16	16	Pilot wire watch relay

Basic device number	Device number	Device title
17	17	Pilot wire relay
18	18	Increasing or decreasing contactor or increasing or decreasing relay
19	19	Changeover contactor of start-operation or relay
20	20	Auxiliary machine valve
	20A	Air valve
	20B	Bypass valve
	20C	Electromagnetic valve of control
	20F	Fuel valve
	20G	Gas valve
	20Q	Oil valve
	20S	Steam valve
	20SS	Steam safety valve
	20V	Vacuum valve
	20W	Water valve
21	—	Main machine valve
	21B	Boiler main steam valve
	21F	Fuel cut valve
	21T	Turbine main steam valve
	21TR	Turbine reheat steam stop valve
	21W	Boiler main feed water valve
22	22	Earth leakage breaker, contactor or relay
23	23	Temperature controller or relay
	23Q	Oil temperature controller
24	24	Tap changer
	24LR	Tap changer (for on-load voltage regulator)
25	—	Synchronous detector
	25	Synchronous detector or automatic synchronous closing equipment
	25A	Automatic synchronous closing equipment
	25B	Automatic synchronous closing equipment (for backup)
26	26	Temperature switch for static machine or relay
	26LR	Temperature switch or Relay (for On-Load voltage regulator)
	26RG	Temperature switch or Relay (for recirculation gas)
	26SSH	Temperature switch or Relay (for Superheating steam)
	26T	Temperature switch or Relay (for Transformer)
27	27	AC undervoltage relay
	27C	AC undervoltage relay (for control power source)
28	28	Alarm device

Basic device number	Device number	Device title
28	28B	Bell relay
	28F	A fire detector
	28LA	Lightning arrester action detector
	28Z	Buzzer relay
29	29	Fire extinguisher
30	30	Status of equipment or fault annunciator
	30F	Fault annunciator
	30S	Status annunciator
31	31	Field change breaker, switch, contactor or relay
32	32	DC reverse current relay
33	33	Position detector switch or equipment
	33C	Level switch (for coal)
	33NL	Position detector switch (for no load)
	33Q	Oil level detector switch or equipment
	33T	Torque switch
	33W	Water level detector switch or equipment
34	34	Motor－operated sequence controller
	34B	Boiler starting sequence controller
35	35	Blush handling equipment or slip ring short circuit equipment
36	36	Polarity relay
37	37	Undercurrent relay
	37B	Automatic trip detector of distribution circuit breaker
	37F	Fuse blow detector
38	38	Bearing temperature switch or relay
39	39	Mechanical abnormal monitoring equipment or detect switch
40	40	Field current relay or field loss relay
41	41	Field circuit breaker, switch or contactor
	41A	Field switch or contactor (for put field amplifier in circuit)
	41C	Closing coil for device No.41
	41D	Differential field circuit breaker, switch or contactor
	41I	Circuit breaker for initial excitation, switch or contactor
	41M	Field circuit breaker (for main exciter)
	41MP	Field circuit breaker (for main exciter of No.1 generator)
	41MS	Field circuit breaker (for main exciter of No.2 generator)
	41R	Circuit breaker, switch or contactor (for field control)
	41S	Field circuit breaker (for spare exciter)
	41SP	Field circuit breaker (for spare exciter of No.1 generator)

Basic device number	Device number	Device title
41	41 S S	Field circuit breaker (for spare exciter of No.2 generator)
	41 T	Trip coil for device No.41
42	42	Circuit breaker for operation, switch or contactor
43	43	Changeover switch for control circuit, contactor, or relay)
	43-25	Changeover switch (for synchronously detect)
	43-55	Changeover switch (for Automatic power factor regulator)
	43-64 E	Changeover switch (for exciting circuit ground fault relay)
	43-65	Changeover switch (for governor)
	43-77	Changeover switch (for load regulator)
	43-87 B	Changeover switch (for bus protection)
	43-90	Changeover switch (for automatic voltage regulator)
	43-95	Changeover switch (for frequency relay)
	43 A M	Changeover switch (for manual-auto)
	43 L	Changeover switch (for Lock)
	43 R	Changeover switch (for direct-remote)
44	44	Distance relay
	44 G	Distance relay (for generator back up protection)
45	45	DC Overvoltage relay
46	46	Negative phase relay or phase-unbalance current relay
	46 G	Negative phase relay (for generator)
47	47	Open phase relay or negative phase voltage relay
48	48	Jam detector relay
	48-24	Jam detector relay (for tap changer)
	48-25	Jam detector relay (for parallel synchronize)
49	49	Temperature switch for rotating machine or relay or over load relay
	49 R	Temperature relay (for rotor)
	49 S	Temperature relay (for stator)
	49 T	Temperature relay (for low pressure exhaust room)
50	50	Short-circuit selection relay or ground fault selection relay
	50 G	Ground fault selection relay
	50 S	Short-circuit selection relay
51	—	AC overcurrent relay or ground fault overcurrent relay
	51	AC overcurrent relay
	51 B	AC overcurrent relay (for bus line)
	51 G	AC overcurrent relay (for generator) or ground fault overcurrent relay
	51 H	AC overcurrent relay (for house transformer)
	51 N	AC overcurrent relay (for neutral points)

Basic device number	Device number	Device title
51	51 S	AC overcurrent relay (for starting transformer)
	51 V	Voltage control AC overcurrent relay
52	52	AC circuit breaker or contactor
	52 C	Closing coil for device No.52
	52 G	AC circuit breaker (for generator)
	52 H	AC circuit breaker (for house transformer)
	52 N	AC circuit breaker (for neutral points)
	52 N R	AC circuit breaker (for neutral points resistor)
	52 P C	AC circuit breaker (for Petersen coil)
	52 S	AC circuit breaker (for starting transformer)
	52 T	Trip coil for device No.52
53	53	Exciting relay or excitation relay
54	54	High speed circuit breaker
55	55	Automatic power factor regulator or power factor relay
	55 L	Handling relay for device No.55 (lower)
	55 R	Handling relay for device No.55 (raise)
56	56	Slip detector or step out relay
57	57	Automatic current regulator or current relay
58	58	(spare number)
59	59	AC overvoltage relay
	59 F	Voltage/frequency limiter or relay
	59 G	AC overvoltage relay (for generator)
60	60	Automatic voltage balance regulator or voltage balance relay
	60 L	Handling relay for device No.60 (decrease)
	60 R	Handling relay for device No.60 (increase)
	60 V T	Voltage balance relay (for voltage transformer fault detect)
61	61	Automatic current balance regulator or current balance relay
62	62	Time limit relay for stop or open circuit or time delay relay for stop or open circuit
63	63	Pressure switch or relay
	63 A	Air pressure switch or relay
	63 D	Differential pressure switch or relay
	63 F	Fuel oil pressure switch or relay
	63 G	Gas pressure switch or relay
	63 Q	Oil pressure switch or relay
	63 V	Vacuum switch or relay
	63 W	Water pressure switch or relay
64	64	Ground fault overvoltage relay

Basic device number	Device number	Device title
64	64B	Ground fault overvoltage relay (for bus line)
	64D	DC control circuit ground fault relay
	64E	Exciting circuit ground fault relay
	64F	Field circuit ground fault relay
	64G	Ground fault overvoltage relay (for generator)
	64H	Ground fault overvoltage relay (for House transformer)
	64N	Ground fault overvoltage relay (for neutral points)
	64S	Ground fault overvoltage relay (for starting transformer)
65	65	Regulator
	65L	Handling relay for device No.65 (reduce)
	65R	Handling relay for device No.65 (increase)
	65M	Speed control motor for regulator
66	66	Intermittence relay
	66F	Flicker relay
67	67	AC power flow relay or ground directional relay
	67G	AC power flow relay (for generator) or ground directional relay
	67RG	AC reverse power relay
68	68	Mixed detector
	68A-H	Hydrogen purity detector
	68W-Q	Mixed detector (oil)
69	69	Flow switch or relay
	69A	Air flow switch or relay
	69F	Fuel flow switch or relay
	69G	Gas flow switch or relay
	69Q	Hot water quantity switch or relay
	69W	Stream switch or relay
70	—	Adjustable resister
	70	Field regulator
	70E	Field regulator (for field regulator of exciter or manual regulator of exciter)
71	71	Rectifier element fault detector
72	72	DC circuit breaker or contactor
73	73	Circuit breaker of short circuit or contactor
74	—	Control valve
	74	Control valve or vane
	74A	Air control valve
	74G	Gas control valve

Basic device number	Device number	Device title
74	74Q	Oil control valve
	74W	Water control valve
75	75	Controller
76	76	DC over current relay
77	77	Load regulator
	77L	Handling relay for device No.77 (decrease)
	77R	Handling relay for device No.77 (increase)
	77M	Motor for device No.77
78	78	Carrier protection phase comparison relay
79	79	AC reclosing relay
80	80	DC undervoltage relay
	80C	DC undervoltage relay (for control power source)
81	81	Running gear of governor
82	82	DC reclosing relay
83	—	Selection switch, contactor, relay
	83	Changeover switch of power source or contactor
84	84	Voltage relay
85	85	Signal relay
	85F	Flame detector
86	86	Lock-out relay
	86B	Lock-out relay (for cut off boiler fuel)
	86G	Lock-out relay (for generator)
	86T	Lock-out relay (for turbine)
87	87	Differential relay
	87B	Differential relay (for bus line)
	87G	Differential relay (for generator)
	87H	Differential relay (for house transformer)
	87M	Differential relay (for main transformer)
	87S	Differential relay (for starting transformer)
88	88	Circuit breaker for auxiliary machine, switch, contactor or relay
	88C	Circuit breaker for auxiliary machine, switch, contactor or relay (for closing side)
	88F	Circuit breaker for auxiliary machine, switch, contactor or relay (for conversion, forward, up, increase or right side)
	88O	Circuit breaker for auxiliary machine, switch, contactor or relay (for opening side)
	88R	Circuit breaker for auxiliary machine, switch, contactor or relay (for inversion, retreat, down, decrease or left side)
89	89	Disconnection switch or load switch

Basic device number	Device number	Device title
89	89 C	Closing coil for device No.89
	89- I L	Interlock magnet for device No.89
	89 T	Trip coil for device No.89
90	90	Automatic voltage regulator or automatic voltage regulate relay
	90 R	Voltage setting for device No.90
	90 R M	Motor for handling for device No.90
91	91	Automatic voltage regulator or power relay
	91 P	Automatic voltage regulator or power relay
	91 Q	Automatic reactive voltage regulator or reactive power relay
92	92	Door or damper
	92 A	Air damper
	92 C	Coal pulverizer damper
	92 G	Gas damper
93	93	(Spare number)
94	94	Tripfree contactor or relay
95	95	Automatic frequency regulator or frequency relay
96	–	Fault detector for inside of static machine
	96	Buchholtz's relay
	96-1	Buchholtz's relay (for annunciator)
	96-2	Buchholtz's relay (for tripping)
	96 P	Sudden pressure relay
	96 V	Pressure relief valve
97	97	Runner
98	98	Connector
99	99	Automatic recorder
	99 F	Automatic fault recorder
	99 S	Automatic movement recorder

2 Letter symbols

Letter symbols in the case of expressing devices other than the above-mentioned device number is carried out as follows.

Letter symbols	Contents
A B C	Automatic boiler controller
A C C	Automatic combustion controller
A C R	Automatic current regulator
A F C	Automatic frequency controller
A F U	Automatic follow-up device
A L R	Automatic load regulator
A P C	Automatic power controller
A P F R	Automatic power factor regulator
A P R	Automatic power regulator
A Q R	Automatic Q regulator
A S R	Automatic speed regulator
A T S	Automatic turbine start-up controller
A V M	Automatic voltage matcher
A V Q C	Automatic voltage and Q controller
A V Q R	Automatic voltage and Q regulator
A V R	Automatic voltage regulator
C C C	Cross-current compensator
C D T	Cyclic digital telemeter
C P T	Computer
E D C	Automatic economic load dispatching controller
E H C	Electro hydraulic controller
E H G	Electro hydraulic governor
F C B	Fast cut back
L D C	Line drop compensator
O E L	Over excitation limiter
P I O	Process input／output
P M G	Permanent magnet generator
P S S	Power system stabilizer
T C	Tele-control
T M	Tele-metering
T Q R	Total Q regulator
U E L	Under excitation limiter

3 Auxiliary symbols

The auxiliary symbols attached when the kind, the character, use, etc. of an device are shown is carried out as follows.

Auxiliary symbols	Contents	Auxiliary symbols	Contents
A	Alternating current	A	Air flow
	Automatic		Amplification
	Air		Ampere
	Air compressor		Analogue
	Air cooler	B	Breaking of wire
	Air pressure		Bypass

Auxiliary symbols	Contents
B	Bell
	Battery
	Bus
	Braking
	Bearing
	Break
	Block
C	Common
	Cooling
	Carrier
	Rotary condenser
	Closing
	Compensation
	Control
	Close
	Capacitor (Condenser)
CA	Current compensation
CH	Charge
	Line charge
CO_2	Carbon-dioxide gas
CPU	Central Processing Unit
D	Direct current
	Direct
	Dial
	Differential
	Digital
	Directional
E	Emergency
	Excitation
F	Fire
	Fault
	Fuse
	Frequency
	Fan
	Feeder
	Flasher.Flashing
	Forward

Auxiliary symbols	Contents
FL	Filter
G	Grease
	Ground fault
	Gas
	Generator
H	High
	House. Station service
	Heater
	Hold
I	Internal
	Initial
IL	Interlock
	Interlocking
IR	Induction voltage regulator
INV	Inverter
J	Joint
	Jet
K	Tertiary
	Casing
L	Lamp. Light
	Leakage. Leak
	Lower, Decrease
	Lock-out. Lock
	Low
	Line
	Load
	Left
LA	Lightning arrester
LD	Leading
LG	Lagging
LR	On-load voltage regulator
M	Meter
	Master. Main
	Mho element
	Motive power.
	Motive force

Auxiliary symbols	Contents
M	Motor
	Manual
N	Nitrogen
	Neutral
	Negative
O	Ohm element
	External (Outer)
	Open
	Operation
P	Program
	Pump
	Primary
	Positive
	Power
	Power flow
	Pressure
	Parallel
	Pulse
PC	Petersen coil
	Programmable controller
PW	Pilot wire
Q	Oil
	Oil pressure
	Oil level
	Oil flow
	Pressur oil equipment
	Pressure oil pump
	Reactive Power
R	Reset
	Raise, Increase
	Regulating
	Remote
	Receiving
	Rotor
	Reactor
	Receiving
	Resistor

Auxiliary symbols	Contents
R	Reverse
	Relay
	Room
	Rectifier
	Right
S	Strainer
	Solenoid
	Status. Operating Sequence
	Synchronism.
	Synchronizing
	Short circuit
	Secondary
	Speed
	Sub
	Sending
	Stator
	Single
	Selective
	Slip
	Seal
	Spare
	Starting
SH	Space heater
SU	Starting unit
T	Transformer
	Temperature
	Time lag
	Time delay
	Tripping. Trip Release
	Turbine
	Tie
	Torque
U	Use
UPS	Uninterruptible power systems
V	Voltage
	Vacuum
	Valve

Auxiliary symbols	Contents	Auxiliary symbols	Contents
VIB	Vibration	WC	Cooling water
W	Water		Cooling water pump
	Water level	Z	Buzzer
	Water flow		Impedance
	Water pressure	A.B.C.	——
	Water feeding	X.Y.Z.	
	Water drain	ϕ	Phase

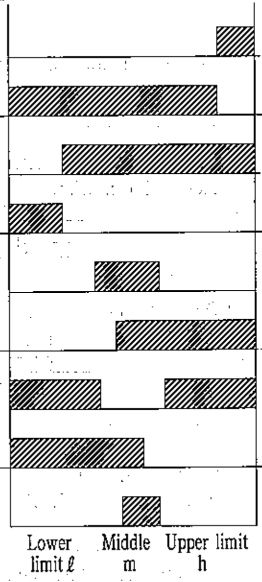
4. Auxiliary number

The auxiliary number in a certain case that two or more same things being within the same equipment is made into "1", "2", "3", and ...

5. Contact symbols of Auxiliary Switch or Auxiliary Contactor

Contact symbol in case an auxiliary switch or an auxiliary contactor is shown as a kind of an auxiliary symbol is carried out as follows.

Contact symbol	Explanation	Example
a	The thing which makes the same a subject, opening and closing, or operation. Or the thing which closes a circuit when it energized.	52a: AC circuit breaker forward auxiliary contactor 52b: AC circuit breaker reverse auxiliary contactor
b	The thing which carries out opposite operation of a.	

Contact symbol	Explanation	Example	
h	The thing which open or close in the upper limit.		h_a : The thing which close in the upper limit h_b : The thing which close in the upper limit
ℓ	The thing which open or close in the lower limit.		ℓ_a : The thing which open in the lower limit. ℓ_b : The thing which close in the lower limit.
m	The thing which open or close in a middle position.		m_a : (1)The thing which closes in the range with middle position. (2)The thing which closes above with middle position .
n	The thing which contacts in a middle position.		m_b : (1)The thing which open in the range with middle position. (2)The thing which open above with middle position .
r	The thing which carries out remains contact.		n : The thing which contacts in a middle position.

Note: You may express the alphabet of a contact symbol using a capital letter.

6. Configuration of device numbers

Device numbers constitute by the following method and are expressed

(1) Basic device numbers — Example: 22 (earth leakage relay)

(2) Basic device numbers — Auxiliary symbol — Example: 88A (contactor for air compressor)

(3) Basic device numbers — Basic device numbers — Example: 43-95 (changeover switch for frequency relay)

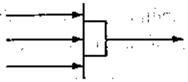
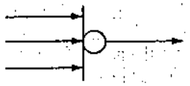
(4) Basic device numbers — Basic device numbers — Auxiliary symbol — Example: 3-52G (control switch for generator circuit breaker)

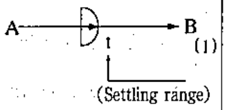
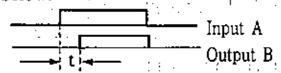
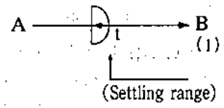
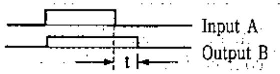
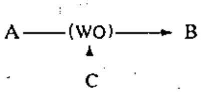
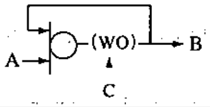
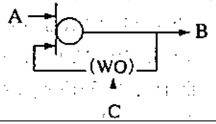
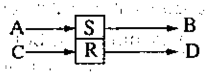
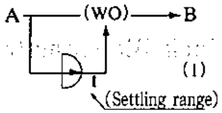
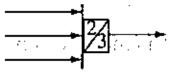
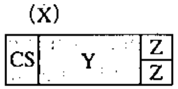
(5) Basic device numbers — Auxiliary symbol — Auxiliary symbol — Example: 20WC (cooling water valve)

Note: When attaching an auxiliary number, it attaches to the end of the above-mentioned composition.
Example: 20WC3 (cooling-water valve 3)

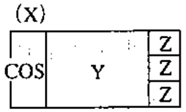
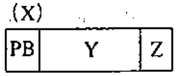
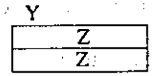
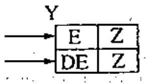
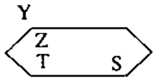
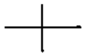
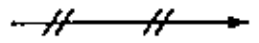
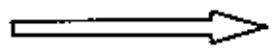
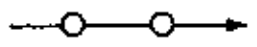
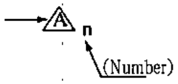
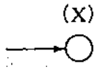
16-28 Symbols used in Interlock Block Diagrams (JEM 1402-1996)

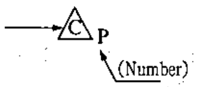
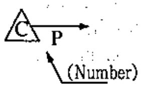
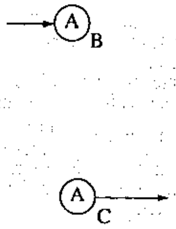
1. Symbols used in interlock block diagrams

Functions	Symbols	Descriptions
A N D		Output is made when all input conditions are met.
O R		Output is made when one of the input conditions at least is met.

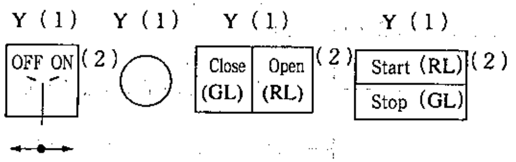
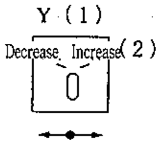
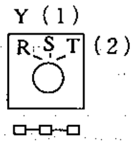
Functions	Symbols	Descriptions
N O T		Reverse condition of the input condition is output.
Delayed operation		Output is made to B after time (t) when condition A is met as shown below. 
Delayed return		Output to B is cut off after time (t) when condition A is nullified as shown below. 
Wipe out		Condition A is output to B when condition C is not met. It is not output to B when condition C is met.
Memory (1)		Condition A is stored and output to B when condition C is not met. Self-storage is reset and condition A is not output to B when condition C is met. (Priority is given to C.)
Memory (2)		Condition A is stored and output to B when condition C is not met. Self-storage is reset when condition C is met and condition A is output to B only when condition A is met. (Priority is given to A.)
Memory (3)		When condition A is met, output to D is cut off and output is made to B, which status is maintained until condition C is met. When condition C is met, output to B is cut off and output is made to D, which status is maintained until condition A is met.
One shot		Output is made to B when condition A is met and is cut off after time (t). 
Redundancy		Output is made when more than a specified number of input conditions are met. (The left symbol shows an example of two out of three)
Control switch		The switch returns to the center automatically, in principle. (X) indicates the installation location (such as a location symbol or the like). Y indicates the name of equipment to be handled. Z indicates the name of handling (such as activation, inactivation and etc.)

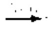
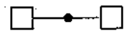
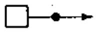
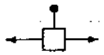
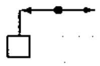
Note: Setting values should desirably be specified in parentheses.

Functions	Symbols	Descriptions
Changeover switch		(X) indicates the installation location (such as a location symbol and etc.). Y indicates the name of equipment to be operated. Z indicates the name of handling (such as activation, deactivation and etc.).
Push button switch		
Controlled equipment		Equipment to be controlled. Y indicates the character code of equipment to be controlled. Z indicates the name of operation (such as starting, stopping, opening, closing and etc.).
Solenoid valve		Y indicates the name of the solenoid valve. E: Energize (Electrification) DE: De-energize (No electrification) Z which shows an operation name (starting, stop, open, closed etc.).
Condition signal		Y indicates an instrument number, which is specified if there is. Z indicates the name of the condition signal. T indicates the judgment condition (such as >, ≥, <, ≤ or the like). S indicates the set value or signal occurrence operation.
Transmission signal		Electric signal  Indicates branching of a signal.  Indicates that a signal is not branched.
		Air signal
		Mechanical signal
		Oil pressure signal
Alarm		n indicates the number of a column where the alarm is written. Indicator lamp
Display lamp		(X) indicates the installation location (such as a location symbol or the like). The lamp color (such as RL, GL and etc.) is written in the circle. RL: Red, GL: green, OL: Orange, YL: Yellow, WL: White, etc.

Functions	Symbols	Descriptions
Computer input		P indicates the input point number of a computer.
Computer output		P indicates the output point number of a computer.
Match mark		The match mark indicates connection of a signal. Transmission sheet A indicates the match mark. B indicates the reception sheet. (There may be more than two reception sheets.) Reception sheet A indicates the match mark. C indicates the transmission sheet.

2. Symbols of handling devices

	Symbols	Descriptions
Types		Lamp colors shall be specified for operation switches, pushbuttons, and switches with indicator lamps.
		Control switch
		Selector switch
Functions		Original point of a handling switch
		Hold or lock position

	Symbols	Descriptions
Functions		Automatic return (by spring)
		Automatic return by twisting to right and left
		Manual return by twisting to right and left
		Manual return by twisting to left, automatic return by twisting to right
		Pulling, then twisting to right and left Automatic return by pulling or twisting to right and left
		Pulling, then twisting to right and left. Pull-out position maintained, automatic return by twisting to right and left
		Automatic return by twisting to right and left, pull-out position maintained at left twisting position
		Automatic return by twisting to right and left, push-down position maintained at left twisting position
		Automatic return by twisting to right and left, automatic return by pushing center

Note: (1) Y indicates the name of equipment to be operated.
(2) The characters shown in the column "Symbols" are examples.

16-29 Instrumentation Symbols (cited from JIS Z8204-1983)

1. Instrument numbers

Instrument numbers shall be given to detectors, transmitters, indicators, etc. of measuring equipments for identification. Each instrument number shall consist of the following symbols.

Variable symbol | Variable modification symbol | Function symbol — Individual number

Example: TIC-123……Temperature indicating controller123

(1) The table below shows the variable symbols, variable modification symbols and function symbols.

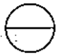
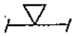
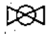
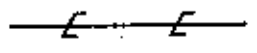
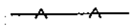
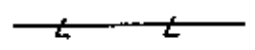
Character symbols	Meanings of symbols		
	Variable symbols	Variable modification symbols	Function symbols
A			Alarm
B			Status indication or operating indication
C			Adjustment
D	Density or specific gravity	Difference	
E	Electric quantity		Detector
F	Instantaneous flow	Ratio	
G	Position or length		Glass
H	Manual		
I			Indication
J		Automatic scanning	
K	Time		Operating station
L	Level		
M	Water content or moisture		
N	Optional		Optional (2)
O	Optional		Limiting orifice
P	Pressure or vacuum		Sample taking point or measuring point
Q	Quality, e.g., composition, density, conductivity	Accumulation	Integration
R	Readiation		Recording
S	Speed, revolution or frequency		Switch
T	Temperature		Transmission
U	Various variables		Multi-function instrument
V	Viscosity		Valves controller
W	Mass or force		Protection tube
X	Indefinite variable		Other functions
Y	Optional		Computing element, converter or relay
Z			Safety or emergency

The variable symbols indicate variables to be measured and cause variables. The variable modification symbols are used with variable symbols if necessary. The function symbols indicate the functions or types of measuring equipment.

(2) Individual numbers
Each measuring equipment shall have an individual number for identification.

2. Symbols

The table below shows the major symbols used to indicate the configurations of measuring equipment.

Classification	Locations		Symbols
Measurement control elements	General cases where monitoring and operating positions need not be discriminated		
	Monitoring and operating positions need to be discriminated	Local	
		Instrument room	
Control end symbols	Controller types not determined		
	Valve (General)		
	Angle valve		
	3-way valve		
	Butterfly valve, damper or louver		
	Ball valve		
Operating device symbols	Automatic operation		
	Manual operation		
	Diaphragm type		
	Diaphragm type (Pressure balance type)		
	Motor driven type		
	Electromagnetic type		
	Piston type		
	Hydraulic type		
Signal wire symbols	Electric signal (E)		
	Pneumatic pressure signal (A)		
	Hydraulic oil signal (L)		

17-1 Table of Testing Methods for Water

The scope of measurement and determination according to JIS K 0101(1998), JIS B 8224(1993), JIS K 0102(1998) etc., analytical accuracy, minimum limit concentration of determination, and maximum sample volume are summarized in the following table.

○ : JIS K 0101, △ : JIS B 8224, ● : JIS K 0102, □ : Notification by Environmental Agency

Item	Testing method	Determination range or unit	Repeatability (%)	Minimum limit concentration of determination (mg/ℓ)	Maximum sample volume (mℓ)	Remarks
pH	Glass electrode method JIS Z 8802 type Ⅱ					○△●□
Conductivity	Electric resistance method, Conductivity meter	mS/cm	±3			○ △
Ammonium ion	Indophenol blue absorptiometry	5 to 100μg	2 to 10	0.2	350	○△●
	Neutralization titrimetry	0.3 to 40mg	3 to 10	0.9	350	○●
	Ion-selective electrode method	0.1 to 100mg/ℓ	5 to 20	0.1	350	○△●
	Ion chromatography	0.1 to 30mg/ℓ	2 to 10	0.1		○△
Sodium	Flame photometry	0.03 to 30mg/ℓ	3 to 10	0.03		○△●
	Ion-selective electrode method	1 to 100mg/ℓ	5 to 20	1		○
	Flame atomic absorption spectrometry	0.05 to 4mg/ℓ	2 to 10	0.05		○△●
	Ion chromatography	0.1 to 30mg/ℓ	2 to 10	0.1		○△●
Chloride ion	Mercuric thiocyanate absorptiometry	0.02 to 0.5mg	2 to 10	0.4	50	○△
	Mercuric sulfate titrimetry	0.1 to 5mg		1	100	○△
	Ion-selective electrode method	5 to 1,000mg/ℓ	5 to 20	5	100	○△●
	Ion chromatography	0.05 to 25mg/ℓ	2 to 10	0.05		○△●
Residual chlorine	O-tolidine colorimetry	0.01 to 2.0mgCl/ℓ	5 to 10	0.01	100	○●
	Iodometry	Min. 0.1mgCl		0.3	300	○●
Silica	Molybdenum yellow absorptiometry	0.1 to 1mg	2 to 10	2	50	○△
	Molybdenum blue absorptiometry	10 to 100μg	2 to 10	0.2	50	○△
	Molybdenum blue extraction absorptiometry	0.5 to 10μg	5 to 20	0.0025	200	○△
	Gravimetry	5mg	3 to 10			○△
Iron	Phenanthroline absorptiometry	20 to 500μg	2 to 10	0.1	200	○△●
	Flame atomic absorption spectrometry	0.3 to 6mg/ℓ	2 to 10	0.3		○△●□
	Electrothermal type in atomic absorption spectrometry	5 to 100μg/ℓ	2 to 10	0.005		○△●□
	TPTZ	0.001 to 0.03mg		0.005	200	△
	ICP emission spectrometry	20 to 500μg/ℓ	2 to 10	0.02		○△●□
Copper	Diethyldithiocarbamic acid absorptiometry	2 to 30μg	2 to 10	0.008	250	○△●
						●□
	Flame atomic absorption spectrometry	0.2 to 4mg/ℓ	2 to 10	0.2		○△●□
	Electrothermal type in atomic absorption spectrometry	5 to 100μg/ℓ	2 to 10	0.005		○△●□
	ICP emission spectrometry	20 to 5,000μg/ℓ	2 to 10	0.02		○△●□

Item	Test method	Scope of measurement and determination or unit	Analytical accuracy (%)	Minimum limit concentration of determination (mg/ℓ)	Maximum sample volume (mℓ)	Remarks
Phosphate ion	Molybdenum blue (ascorbic acid reduction) absorptiometry	2.5 to 75μg	2 to 10	0.1	25	○△●
	Molybdenum blue (tin Ⅱ chloride reduction) absorptiometry	5.0 to 150μg	2 to 10	0.2	40	○△●
Hydrozinium ion	Para-dimethylaminobenzaldehyde absorptiometry	0.5 to 12μg		0.01	50	△
Dissolved oxygen	Winkler titration Potentiometric titration	below 0.01mg/ℓ		0.002	500	△
	Amperometric titration	below 0.01mg/ℓ		0.004	500	△
	Sodium azide modification	Min. 0.5mg/ℓ		0.5		○●
	Indigocarmine colorimetry	0.000 to 0.06mg/ℓ		0.000	100	△
	Membrane electrode method	Min. 0.5mg/ℓ	2 to 10	0.5		○●
Boron	Methylene blue absorptiometry	0.1 to 1μg	3 to 10	0.007	15	○●
	ICP emission spectroanalysis	20 to 8,000μg/ℓ	2 to 10	0.02	100	○●
Turbidity	Visual turbidity	1 to 10deg. (Kaolin)				○
	Transmitted light turbidity	5 to 250deg.(Kaolin)				○
		4 to 400deg.(Formazin)				○
	Turbidity by integrating sphere photometer	0.2 to 100deg. (Kaolin, Formazin)				○
Calcium	Chelatometry	0.2 to 5.0mg		4	50	○△●
	Flame atomic absorption spectrometry	0.2 to 4mg/ℓ	2 to 10	0.2	100	○△●
	ICP emission spectrometry	0.01 to 5mg/ℓ	2 to 10	0.01		○△●
Magnesium	Chelatometry	(Ca) 0.15 to 5mg		3	50	○△●
	Flame atomic absorption spectrometry	20 to 400μg/ℓ	2 to 10	0.02	100	○△●
	ICP emission spectrometry	0.005 to 3mg/ℓ	2 to 10	0.005		○△●
Potassium	Flame photometry	0.04 to 40mg/ℓ	3 to 10	0.04		○●
	Flame atomic absorption spectrometry	0.05 to 5mg/ℓ	2 to 10	0.05		○●
	Ion chromatography	0.1 to 30mg/ℓ	2 to 10	0.1		○●
Aluminum	Flame atomic absorption spectrometry	5 to 100mg/ℓ	2 to 10	5		○●
	Electrothermal type in atomic absorption spectrometry	20 to 200μg/ℓ	2 to 10	0.02		○●
	ICP emission spectrometry	80 to 4000μg/ℓ	2 to 10	0.08		○●
Acid consumption	pH4.8	mgCaCO$_3$/ℓ				○△
Sulfate ion	Barium chromate-diphenylcarbazide absorptiometry	2 to 50μg	3 to 10	0.2	10	○●
	Ion chromatography	0.2 to 100mg/ℓ	2 to 10	0.2		○●
	Gravimetry	Min. 10mg	2			○●
Sulfite ion	Iodimetry	Min. 0.2mg		2	100	○△

Item	Test method	Scope of measurement and determination or unit	Analytical accuracy (%)	Minimum limit concentration of determination (mg/ℓ)	Maximum sample volume (mℓ)	Remarks
Sulfide ion	Methylene blue absorptiometry	5 to 40μg	3 to 10	0.2	40	○●
	Iodimetry	Min. 0.2mg		0.4	500	○●
Cadmium	Flame atomic absorption spectrometry	50 to 2,000μg/ℓ	2 to 10	0.05		●□
	Electrothermal type in atomic absorptiometry	0.5 to 10μg/ℓ	2 to 10	0.0005		○●□
Total cyanide	4-pyridine carboxylic acid-pirazolone absorptiometry	0.5 to 9μg	2 to 10	0.1	50	○●□
Organic phosphorus pesticide	Gas chromatography	1 to 20ng	5 to 10			●□
Lead	Flame atomic absorption spectrometry	1 to 20mg/ℓ	2 to 10	1		○●□
Hexavalent chromium	Diphenyl carbazide absorptiometry	2 to 50μg	3 to 10	0.04	50	●□
	Flame atomic absorption spectrometry	0.2 to 5mg/ℓ	2 to 10	0.2		●□
Arsenic	Silver diethyldithiocarbamate absorption spectrophotometry	2 to 10μg	2 to 10	0.002	1ℓ	●□
Total mercury	Atomic absorption spectrometry by reduction and vaporization	0.5 to 10μg/ℓ	4 to 10	0.0005	200	○●□
Alkyl mercury compound	Gas chromatography	0.5μg/ℓ		0.0005	200	□ JIS K 0125
P C B	Gas chromatography	Min. 0.001mg	5 to 10	0.001	1,000	□ JIS K 0093
Trichloroethylene	Solvent extraction gas chromatography	0.016 to 0.32ng	5 to 10	0.002	40	□ JIS K 0125
Tetrachloroethylene	Solvent extraction gas chromatography	0.004 to 0.08ng	5 to 10	0.0005	40	□ JIS K 0125
1-1-1 trichloroethane	Solvent extraction gas chromatography	0.004 to 0.08ng	5 to 10	0.0005	40	□ JIS K 0125
Carbon tetrachloride	Solvent extraction gas chromatography	0.001 to 0.02ng	5 to 10	0.0005	40	□ JIS K 0125
Biochemical oxygen demand	Dissolved oxygen consumed after the sample diluted with water is left at 20 ℃ for five days	BOD mgO/ℓ				○●□
Chemical oxygen demand	Oxygen demand by potassium permanganate at 100℃.	COD_{Mn} mgO/ℓ				○△●□
Suspended substances	Filter the sample, and dry the substance remaining on the filtrant at 105 to 110℃. Then take measurement.	Min. 2mg				○△●□
Hexane extracts	Liquid-liquid extraction method	5 to 200mg	10 to 20	5	1ℓ	○△●□
Total organic carbon	Combustion oxidation-infrared type TOC analysis method	C 1 to 150mg/ℓ	3 to 10	1	150μℓ	○●
	Combustion oxidation-infrared type TOC automatic analysis method	0.05 to 150mg/ℓ	3 to 10	0.05		○●
Phenols	4-aminoantipyrine absorptiometry extraction method	2.5 to 50μg	3 to 10	0.005	500	○●□
	direction method	50 to 500μg	3 to 10	0.2	250	○●□
Zinc	Flame atomic absorption spectrometry	50 to 2,000μg/ℓ	2 to 10	0.005		●□
	Electrothermal type in atomic absorption spectrometry	1 to 20μg/ℓ	2 to 10			○●
	ICP emission spectrometry	10 to 6,000μg/ℓ	2 to 10			○●
	ICP mass spectrometry	0.5 to 500μg/ℓ	2 to 10			○●

Item	Test method	Scope of measurement and determination or unit	Analytical accuracy (%)	Minimum limit concentration of determination (mg/ℓ)	Maximum sample volume (mℓ)	Remarks
Manganese	Flame atomic absorption spectrometry	0.1 to 4mg/ℓ	2 to 10	0.1		○●□
Chromium	Flame atomic absorption spectrometry	0.2 to 5mg/ℓ	2 to 10	0.2		Total chromium ●□
Fluoride compounds	Lanthanum arizarine complexon absorptiometry	0.004 to 0.05mg	3 to 10	0.03	1,000	○●□
Coliform group	Cultured on the desoxycholate medium at 36℃ ± 1℃ for 18 to 20 hours	1/mℓ				●□
Nickel	Dimethyl glyoxyl absorption spectrophotometry	2 to 50μg	2 to 10	0.004	500	○●
	Flame atomic absorption spectrometry	0.3 to 6mg/ℓ	2 to 10	0.3		○●
	ICP emission spectrometry	40 to 2,000μg/ℓ	2 to 10	0.04		○
Nitrate ion	Brucine absorptiometry	5 to 100μg	3 to 10	2.5	2	○●
	Neatralization titration after reducing distillation	1 to 140mg	3 to 10	10.3	300	○●
	Ion chromatography	0.1 to 40mg/ℓ	2 to 10	0.1		○●
Nitrite ion	Naphthylethylenediamine absorptiometry	0.6 to 6μg	3 to 10	0.06	10	○●
	Ion chromatography	0.1 to 40mg/ℓ	2 to 10	0.1		○●
Organic nitrogen	Indophenol blue absorptiometry	4 to 80μg	3 to 10	0.07	500	○●
Total nitrogen	Summation method	0.008 to 0.16mg	3 to 10			○●□
	Thermal decomposing method	1 to 200mg/ℓ	3 to 10			○●□
Total phosphorus	Decomposition by potassium peroxydisulfate	1.25 to 25μg	2 to 10			●□
	Decomposition by nitric acid-sulfuric acid	1.25 to 25μg	2 to 10			○●□

17-2 Molecular Weight, Equivalence, and Conversion Coefficient to $CaCO_3$ of Ion, Salt and Gas

Name		Molecular weight	Equivalence	Conversion coefficient as $CaCO_3$
Aluminum ion	Al^{3+}	27.0	9.0	5.56
Calcium ion	Ca^{2+}	40.1	20.0	2.50
Copper (I) ion	Cu^{+}	63.5	63.5	0.79
Copper (II) ion	Cu^{2+}	63.5	31.8	1.57
Iron (II) ion	Fe^{2+}	55.8	27.9	1.79
Iron (III) ion	Fe^{3+}	55.8	18.6	2.69
Hydrogen ion	H^{+}	1.01	1.01	50.0
Potassium ion	K^{+}	39.1	39.1	1.28
Magnesium ion	Mg^{2+}	24.3	12.2	4.10
Sodium ion	Na^{+}	23.0	23.0	2.18
Ammonium ion	NH_4^{+}	18.0	18.0	2.78
Chloride ion	Cl^{-}	35.5	35.5	1.41
Carbonate ion	CO_3^{2-}	60.0	30.0	1.67
Bicarbonate ion	HCO_3^{-}	61.0	61.0	0.82
Nitrate ion	NO_3^{-}	62.0	62.0	0.81
Hydroxide ion	OH^{-}	17.0	17.0	2.94
Phosphate ion	PO_4^{3-}	95.0	31.7	1.58
Sulfate ion	SO_4^{2-}	96.1	48.0	1.04
Sulfite ion	SO_3^{2-}	80.1	40.0	1.25
Silica	SiO_2	60.1	30.0	1.67
Hydrochloric acid	HCl	36.5	36.5	1.37
Nitric acid	HNO_3	63.0	63.0	0.79
Sulfuric acid	H_2SO_4	98.1	49.0	1.02
Phosphoric acid	H_3PO_4	98.0	32.7	1.53
Aluminum hydroxide	$Al(OH)_3$	78.0	26.0	1.92
Potassium hydroxide	KOH	56.1	56.1	0.89
Sodium hydroxide	$NaOH$	40.0	40.0	1.25
Ammonium hydroxide	NH_4OH	35.0	35.0	1.43
Aluminum sulfate	$Al_2(SO_4)_3 \cdot 18H_2O$	666.4	111.1	0.45
Alumina	Al_2O_3	102.0	17.0	2.94
Calcium carbonate	$CaCO_3$	100.09	50.0	1.00
Calcium oxide	CaO	56.1	28.0	1.79
Calcium sulfate	$CaSO_4 \cdot 2H_2O$	172.2	86.1	0.58
Iron (II) sulfate	$FeSO_4 \cdot 7H_2O$	278.0	139.0	0.36
Iron (III) chloride	$FeC\ell_3 \cdot 6H_2O$	270.3	90.1	0.56
Iron oxide	Fe_2O_3	159.7	26.6	1.88
Magnesia	MgO	40.3	20.2	2.48
Sodium bicarbonate	$NaHCO_3$	84.0	84.0	0.60
Sodium carbonate	Na_2CO_3	106.0	53.0	0.94
Salt	$NaCl$	58.4	58.4	0.86
Sodium nitrate	$NaNO_3$	85.0	85.0	0.59
Sodium aluminate	$Na_2Al_2O_4$	163.9	82.0	0.61
Sodium primary phosphate	$NaH_2PO_4 \cdot H_2O$	138.0	138.0	0.36
Sodium secondary phosphate	$Na_2HPO_4 \cdot 12H_2O$	358.1	179.1	0.28
Sodium tertiary phosphate	$Na_3PO_4 \cdot 12H_2O$	380.1	126.7	0.40
Carbon dioxide gas	CO_2 (monovalence)	44.0	44.0	1.14
Carbon dioxide gas	CO_2 (bivalence)	44.0	22.0	2.27
Ammonium	NH_3	17.0	17.0	2.94

Notes: 1. Commonly used names instead of formal names are partly used.

2. In calculating the ion exchange capacity, the conversion coefficients as $CaCO_3$ of SiO_2 and CO_2 (free carbonate) are 0.83 and 1.14, respectively.

3. The conversion coefficient as $CaCO_3$ of other substance is obtained by 50/equivalence.

17-3 Solubility of Gases in Water

Temperature t (℃)	Air		N_2 (including 1.2v/v% Ar)		O_2		H_2	
	$N_2\ \ell$ [mℓ/mℓ] $(\times 10^3)$	$O_2\ \ell$ [mℓ/mℓ] $(\times 10^3)$	α [mℓ/mℓ] $(\times 10^3)$	q [g/100g] $(\times 10^3)$	α [mℓ/mℓ] $(\times 10^3)$	q [g/100g] $(\times 10^3)$	α [mℓ/mℓ] $(\times 10^3)$	q [g/100g] $(\times 10^3)$
0	18.4	10.2	23.5	2.94	48.9	6.95	21.4	0.193
5	16.3	8.9	20.9	2.60	42.9	6.07	20.4	0.184
10	14.5	7.9	18.6	2.31	38.0	5.37	19.5	0.176
15	13.1	7.0	16.9	2.09	34.2	4.80	18.8	0.169
20	11.9	6.4	15.5	1.90	31.0	4.34	18.2	0.162
25	11.0	5.7	14.3	1.75	28.3	3.93	17.5	0.156
30	10.3	5.1	13.4	1.62	26.1	3.59	17.0	0.147
35	—	—	12.6	1.50	24.4	3.32	16.7	0.143
40	8.7	4.5	11.8	1.39	23.1	3.08	16.4	0.139
45	—	—	11.3	1.30	21.9	2.86	16.2	0.134
50	7.5	3.9	10.9	1.22	20.9	2.66	16.1	0.129
60	6.5	3.3	10.2	1.05	19.5	2.27	16.0	0.119
70	—	—	9.8	0.85	18.3	1.86	16.0	0.102
80	4.0	2.0	9.6	0.66	17.6	1.38	16.0	0.079
90	—	—	9.5	0.38	17.2	0.79	16.0	0.046
100	0.0	0.0	9.5	0.00	17.0	0.00	16.0	0.000

Temperature t (℃)	H_2S		HCl(p=760mmHg)		NH_3(p=760mmHg)		Cl_2	O_3
	α〔mℓ/mℓ〕	q〔g/100g〕 (×10³)	α〔mℓ/mℓ〕	〔g/100gH₂O〕	〔g/100gH₂O〕	〔mℓ/1gH₂O〕	q〔g/100g〕 (×10³)	q〔g/100g〕 (×10³)
0	4.621	699	517	82.3	87.5	1,299	1,460	3.94
5	3.935	593	—	79.7$_4$	77.5	1,019	—	3.43$_6$
10	3.362	505	474	76.3$_{12}$	67.9	910	997	2.99$_{11.8}$
15	2.913	436	—	74.9$_{14}$	60.0	802	850	2.59
20	2.554	380	442	71.9	52.6	710	729	—
25	2.257	334	—	—	46.0	635	641	1.39$_{27}$
30	2.014	295	412	67.3	40.3	—	572	0.77$_{33}$
35	1.811	262	—	—	35.5	—	510	—
40	1.642	233	386	63.3	30.7	—	459	0.42
45	1.499	209	—	—	27.0	—	423	—
50	1.376	186	362	59.6	22.9	—	393	0.06$_{55}$
60	1.176	146	339	56.1	—	—	330	0
70	1.010	109	—	—	—	—	279	—
80	0.906	76	—	—	—	—	223	—
90	0.835	41	—	—	—	—	127	—
100	0.800	0	—	—	—	—	0	—

＊Subscript figures in this table show the measured temperature.

Temperature t (℃)	CO		CO_2		N_2O	NO	SO_2	
	α〔mℓ/mℓ〕 (×10³)	q〔g/100g〕 (×10³)	α〔mℓ/mℓ〕	q〔g/100g〕 (×10³)	α〔mℓ/mℓ〕	α〔mℓ/mℓ〕 (×10³)	α〔mℓ/mℓ〕	q〔g/100g〕
0	35.4	4.40	1.713	334.6	—	73.8	79.789	22.83
5	31.5	3.90	1.424	277.4	1.1403	64.6	67.485	19.31
10	28.2	3.48	1.194	231.8	0.9479	57.1	56.647	16.21
15	25.4	3.13	1.019	197.0	0.7896	51.5	47.276	13.54
20	23.2	2.84	0.878	168.8	0.6654	47.1	39.374	11.28
25	21.4	2.60	0.759	144.9	0.5752	43.0	32.786	9.41
30	20.0	2.41	0.665	125.7	—	40.0	27.161	7.80
35	18.8	2.23	0.592	110.5	—	37.3	22.489	6.47
40	17.8	2.08	0.530	97.3	—	35.1	18.766	5.41
45	16.9	1.93	0.479	86.0	—	33.1	—	—
50	16.2	1.80	0.436	76.1	—	31.5	—	—
60	14.9	1.52	0.365	57.6	—	29.5	—	—
70	14.4	1.28	0.319	—	—	28.1	—	—
80	14.3	0.98	—	—	—	27.0	—	—
90	14.2	0.57	—	—	—	26.5	—	—
100	14.1	0.00	—	—	—	26.3	—	—

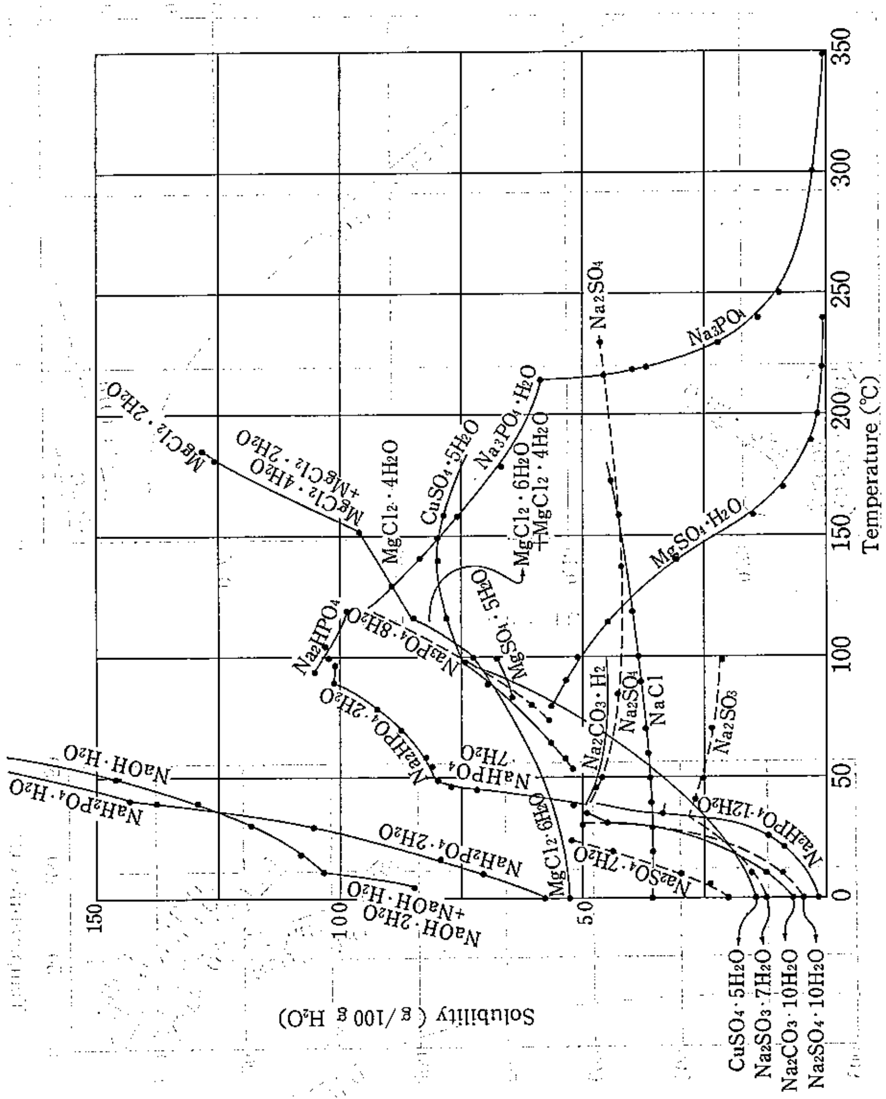
Indications of solubility

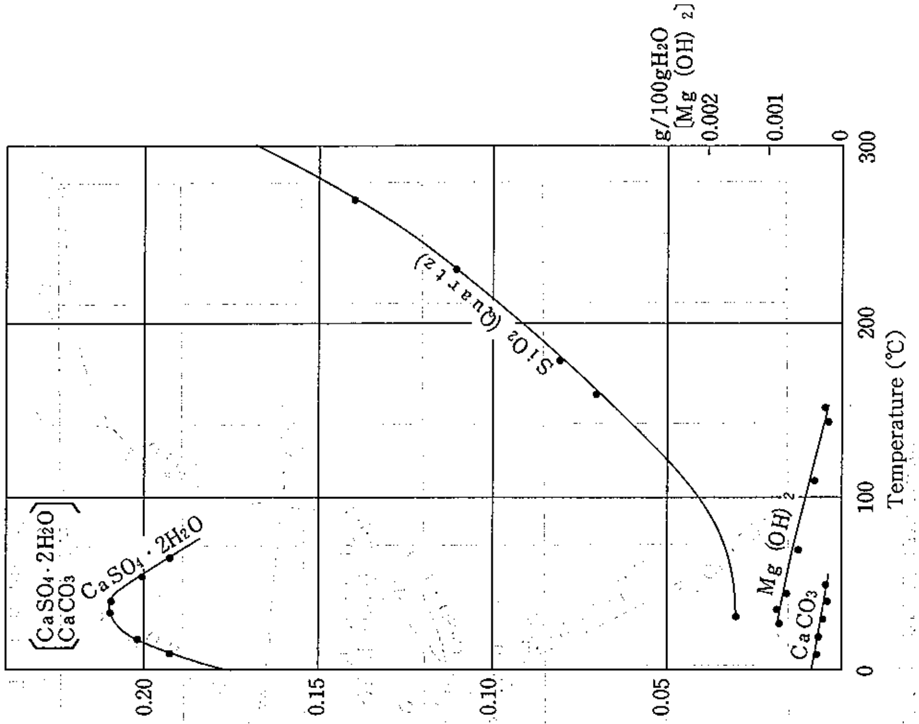
α: Bunsen absorption coefficient = indicates the volume (mℓ) of the gas dissolved in 1 mℓ of solvent at t ℃ converted into the equivalent at 0 ℃, 760 mmHg, when gas partial pressure 760 mmHg.

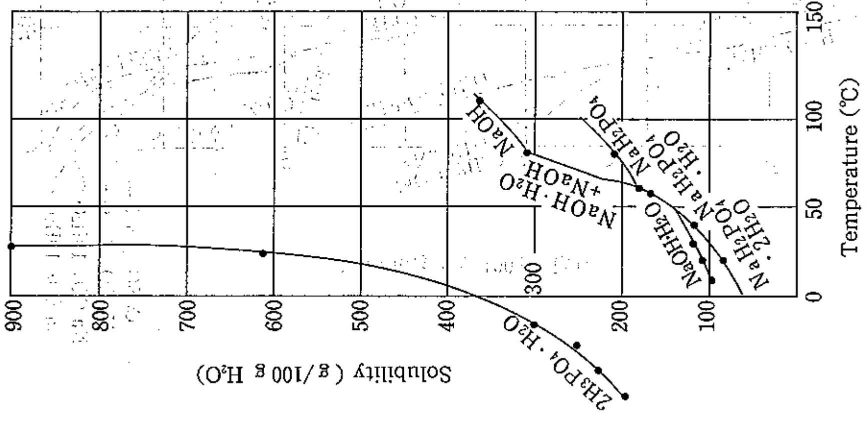
ℓ: indicates the volume (mℓ) of the gas dissolved in 1 mℓ of solvent at t ℃ converted into the equivalent at 0 ℃, 760 mmHg, when the total pressure of gas phase (gas partial pressure + solvent vapor pressure) is 760 mmHg.

q: indicates the mass (g) of the gas dissolved in 100 grams of solvent at t℃ when the total pressure of gas phase (gas partial pressure + solvent vapor pressure) is 760 mmHg.

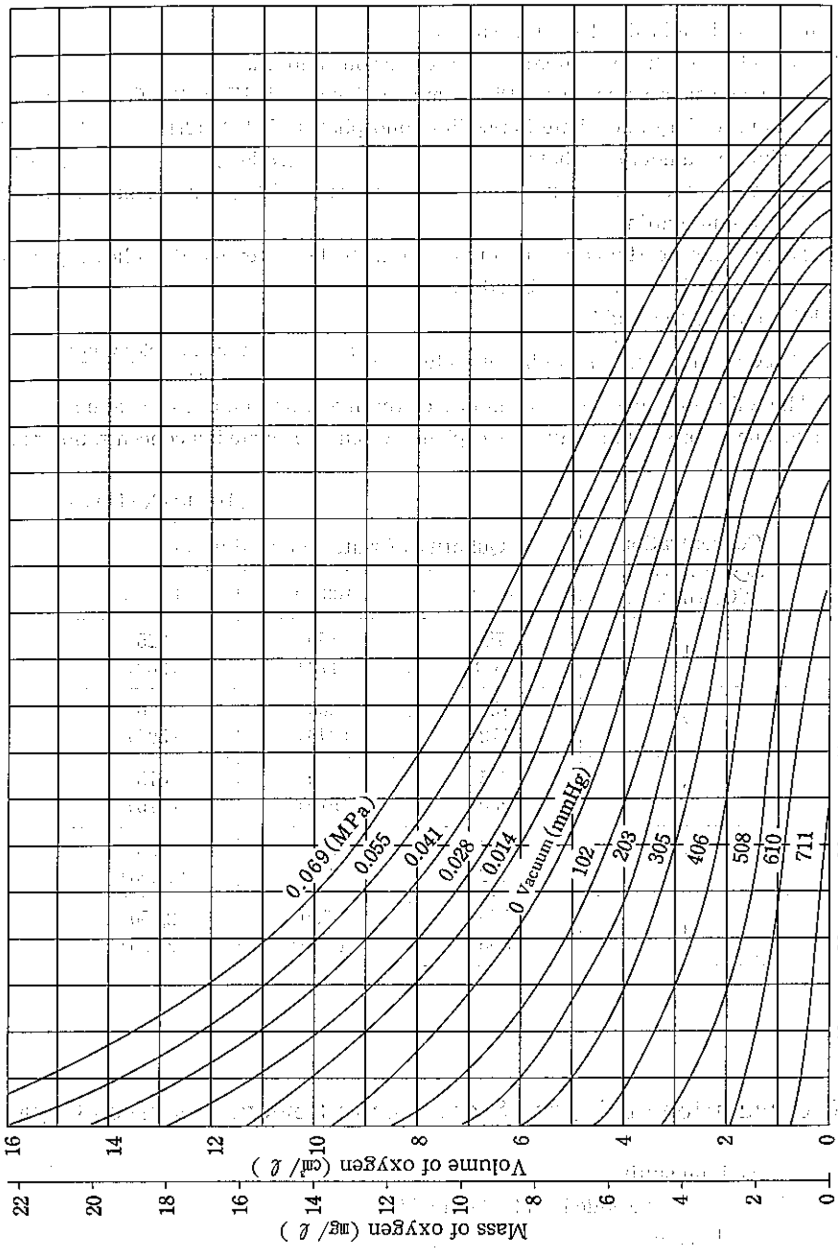
17-4 Solubility of Inorganic Compounds







17-5 Solubility of Oxygen in Pure Water



〔Reference: W. H. & L. D. Betz (1953), Betz Handbook of Industrial Water Conditioning, 4th ed.〕

17-6 Calculation of Required Phosphate Quantity to Remove Hardness

PO_4^{3-} (mg/l) to be added $= 1.43 \times Ca^{2+}$ (mg/l)

Note: 1. The following shows contents of PO_4^{3-} of various phosphates:

Sodium secondary phosphate (Disodium phosphate)	$Na_2HPO_4 \cdot 12H_2O$	PO_4% 26.5
Sodium tertiary phosphate (Trisodium phosphate)	$Na_3PO_4 \cdot 12H_2O$	PO_4% 25
Sodium hexametaphosphate	$(NaPO_3)_6$	PO_4% 93.2

2. The above equation can not apply in the presence of Mg^{2+} in the hardness content (magnesium hardness)
3. To maintain a certain quantity of PO_4^{3-} in the boiler water, use the following equation to calculate the quantity to be added.

   PO_4^{3-} (mg/l) to be added

   $$= 1.43Ca^{2+} + PO_4^{3-}\text{(mg/}l\text{) in boiler water} \times \frac{\text{Percentage of blow in boiler water(\%)}}{100}$$

4. The following table shows examples of the injection amount of sodium secondary phosphate (or sodium tertiary phosphate) when phosphate ion concentration reduces;

Na_2HPO_4g(Na_3PO_4g)

Concentration to be increased PO_4 (mg/l)	Quantity of water retained in boiler		
	50 t	100 t	150 t
1	75 (87)	150 (173)	225 (260)
2	150 (173)	300 (346)	450 (504)
3	225 (260)	450 (519)	675 (775)
5	375 (432)	750 (865)	1,125 (1,298)
10	750 (865)	1,500 (1,730)	2,250 (2,595)

17-7 Calculation of Oxygen Scavenger to Remove Dissolved Oxygen

(1) In case of sodium sulfite

Na_2SO_3(mg/l) to be added $= 7.9 \times O_2$(mg/l):

(2) In case of hydrazine

N_2H_4(mg/l) to be added $= O_2$(mg/l)

Note: O_2(mg/l) $\times 0.7 \fallingdotseq O_2ml$/$l$

17-8 Physical Properties of Sodium and Boric Acid

Sodium (Na)

Atomic number	11
Atomic weight	22.9898
Melting point	97.82℃
Boiling point	881℃
Heat of fusion	114J/g
Heat of evaporation	3880J/g (2 times, 315℃)
Density	
Solid	0.9684g/㎤ (20℃)
Liquid	0.8563g/㎤ (400℃)
Coefficient of volume expansion	2.71%
Specific heat	
Solid	2.009kJ/(kg•K) (20℃)
Liquid	1.467kJ/(kg•K) (400℃) (about 2 times)
Thermal conductivity	71.57W/(m•K) (400℃) (about 100 times) (3.4 times that of the stainless steel)
Heat transfer coefficient	2.62×10^5 W/(㎡•K) for forced convection (about 2.2 times)
Viscosity	1.005kg/m•h (400℃) (about 2 times, 315℃)
Steam pressure	9mmHg
Electric resistance	2.9mS/m(0.41 times that of the stainless steel)
Surface tension	0.1667N/m (about 2.66 times, 80℃)

Note: Values in parentheses represent ratios to values of water unless otherwise.

[Source: Chuichi Asada, et al., New Nuclear handbook, Ohmsha. Ltd. (1989)]

Boric acid (H_3BO_3)

Molecular weight	61.8
Color and crystal	No color, triclinic
Specific gravity	1.5128
Melting point	169℃ (decomposed into HBO_2)
Boiling point	300℃ ($-1.5H_2O$)
Solubility	2.70g/100g water (0℃), 27.53/100g (100℃)

[Source: Chemical Handbook, Introductory volume, Revised 4th Edition (1993) and "13398 Chemical Products", edited by Chemical Industrial Journal Co., Ltd. (1998)]

Reaction of boric acid

(1) Boric acid neutron absorption reaction is used to control nuclear reactivity (primary system of PWR).

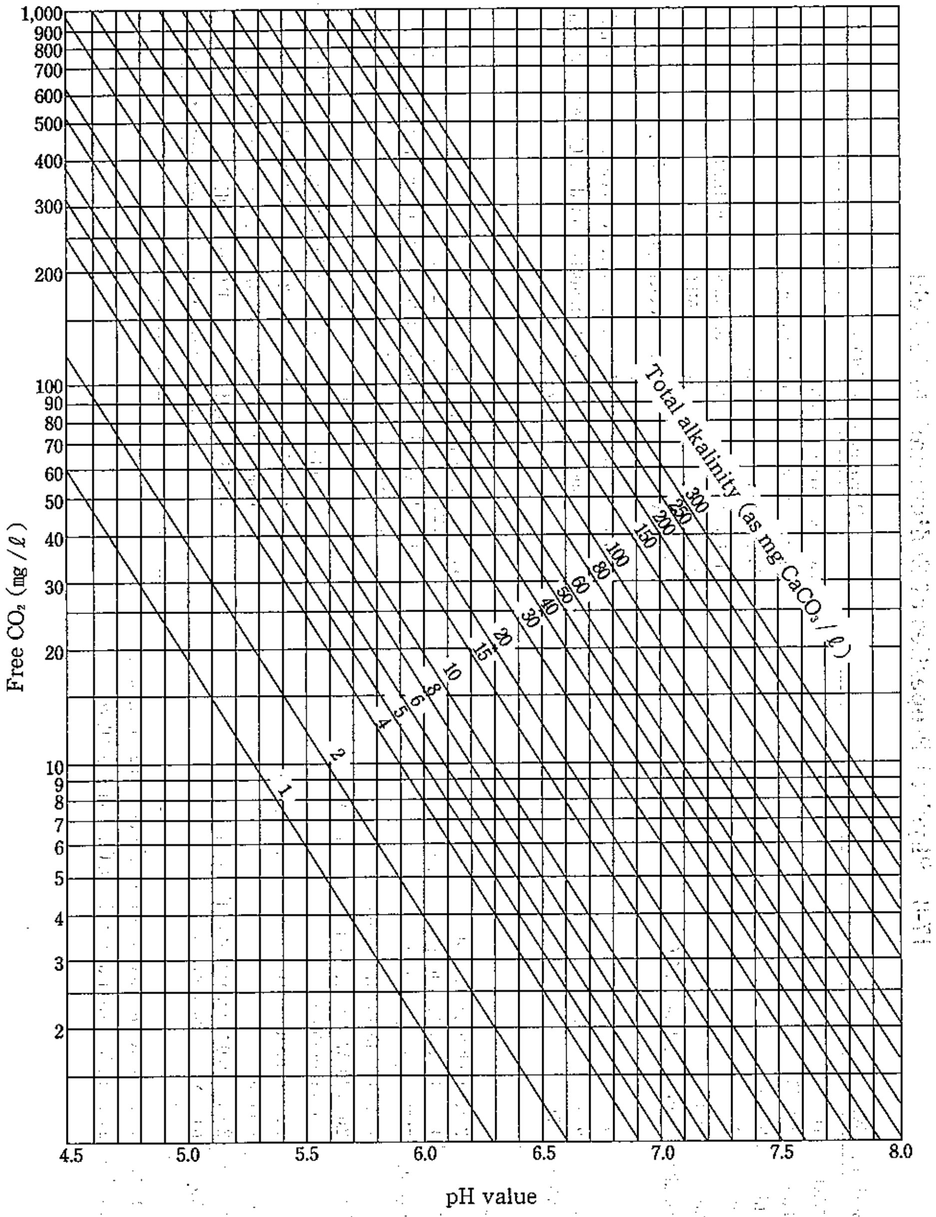
$${}^{10}B(n,\ \alpha)\ {}^{7}Li$$

(2) Gigantic iron borate compound is generated by reaction with magnetite.

- $4Fe_3O_4 + H_3BO_3 + 6H_2O \rightarrow 2Fe_2O_5 + 3Fe_2O_3 \cdot 3H_2O$
- $6Fe_3BO_5 + 22H_3BO_3 \rightarrow 4Fe_3B_7O_{13} \cdot OH + 3Fe_2O_2 \cdot 3H_2O + 22H_2O$
- $Fe_3B_7O_{13} \cdot OH + Cl^- \rightarrow Fe_3B_7O_{13} \cdot Cl + OH^-$

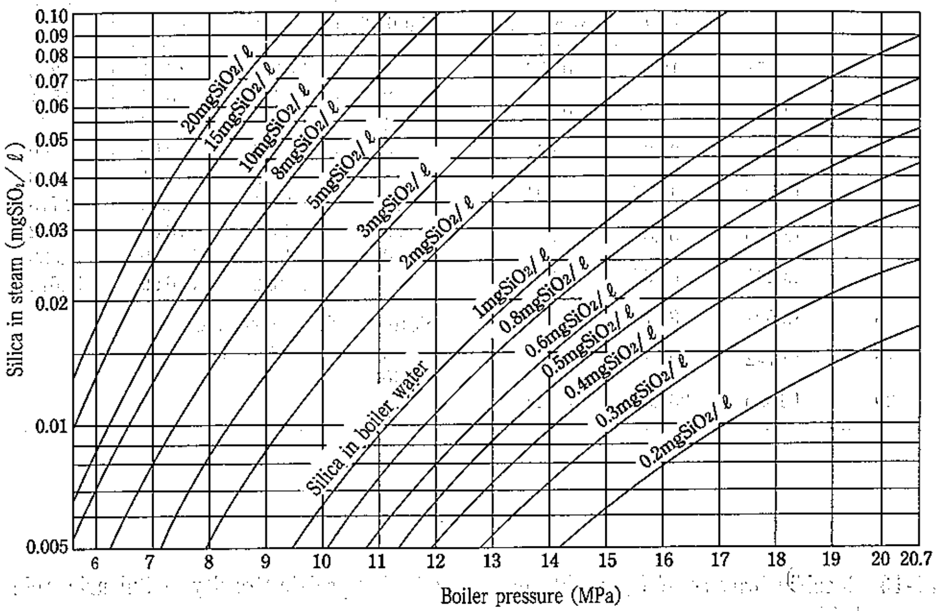
Note: Fe_3BO_5 : Hulsite $Fe_3B_7O_{13} \cdot OH$: Boracite

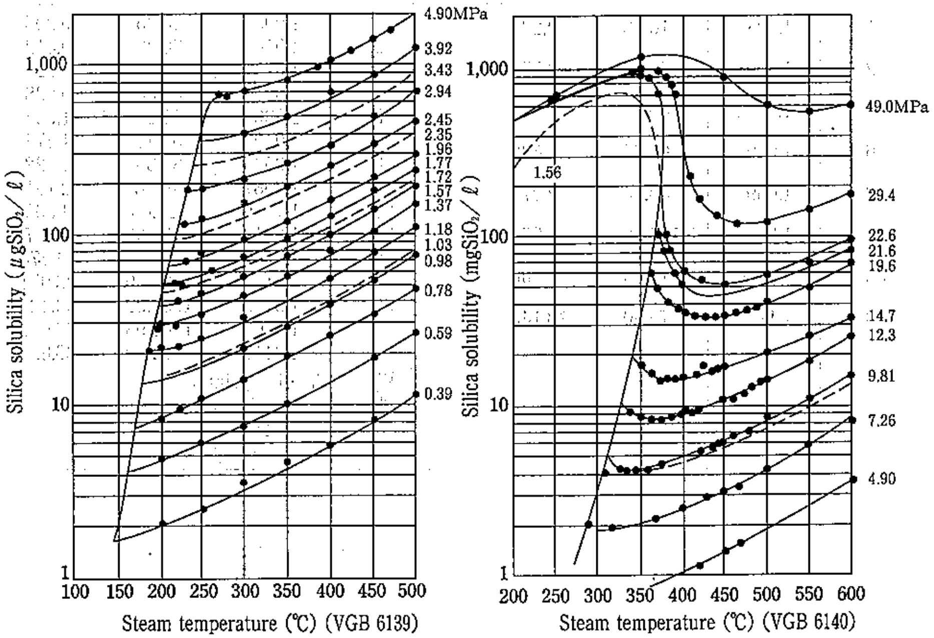
17-9 Relationship among Alkalinity, pH and CO₂ Concentration



〔Reference: W. H. & L .D. Betz (1953), Betz Handbook of Industrial Water Conditioning, 4th ed.〕

17-10 Relationship between Silica and Pressure in Boiler Water and Steam





17-11 Specific Gravity of Salt Solution

NaCl %	Specific gravity (15/4℃)	g/ l	Normality
1	1.0071	10.07	0.172
2	1.0144	20.29	0.347
3	1.0218	30.65	0.524
4	1.0292	41.17	0.704
5	1.0366	51.83	0.887
6	1.0441	62.65	1.072
8	1.0591	84.73	1.450
10	1.0742	107.42	1.838
20	1.1525	230.50	3.944

17-12 Specific Gravity of Caustic Soda Solution

NaOH %	Specific gravity (15/4℃)	g/ l	Normality
1	1.0106	10.11	0.253
2	1.0219	20.44	0.511
4	1.0444	41.78	1.045
6	1.0666	64.00	1.600
8	1.0889	87.11	2.178
10	1.1111	111.10	2.778
22	1.2440	273.68	6.842
40	1.4333	573.30	14.333
45	1.4822	666.99	16.674
(Note)	Freezing point ℃		
22	−25		
40	−3		
45	2		

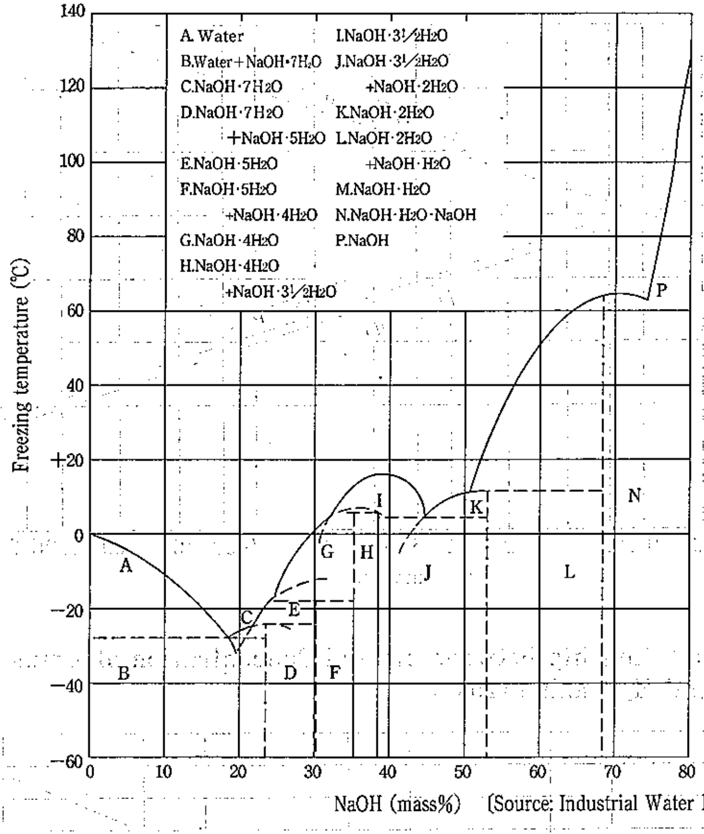
17-13 Specific Gravity of Hydrochloric Acid

HCl %	Specific gravity (15/4℃)	g/ l	Normality
1	1.0043	10.43	0.287
2	1.0093	20.19	0.553
4	1.0194	40.78	1.117
6	1.0293	61.75	1.692
8	1.0392	83.14	2.278
10	1.0492	104.92	2.875
35	1.1780	412.40	11.300
40	1.1990	479.60	13.140

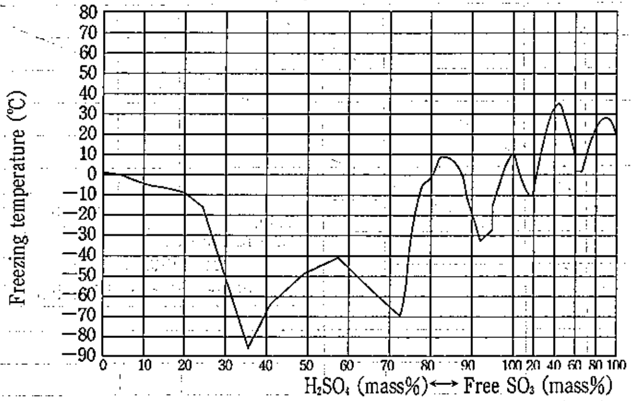
17-14 Specific Gravity of Sulfuric Acid

H_2SO_4 %	Specific gravity (15/4℃)	g/ l	Normality
1	1.0054	10.05	0.205
2	1.0102	20.20	0.412
3	1.0198	30.59	0.624
4	1.0266	41.06	0.838
5	1.0334	51.67	1.054
6	1.0403	62.42	1.274
8	1.0545	84.36	1.722
10	1.0687	106.87	2.181
20	1.1430	228.60	4.665
30	1.2213	366.36	7.477
50	1.3989	699.45	14.274
70	1.6150	1130.50	23.071
90	1.8198	1637.82	33.424
96	1.8406	1766.98	36.060
98	1.8411	1804.29	36.822
(Note)	Freezing point ℃		
90	−5		
96	−20		
98	7		

17-15 Freezing Point of Sulfuric Acid and Caustic Soda



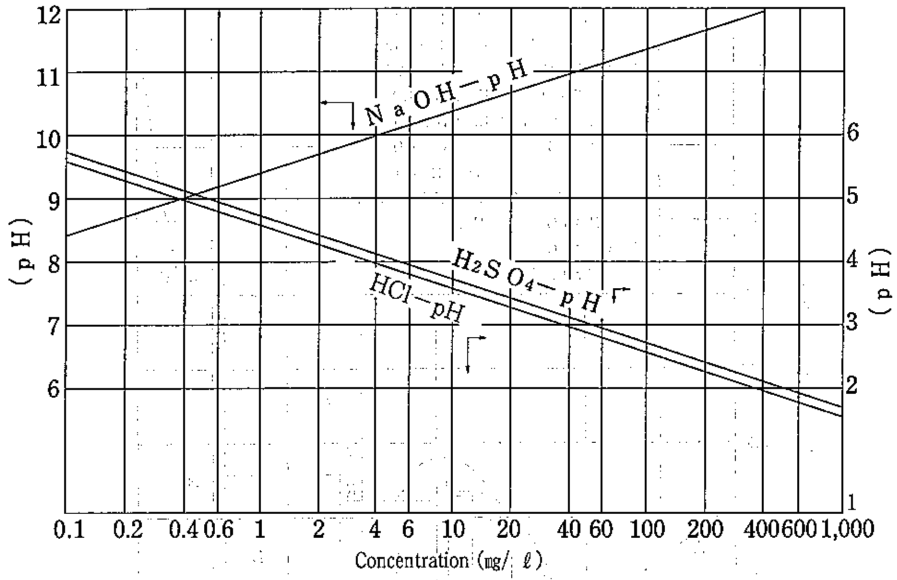
[Source: Industrial Water Handbook]



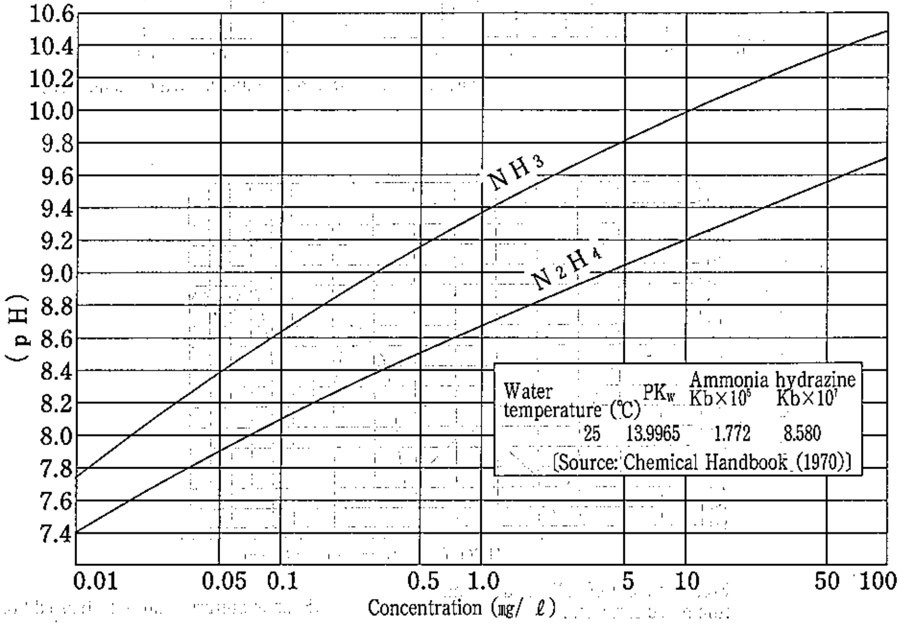
Freezing point of sulfuric acid and fuming sulfuric acid

[Source: Sulfuric acid note 1997 edition]

17-16 Relationship between pH and Concentration of Hydrochloric Acid, Sulfuric Acid and Caustic Soda (25℃)



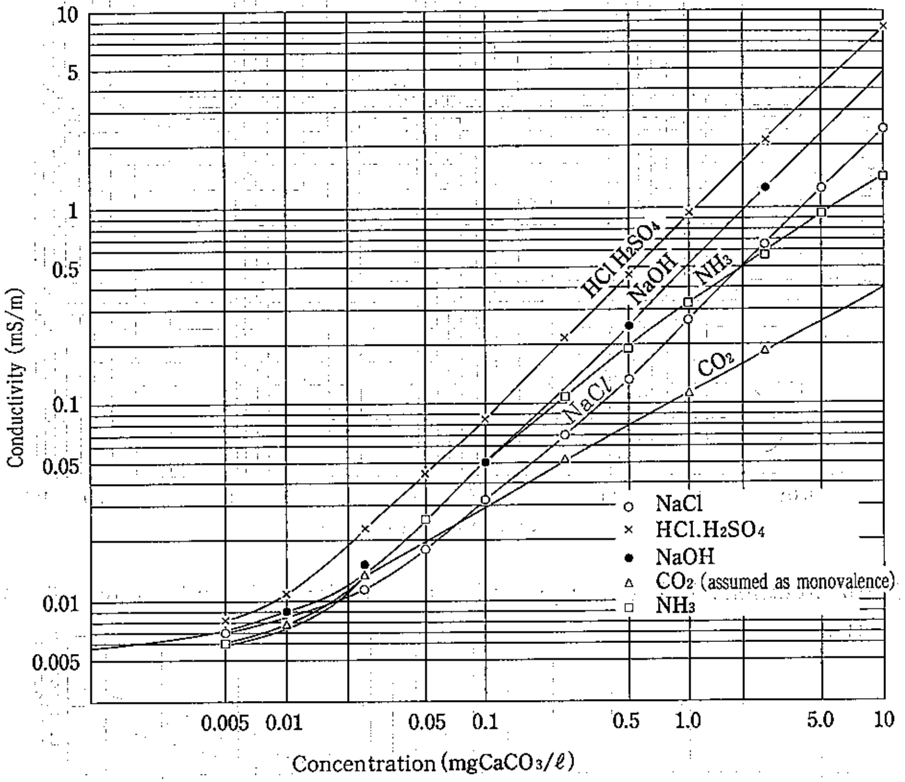
17-17 Relationship between pH and Concentration of Ammonia and Hydrazine (25℃)



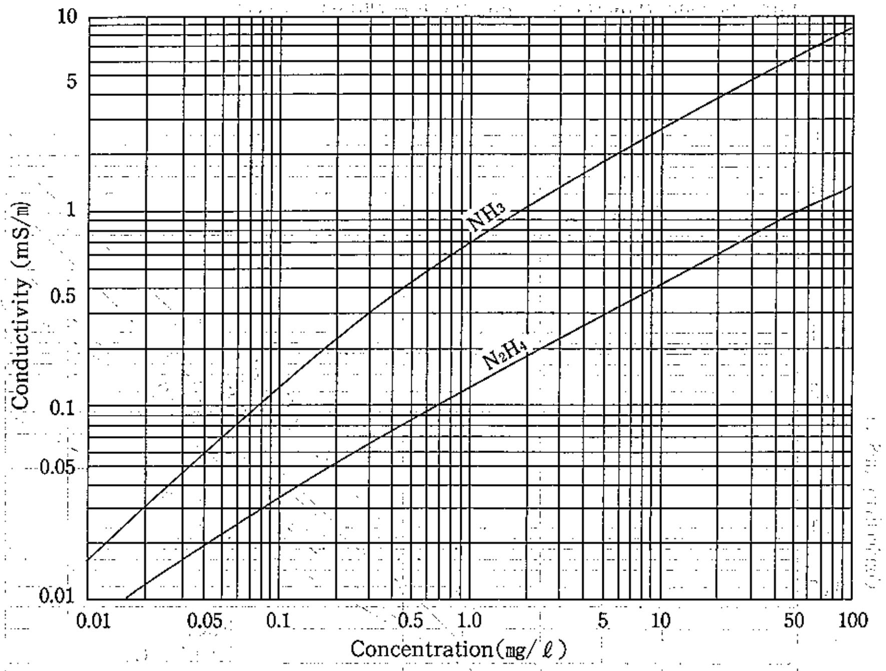
Water temperature (℃)	PK$_W$	Ammonia Kb×10^5	hydrazine Kb×10^7
25	13.9965	1.772	8.580

[Source: Chemical Handbook (1970)]

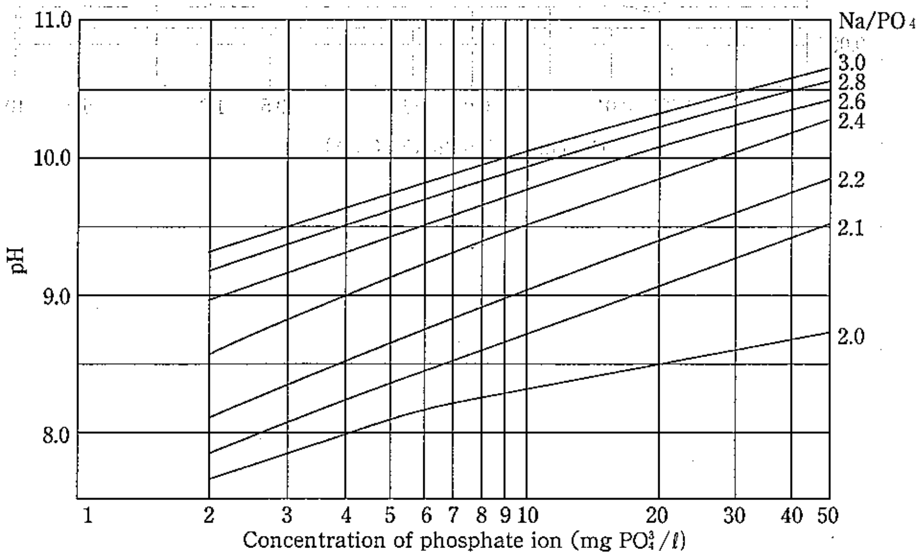
17-18 Relationship between Conductivity and Concentration of Hydrochloric Acid, Sulfuric Acid, Caustic Soda and Sodium Chloride (25℃)



17-19 Relationship between Conductivity and Concentration of Ammonia and Hydrazine (25℃)



17-20 Relationship between pH and Concentration of Phosphate Ion (25 ℃)



〔Reference:V. M. Marcy, S. L. Halstead (1964): Combustion 36, 45〕

17-21 Chemical Cleaning of Boiler and Chemical Decontamination of Nuclear Reactor

(1) Chemical cleaning of boiler

(a) Chemical cleaning method

Type	Used chemicals and concentration (%)	Cleaning conditions	Features
Degreasing	Alkali agent 0.3 to 0.5 Surfactant 0.05 to 0.2	Circulated at 60℃ to 80℃ for 6 to 8 hours	Used for new boilers and others containing much oil and fat
Ammonia cleaning	Ammonia 2 to 3 Copper dissolving agent 0.3 to 1.0 Oxidant 0.2	Circulated at 40℃ to 70℃ for 4 to 6 hours	This method is used to remove copper before pickling, when much copper is contained in the scale.
Inorganic acid cleaning	Hydrochloric acid 5 to 10 Inhibitor 0.3 to 0.5 Reducing agent 0.1 to 0.3 Copper ion sequestering agent 0.3 to 2.0 Dissolution accelerator 0.2 to 1.0	Circulated at 50℃ to 60℃ for 4 to 8 hours	Hydrochloric acid is generally used as inorganic acid. It is less costly and has a great capacity to dissolve scales. It is not suited for the tube material of the austenitic group. Use care in handling hydrochloric acid to see if hydrogen gas is generated. Note that the dissolution accelerator also corrodes the base metal.
Organic acid cleaning	Organic acid 3 to 6 Inhibitor 0.3 to 0.5 Reducing agent 0.1 to 0.3 Copper ion sequestering agent 0.3 to 2.0	Circulated at 80℃ to 90℃ for 4 to 8 hours	Ammonium citrate, the mixture of citric acid and hydroxyacetic acid, and the mixture of formic acid and hydroxyacetic acid are generally known as organic acid. The corrosion rate is smaller than that of hydrochloric acid. Applicable to austenite tube material. It produces hydrogen gas.
Chelate cleaning	EDTA ammonium salt 10 to 18 Inhibitor 0.1 to 0.3	Processed at 130℃ to 150℃ for 6 to 10 hours to remove iron and below 70℃ for 4 to 6 hours to remove copper.	This is more expensive than the organic acid. Only one type of solution can remove iron, copper and rust. It is suited to the piping material of the austenitic group, and has a great capacity to dissolve spinel. Since cleaning is performed in the alkali area, it is easy to handle, without generation of hydrogen gas.

Remark: 1. Flow rate at acid cleaning should be 2 m/s or less.

(b) Mass (mg/㎠) and thickness (㎜) of scales requiring chemical cleaning.

Categories \ Normal pressure	8MPa class	12MPa class	18MPa class	Supercritical pressure
Combustion by coal only		90 to 135mg/㎠ (0.3 to 0.45㎜)	75 to 105mg/㎠ (0.25 to 0.35㎜)	45 to 75mg/㎠ (0.15 to 0.25㎜)
Combustion by coal and oil	90 to 120mg/㎠ (0.3 to 0.4㎜)	75 to 105mg/㎠ (0.25 to 0.35㎜)	60 to 90mg/㎠ (0.20 to 0.30㎜)	36 to 60mg/㎠ (0.12 to 0.20㎜)
Combustion by oil only	75 to 105mg/㎠ (0.25 to 0.35㎜)	60 to 90mg/㎠ (0.20 to 0.30㎜)	45 to 75mg/㎠ (0.15 to 0.25㎜)	24 to 36mg/㎠ (0.08 to 0.12㎜)
Combustion by gas only		90 to 135mg/㎠ (0.3 to 0.45㎜)	75 to 105mg/㎠ (0.25 to 0.35㎜)	45 to 75mg/㎠ (0.15 to 0.25㎜)

Remark: 1. The volume of scales shall take the value on the flame side (180 deg.) of the inner side of the boiler tube.
2. The once-through boiler of 18MPa or less shall take 2／3 of the value in the table.
3. If the operation time exceeds 50,000 hours, chemical cleaning is recommended, for the values below those in the Table.

(c) COD value of 0.1% solution of major chemicals for chemical cleaning*1 (unit: mg/ℓ)

Chemicals	COD	Chemicals	COD	Chemicals	COD
Formic acid	50	EDTA	840	Tin (I) chloride	200
Citric acid	450	Inhibitor	50 to 640	Hydrazine	470
Hydroxyacetic acid	490	Thiourea	840	Sodium sulfite	220

＊1; Oxygen demand by potassium permanganate at 100℃ according to JIS K 0102 (1998).

(2) Chemical decontamination of nuclear reactor

(a) PWR chemical decontamination

(Part 1)

Country Research institute	Name of decontamination	Concentrated or Dilute	Decontaminant mixing ratio			Decontamination conditions			DF	Features	Application to nuclear reactor
			Step	Composition	Concentration	Temperature(℃)	Time (h)	pH			
U.K. NE (Former CEGB)	POD	Dilute	phase I (NP)	Potassium permanganate Nitric acid	1 g/ℓ 0.25 g/ℓ	90	24	2.5	20 (Stainless steel) ~ 50 (Ågesta SG tube)	Oxidation treatment is performed in an acid environment, so rinsing like AP method is not required. This is 1 step method substantially. Only purification at phase Ⅲa, and regeneration and purification of decontaminant at phase Ⅲ b are performed by ion exchange resin..	Not applied
			phase Ⅱ	Oxalic acid Nitric acid	1.4 g/ℓ 1.25 g/ℓ		0.5 to 1				
			phase Ⅲa	Oxalic acid Citric acid Sodium hydroxide	0.45 g/ℓ 0.96 g/ℓ 0.42 g/ℓ	80	5 to 7	to 2.5			
			phase Ⅲb	Oxalic acid Citric acid	0.225 g/ℓ 0.48 g/ℓ	80	5 to 7	2.5			
U.K. NE (Former CEGB)	NP-LOMI	Dilute	step 1 (NP)	Potassium permanganate Nitric acid	1 g/ℓ 0.25 g/ℓ	90	24	2.5	4.3~12 (SGHWR) 25~29 (Ågesta)	The conventional LOMI method can dissolve the crud only which chromium ratio is below 20% . This method can dissolve the crud even if the ratio is over 20% . Rinse is unnecessary, so 1 stage method, in substance. This is advantageous when the nitric acid concentration is high.	Applied (Winfrith SGHWR) Partly applied (Monticello BWR)
			step 2 (LOMI)	LOMI	0.1 to 0.3mass%	80	2 to 6	4.8			
Canada AECL, CRNL	Ozone CAN-DECON	Dilute	step 1	Ozone Chromic acid (as Cr)	to 250μM/ℓ 0.1 g/ℓ	<40 (25)	5	2.7 to 2.8	>100 (SUS304)	The step 2 is CAN-DECON method. The overall effect is similar to but the amount of corrosion waste solution and corrosion rate are smaller than those of AP-Citrox method.	Not applied
			step 2	LND-101	0.1mass %	85					
Sweden STUDSVIK	AP-ACE (improved)	Dilute	step 1 (AP)	Potassium permanganate Sodium hydroxide	1 g/ℓ 1 g/ℓ	90 to 95	10 to 20		10~25 (SG tube AISI304) 3~5 (Inconel 600)	Step 1 uses the AP with diluted solution. Ion exchange resin is used for regeneration and purification.	Not applied
			step 2	EDTA (DTPA) Oxalic acid Citric acid Ascorbic acid	0.5 g/ℓ 0.2 g/ℓ 0.4 g/ℓ 0.4 g/ℓ	90	10 to 20	3.2			

(Part 2)

Country Research institute	Name of decontamination	Concentrated or Dilute	Decontaminant mixing ratio			Decontamination conditions			DF	Features	Application to nuclear reactor
			Step	Composition	Concentration	Temperature(℃)	Time (h)	pH			
U.S.A. Battelle, PNL (EPRI)		Dilute	Single	Hydrogen petroxide Citric acid Boric acid Lithium hydroxide Ammonium hydroxide (for pH value adjustment)	100 mM 50 mM 185 mM 0.3 mM	150 to 180		3.5	Decontamination rate to 0.1%/min	Comparatively high temperature conditions. Use of the ion exchange ion is being studied in the diluent solution step 1 method by oxidizing and chelating agent. Decontamination speed is high.	Not applied
Germany KWU		Dilute	Single	Complex organic acid	250 to 500ppm	90 to 100	80 to 100	2.5 to 3.5	2 to 5 (Expected value)	The special ion exchange resin is used for regeneration and purification.	Not applied
Switzerland SFIRR	AP-AC (improved)	Dilute	step 1 (AP)	Potassium permanganate Sodium hydroxide	4g/ℓ	60	10 to 100		5 to 15 (Ågesta SG tube)	Step 1 uses the electrolytic process to keep the redox potential constant. step 1→ step 2 continuous. The ion exchange resin is used for both regeneration and purification. Low corrosion.	Not applied
			step 2 (AP)	Reducing agent Complexing agent	5 to 40g/ℓ	80 to 95		to 4			
Germany KWU	AP-AC (improved)	Concentrated (hard)	step 1 (AP)	Potassium permanganate Sodium hydroxide	to 50g/ℓ	90 to 100	2 to 4		>10 (Expected value)	Demineralized water is used for cleaning in transfer from step 1 to step 2. For decommissioning of the reactor and decontamination For reactor decommissioning.	Not applied
			step 2 (ACE)	Reducing organic acid Chelating agent Inhibitor (ammonia is used for pH adjustment)	40 to 60g/ℓ	90 to 100	6 to 8	3.5			
Switzerland SFIRR	AP-F	Dilute (hard)	step 1 (AP)	Potassium permanganate Sodium hydroxide	4g/ℓ	60	10 to 100		>100 (Ågesta SG tube)	Step 1 uses the same operating conditions as those of the AP-AC (improved). The ion exchange resin is used for both regeneration and purification in step 2. High corrosion	Not applied
			step 2	Strong acid, including fluoride	3 to 10g/ℓ	80 to 95	10 to 100				

(Part 3)

Country Research institute	Name of decontamination	Concent-rated or Dilute	Decontaminant mixing ratio			Decontamination conditions			DF	Features	Application to nuclear reactor
			Step	Composition	Concentration	Temperature(℃)	Time (h)	pH			
	AP-AC	Dilute	step 1 (AP)	Potassium permanganate Sodium hydroxide	32g/ℓ 105g/ℓ	105	1 to 2		3 to 50	Pretreatment agent to remove chromium oxide generated on the stainless steel surface.	Applied Shippingport Reinsberg Gundremingen
			step 2 (AC)	Diammonium citrate	100g/ℓ	85 to 95	1 to 4	3.5		This is corrosive to carbon steel if corrosion suppression is not provided.	
	AP-Citrox	Concent-rated	step 1 (AP)	Potassium permanganate Sodium hydroxide	32g/ℓ 105g/ℓ	105	1 to 2		3 to 200	Carbon steel is less subjected to corrosion. It is comparatively stable in the presence of carbon steel. This is an agent to remove ion oxides by dissolving without forming sedimentation even after being subjected to the carbon steel at 85℃ for several hours.	Applied (SENA PRTR)
			step 2 (Citorox)	Oxalic acid Diammonium citrate Ion (Ⅱ) nitrate Diethylthiourea	25g/ℓ 50g/ℓ 2g/ℓ 1g/ℓ	85	1 to 4				
U.S.A Dow Chemical IT	dilute-NS-1 modify	Dilute	step 1	Dow pretreatment agent before oxidation (alkaline oxidizing agent)		120	6		(JPDR cleaning system piping)		Not applied
			step 2	dilute NS-1	0.7mass%	120	24				
Germany SIEMENS	CORD	Dilute	step 1	Permanganate acid	0.2g/ℓ	90 to 95	12		20 to (Performed for 3 cycles)	Used for large scale decontamination such as reactor primary system. Operation is simple. Small amount of waste.	Applied (Tsuruga 2)
			step 2	Oxalic acid	2g/ℓ	〃	24				
			step 3	Permanganate acid or UV irradiation		〃	12				

(b) BWR chemical decontamination

Country Research institute	Name of decontamination	Concen-trated or Dilute	Decontaminant mixing ratio		Decontamination conditions			DF	Features	Application to nuclear reactor
			Composition	Concentration	Temperature (℃)	Time (h)	pH			
U.S.A. Dow chemical (DOE)	NS-1	Concent-rated	Chelating agent Organic acid Inhibitor Surfactant	7mass%	120	100 to 200		50 to 100	A great DF is ensured. Low corrosion. Much volume of decontaminated waste water.	Applied (Peach Bottom 2 & 3 Dresden-1)
U.S.A. Dow chemical IT	dilute-NS-1	Dilute	Chelating agent Organic acid Inhibitor Surfactant	0.7mass%	120	24		20 to 50	Decontaminant liquid is cleaned by reverse osmotic membrane treatment.	Applied (Pilgrim)
Canada AECL.CRNL LNL	CAN-DECON LND-101	Dilute	Chelating agent Organic acid	0.1mass%	80 to 130	20 to 30		3 to 10	The ion exchange resin is used for regeneration of decontaminant. Small amount of liquid waste.	Applied (CANDU BWR)
U.S.A. GE, VNC (DOE)	GE-dilute	Dilute	Oxalic acid Citric acid Dissolved oxygen	12mM 5mM 0.75ppm	90	12	3	3 to 5	Ditto (Target set at decontamination of all system including the fuel)	Not applied
U.K. CEGB, BNL (EPRI)	LOMI	Dilute	Vanadium (divalent) Picolinic acid Formic acid Na (for pH adjustment)	12mM 70mM 80mM 70mM	80	2 to 6	4.8	1.1 to 5	Ditto (Reducing metallic ion and chelate ligand are used as decontaminants).	Applied (WSGHWR)
Switzerland SFIRP	Formic acid – formaldehyde method	Concent-rated	Formic acid Formaldehyde method Inhibitor	2M 0.1M 0.01M	40 to 100	>100		to 1000	For BWR and PWR. Most of the radioactive substances are captured by electrolysis and the decontaminant is decomposed into carbon dioxide gas and water.	Not applied
Japan, Hitachi	Electrolytic reduction method	Dilute	EDTA Citric acid Oxalic acid (ammonia is used for pH adjustment)	2mM 100mM 100mM	85		6.5		The target is placed on decontamination in the neutral solution. Reducing agent is generated by electrolysis.	Not applied
Japan, Toshiba	TED-40	Concent-rated	Chelating agent Organic acid Inhibitor	1 to 5%	90	24	3.5	5 to 20	The operation is simple. Waste water is treated by plastic solidification at the site.	Not applied
Germany SIEMENS	CORD	Dilute	Oxalic acid Permanganate acid (UV irradiation)	2g/ℓ 0.2g/ℓ	90 to 95	48 (1 cycle)		20 to	Operation is simple. Small amount of waste. See (a) PWR chemical decontamination.	Applied (2F-3)

17-22 Application of Ion Exchange Resins in Water Treatment

Resin \ Application	For general water treatment					For nuclear power	Remarks
	Make-up demineralization	Polisher	Condensate demineralization	Acid resistance	Resistance against organic contamination		
Strong acidic resin	Amberlite IR-120B,124 Diaion SK1B Dowex HCR-W2,HCR-S Duolite C-20,20HC Lewatit S 100,100WS	Amberlite IR 120B,124, 200C Diaion SK1B Dowex HCR-W2 Duolite C-20 Lewatit S 100MB	Amberlite 200C,201B, XT-1006 Diaion PK216L,228L Dowex HCR-W2,HGR 650C Duolite C-20L,25 Lewatit SP112	Amberlite 200C,IR-124 Diaion PK228,SK110,112 Dowex HGR Duolite C-27 Lewatit 120	Amberlite 252,200C Diaion PK212 Dowex MCP-1 Duolite C-25 Lewatit SP112	Amberlite IRN-77 IR-120B,120BN,201B Diaion SKN1,3 Dowex HCR-W2-H HGR-W2-H Duolite ARC Lewatit S100KR/H Cl-free	1. Manufacturers Amberlite : Rohm & Haas Diaion : Mitsubishi Chemical Industries, Ltd. Dowex : Dow Chemical Duolite : Rohm & Haas Lewatit : Bayer (Mitsui Toatsu Fine Chemicals) 2. Other manufacturers Kastel : Monticatini Permutit : Rit ter Pfaundler Ionac : Sybron
Strong basic resin	Amberlite 1RA-400,410,402 Diaion SA10A,20A,PA416 Dowex SBR,SAR,SBR-P Duolite A-101,102,101D,102D Lewatit 504WS M500,600,MP500,600	Amberlite IRA-400, 402BL,900 Diaion SA10A,11A Dowex SBR,SBR-P Duolite A-101,101D Lewatit M500MB, M504MB	Amberlite IRA-900 Diaion PA312L,316L, 318L Dowex SBR,SBR-P,550A Duolite A-101DL Lewatit MP500	Amberlite IRA-900 Diaion PA318,418 Dowex SBR-P Duolite A-101D Lewatit MP500	Amberlite 1RA-402 450-900 Dian PA312,412 Dowex 11,SRR-P Duolite A-101D,102D Lewatit MP500,M504	Amberlite IRN-78 IRN-400,400T,900 Diai on SAN1 Dowex-P-C-OH Duolite ARA Lewatit M500KR/OH Cl-Free	
Weak acidic resin	Amberlite IRC-50,76, SWA-100 Diaion WK10,11,20 Dowex CS-101,ES-80 Lewatit CNP 80					Duolite CS-100	
Weak basic resin	Amberlite IRA-93,94 Diaion WA20,21,30 Dowex 66 Duolite ES-15,A-30B Lewatit MP62,64			Amberlite IRA-93,94 Diaion WA30 Dowex 4P Duolite ES-57,A-30B Lewatit MP62,64	Amberlite IRA-68,93,94 Diaion WA20,21,30 Duolite A-2,ES-57 Lewatit MP62,64		
Special resin			Powdered resin Diaion FDK10,FMK10 FDA10,FMK10 Powdex PCH,PCN, PAO Epicor PD-1,3 Lewasorb A10,50			(Mixed resin) Amberlite IRN-150,217 Diaion SMN1,3 Dowex RM-3 Duolite ARM Lewatit SM600KR Cl-Free	

Note: Application classification is given as a reference, not based on rigid scientific classification procedure.

17-23 Boiler Water Quality

(1) Water quality of feed water and boiler water for cylindrical boilers (JIS B 8223-1999)

Classification	Maximum allowable working pressure MPa	1 or less			Over 1 up to and including 2
	Evaporating rate on heating surface [kg/(m²・h)]	Max. 30 (¹)	30Over 30 up to and including 60	Over 60	—
	Type of make-up water	Raw water (²)	Softened water (²)		
Feed water	pH (at 25℃)	5.8 to 9.0	5.8 to 9.0	5.8 to 9.0	5.8 to 9.0
	Hardness (mgCaCO₃/*l*)	Max. 60	Max. 1	Max. 1	Max. 1
	Oil and fat (mg/*l*) (³)	(⁴)	(⁴)	(⁴)	(⁴)
	Dissolved oxygen (mgO/*l*)	(⁴)	(⁴)	(⁴)	(⁴)
Boiler water	Treatment	By alkali			
	pH (at 25℃)	11.0 to 11.8	11.0 to 11.8	11.0 to 11.8	11.0 to 11.8
	Acid consumption(pH4.8)(mgCaCO₃/*l*)	100 to 800	100 to 800	100 to 800	Max. 600
	Acid consumption(pH8.3)(mgCaCO₃/*l*)	80 to 600	80 to 600	80 to 600	Max. 500
	Total residue after evaporation (mg/*l*)	Max. 4 000	Max. 3 000	Max. 2 500	Max. 2 300
	Conductivity (mS/m)(at 25℃)	Max. 600	Max. 450	Max. 400	Max. 350
	Chloride ion(mgCl⁻/*l*)	Max. 600	Max. 500	Max. 400	Max. 350
	Phosphate ion(mgPO₄³⁻/*l*) (⁵)	20 to 40	20 to 40	20 to 40	20 to 40
	Sulfite ion(mgSO₃²⁻/*l*) (⁶)	10 to 50	10 to 50	10 to 50	10 to 50
	Hydrazine(mgN₂H₄/*l*) (⁷)	0.1 to 1.0	0.1 to 1.0	0.1 to 1.0	0.1 to 1.0

Note:

(¹) Applied to the case of the cast-iron boiler using raw steam and make-up water at all times.

(²) City water, industrial water, underground water, river water, lake water, etc. The softened water refers to the raw water treated by water softening equipment (filled with cation exchange resin) or by reverse osmotic treatment.

(³) Hexane extract (refer to JIS B 8224).

(⁴) Preferable to keep at a lower value

(⁵) Applied when phosphate is added.

(⁶) Applied when sulfite is added for deoxidation. Preferable to adjust to 10 through 20 $mgSO_3^{2-}/\ell$, when the de-aerator is used.

(⁷) Applied when hydrazine is added for deoxidation to cylindrical boiler and water tube boiler with the maximum allowable working pressure of 2 MPa or less. However, preferable to adjust to 0.1 through 0.5 mg N_2H_4/ℓ, when the de-aerator is used. In addition, hydrazine desolutes and exists as hydrazine ion ($N_2H_5^+$) in a boiler water.

Remark:

1. In using ion exchange for makeup water of cylindrical boiler, it applies the water quality of section (2), that is demineralized water for makeup water of the pressure classification of the exceeding 1 MPa and 2 MPa or less.
2. In using for ships, it applies the water quality of section (2), which is demineralized water for makeup water of the pressure classification of the exceeding 1 MPa and 2 MPa or less. However, the concentration of phosphate ion is preferable to be adjusted higher in consideration of sea water leakage.
3. Either hydrazine or sulfite selected for deoxidation is added in principle.
4. The sample to test the boiler water shall be taken from the position where the boiler water is most concentrated.
5. In case of boiler used in the pressure of the exceeding 2 MPa, it applies water quality of the water tube boiler shown as section (2) and same classification.

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(2) Water quality of feed water and boiler water for water tube boilers (circulation boilers) (JIS B 8223-1999)

Classification	Maximum allowable working pressure MPa	1 or less		Over 1 up to and including 2			Over 2 up to and including 3		Over 3 up to and including 5	
	Evaporating rate on heat heating surface (kg/(m²・h))	Max. 50	over 50	—	—		—		—	
	Type of make-up water	Softened water (²)			Ion exchange water (⁸)		Ion exchange water (⁸)		Ion exchange water (⁸)	
Feed water	pH (at 25℃)	5.8 to 9.0	5.8 to 9.0	5.8 to 9.0	8.8 to 9.5		8.8 to 9.5		8.8 to 9.5	
	Conductivity (mS/m) (at 25℃)	–	–	–	–		–		–	
	Hardness (mgCaCO₃/*l*)	Max. 1	Max. 1	Max. 1	Not detected (¹²)		Not detected (¹²)		Not detected (¹²)	
	Oil and fat (mg/*l*) (³)	(⁴)	(⁴)	(⁴)	(⁴)		(⁴)		(⁴)	
	Dissolved oxygen (μgO/*l*)	(⁴)	(⁴)	Max. 500	Max. 500		Max. 100		Max. 30	
	Iron (μgFe/*l*)	–	Max. 300	Max. 300	Max. 100		Max. 100		Max. 100	
	Copper (μgCu/*l*)	–	–	–	–		–		Max. 50	
	Hydrazine (mgN₂H₄/*l*) (²²)	–	–	–	–		0.2Min.		0.06Min.	
Boiler water	Treatment	By alkali matters				By phosphate treatment	By alkali matters	By phosphate treatment	By alkali matters	By phosphate treatment
	pH (at 25℃)	11.0 to 11.8	11.0 to 11.8	11.0 to 11.8	10.5 to 11.5	9.8 to 10.0	10.0 to 11.0	9.4 to 10.5	9.6 to 10.8	9.4 to 10.5
	Acid consumption(pH4.8)(mgCaCO₃/*l*)	100 to 800	100 to 800	Max. 600	Max. 250	Max. 130	Max. 150	Max. 100	–	–
	Acid consumption(pH8.3)(mgCaCO₃/*l*)	80 to 600	80 to 600	Max. 500	Max. 200	Max. 100	Max. 120	Max. 80	–	–
	Total residue after evaporation (mg/*l*)	Max. 3 000	Max. 2 500	Max. 2 000	–	–	–	–	–	–
	Conductivity (mS/m) (at 25℃)	Max. 450	Max. 400	Max. 300	Max. 150	Max. 120	Max. 100	Max. 80	Max. 80	Max. 60
	Chloride ion (mgCl⁻/*l*)	Max. 500	Max. 400	Max. 300	Max. 150	Max. 150	Max. 100	Max. 100	Max. 80	Max. 80
	Phosphate ion (mgPO₄³⁻/*l*) (⁵)	20 to 40	20 to 40	20 to 40	10 to 30	10 to 30	5 to 15	5 to 15	5 to 15	5 to 15
	Sulfite ion (mgSO₃²⁻/*l*)	10 to 50 (⁶)	10 to 50 (⁶)	10 to 20	10 to 20	10 to 20	5 to 10	5 to 10	5 to 10	5 to 10
	Hydrazine (mgN₂H₄/*l*) (⁷)	0.1 to 1.0	0.1 to 1.0	0.1 to 0.5	0.1 to 0.5	0.1 to 0.5	–	–	–	–
	Silica (mgSiO₂/*l*)	–	–	–	Max. 50	Max. 50	Max. 50	Max. 50	Max. 20	Max. 20

Note:

(⁸) Water purified by the demineralizer using the strong acidic ion exchange resin and strong basic ion exchange resin. It also includes the water (condensed water) refined by the evaporator.

(⁹) Preferable to adjust pH to a higher value, when the feed water heater tube material is steel.

(¹⁰) Measure the sample by passing it through the column filled with strong acidic cation exchange resin in the form of the hydrogen ion.

(¹¹) Preferable to be 0.01 or less.

(¹²) When hardness is calculated using minimum limit of determination of the applied examination method of the calcium and magnesium of JIS B 8224, it is the value lower than that calculated value.

(2) Water quality of feed water and boiler water for water tube boilers (circulation boilers)(JIS B 8223-1999) (continuation of a front page)

Classification	Maximum allowable working pressure MPa	Over 5 up to and including 7.5			Over 7.5 up to and including 10		Over 10 up to and including 15			Over 15 up to and including 20		
	Evaporating rate on heat heating surface [kg/(m²·h)]	—			—		—			—		
	Type of make-up water	Ion exchange water (8)			Ion exchange water (8)		Ion exchange water (8)			Ion exchange water (8)		
Feed water	Treatment	—			—		—		Oxygen treatment	—		Oxygen treatment
	pH (at 25℃)	8.5 to 9.5 (9)			8.5 to 9.5 (9)		8.5 to 9.5 (9)		8.0 to 9.3	8.5 to 9.6 (9)		8.0 to 9.3
	Conductivity(mS/m)(at 25℃)	—			—		Max. 0.05 (10)		Max. 0.02(10)(11)	Max. 0.05 (10)		Max. 0.02(10)(11)
	Hardness (mg$CaCO_3$/l)	Not detected (12)			Not detected (12)		Not detected (12)		Not detected (12)	Not detected (12)		Not detected (12)
	Oil and fat (mg/l) (3)	(4)			(4)		(4)		(4)	(4)		(4)
	Dissolved oxygen (μgO/l)	Max. 7			Max. 7		Max. 7		20 to 200	Max. 7		20 to 200
	Iron (μgFe/l)	Max. 50			Max. 30 (13)		Max. 30 (13)		Max. 30 (13)	Max. 20 (14)		Max. 20 (14)
	Copper (μgCu/l)	Max. 30			Max. 20		Max. 10		Max. 10	Max. 5		Max. 5
	Hydrazine (mgN_2H_4/l) (22)	Min. 0.01			Min. 0.01		Min. 0.01		—	Min. 0.01		—
Boiler water	Treatment	By alkali matters	By phosphate matters	By volatile treatment	By phosphate matters	By volatile treatment	By phosphate matters	By volatile treatment	— (17)	By phosphate matters	By volatile treatment	— (17)
	pH (at 25℃)	9.6 to 10.5	9.2 to 10.2(15)	8.5 to 9.5	9.2 to 10.0(15)	8.5 to 9.5	8.5 to 9.8(16)	8.5 to 9.6	8.0 to 9.3(17)	8.5 to 9.8	8.5 to 9.6	8.0 to 9.3(17)
	Acid consumption(pH4.8)(mg$CaCO_3$/l)	—	—	—	—	—	—	—	—	—	—	—
	Acid consumption(pH8.3)(mg$CaCO_3$/l)	—	—	—	—	—	—	—	—	—	—	—
	Total residue after evaporation (mg/l)	—	—	—	—	—	—	—	—	—	—	—
	Conductivity(mS/m)(at 25℃)	Max. 50	Max. 40	Max. 6(10)	Max. 15	Max. 6(10)	Max. 6	Max. 2(10)	Max. 0.3 (10)	Max. 6	Max. 2(10)	Max. 0.3 (10)
	Chloride ion (mgCl^-/l)	Max. 50	Max. 50	Max. 2	Max. 10	Max. 2	Max. 2	Max. 1	Max. 0.05(18)	Max. 2	Max. 1	Max. 0.05(18)
	Phoshate ion (mgPO_4^{3-}/l) (5)	3 to 10	3 to 10(15)	(19)	2 to 6(15)	(19)	0.1 to 3(15)	(19)	—	0.1 to 3	(19)	—
	Sulfite ion (mgSO_3^{2-}/l)	—	—	—	—	—	—	—	—	—	—	—
	Hydrazine (mgN_2H_4/l) (7)	—	—	—	—	—	—	—	—	—	—	—
	Silica (mgSiO_2/l)	Max. 5(20)	Max. 5(20)	Max. 5(20)	Max. 2(20)	Max. 2(20)	Max. 0.3(20)	Max. 0.3(20)	Max. 0.3(20)	Max. 0.2(20)	Max. 0.2(20)	Max. 0.2(20)

Note:

(13) Preferable to keep at 20 μgFe/l or less.

(14) Preferable to keep at 10 μgFe/l or less.

(15) Preferable to adjust pH to 9.5 through 10.7, in case of the waste heat recovery boiler of the pressure of the exceeding 5 MPa and 10 MPa or less, and adjust the concentration of the phosphate ion to keep this pH.

(16) Preferable to adjust pH to 9.0 through 10.0, in case of the waste heat recovery boiler of the pressure of the exceeding 10 MPa and 15 MPa or less, and adjust the concentration of the phosphate ion to keep this pH.

(17) Dissolved oxygen concentration in boiler water becomes low. Ammonia or volatile amine is used to adjust pH.

(18) Test in according to article 5 and the note (6) of JIS K 0556.

(19) If calcium, magnesium and other components that will reduce pH are mixed by sea water leakage to the condenser, add the required phosphate sodium hydroxide corresponding to the entrained amount of these components for corrective actions.

(20) Keep the concentration of the silica in the boiler water so that the concentration of silica in steam will be 0.02mg SiO2/l (20 μg SiO2/l) or less, from the relationship between the silica concentration in the boiler water and in the steam.

Remark:

6. By Remark 3.
7. In using for ships, it applies the water quality of section (2), which is demineralized water for makeup water of the same pressure classification. However, the concentration of phosphate ion is preferable to be adjusted higher in consideration of sea water leakage. And in case of 1 MPa or less, applied the water quality of section (2), which is demineralized water for makeup water of the pressure classification of the exceeding 1 MPa and 2 MPa or less. However, the concentration of phosphate ion is preferable to be adjusted higher in consideration of sea water leakage.

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(3) Water quality of feed water and boiler water for special circulation boilers (JIS B 8223-1999)

Classification	Boiler type	Single tube boiler		Multi-tubular boiler	
	Maximum allowable working pressure MPa	1 or less	Over 1 up to and including 3	1 or less	Over 1 up to and including 3
	Type of make-up water	Softened water (2)		Softened water (2)	
Feed water	pH (at 25℃)	11.0 to 11.8	10.5 to 11.0	5.8 to 9.0	5.8 to 9.0
	Hardness (mg$CaCO_3$/l)	Max. 1 (21)	Max. 1 (21)	Max. 1	Max. 1
	Oil and fat (mg/l) (3)	(4)	(4)	(4)	(4)
	Dissolved oxygen (mg$O$/l)	(4)	(4)	(4)	Max. 0.5
	Iron (mgFe/l)	—	—	Max. 0.3	Max. 0.3
	Total residue after evaporation (mg/l)	Max. 3 000	Max. 2 500	—	—
	Conductivity(mS/m) (at 25℃)	Max. 450	Max. 400	—	—
	Acid consumption(pH4.8) (mg$CaCO_3$/ l)	300 to 800	Max. 600	—	—
	Acid consumption(pH8.3) (mg$CaCO_3$/ l)	200 to 600	Max. 500	—	—
	Hydrazine(mgN_2H_4/l) (22)	Min. 0.05	Min. 0.05	—	—
	Chloride ion(mgCl^-/l)	Max. 600	Max. 400	—	—
	Phoshate ion(mgPO_4^{3-}/l) (5)	20 to 60	20 to 60	—	—
Boiler water	Treatment	—		Alkali treatment	
	pH (at 25℃)	—		11.0 to 11.8	11.0 to 11.8
	Acid consumption(pH4.8) (mg$CaCO_3$/ l)	—		100 to 800	Max. 600
	Acid consumption(pH8.3) (mg$CaCO_3$/ l)	—		80 to 600	Max. 500
	Total residue after evaporation (mg/l)	—		Max. 2 500	Max. 2 000
	Conductivity(mS/m) (at 25℃)	—		Max. 400	Max. 300
	Chloride ion(mgCl^-/l)	—		Max. 400	Max. 300
	Phoshate ion(mgPO_4^{3-}/l) (5)	—		20 to 40	20 to 40
	Sulfite ion(mgSO_3^{2-}/l) (6)	—		10 to 50	10 to 20
	Hydrazine(mgN_2H_4/l) (7)	—		0.1 to 1.0	0.1 to 0.5

Note:

(21) Applied to the feed water before the return water is mixed.

(22) Applicable when hydrazine is added for deoxidation. Hydrazine concentration can also be decreased according to the dissolved oxygen concentration at a deaerator exit while the pH does not exceed the maximum. In addition, hydrazine dissolves and exists as hydrazine ion ($N_2H_5^+$) in a water.

Remark:

8. In using ion exchange for makeup water of the special circulation boiler, it applies the water quality of section (2), which is demineralized water for makeup water of the pressure classification of the exceeding 1 MPa and 2 MPa or less.
9. In using for ships, it applies the water quality of section (2), which is demineralized water for makeup water of the same pressure classification of the exceeding 1 MPa and 2 MPa or less. However, the concentration of phosphate ion is preferable to be adjusted higher in consideration of sea water leakage. And in case of 1 MPa or less, it applies the water quality of section (2), which is demineralized water for makeup water of the pressure classification of the exceeding 1 MPa and 2 MPa or less. However, the concentration of phosphate ion is preferable to be adjusted higher in consideration of sea water leakage.
10. The feed water quality of the single tube boiler is applied to chemicals added to the makeup water or the water composed of the mixture between makeup water and condensate supplied with return water.
11. The feed water quality of the multi tube boiler is applied to the feed water before return water is added. The position of sampling is considered 2 points of gas-liquid separator lower part and body lower part with the structure of the boiler marketed now. As it is considered that the former sample is concentrated, it is adjusted slightly high value of water quality. And in case of latter, as water quality may become non-uniformity during operation, the attention is paid to the sampling location and sampling time for obtaining the sample equalized as much as possible.
12. By remarks: 3.

(4) Water quality of feed water for once-through boilers (JIS B 8223-1999)

Classification	Maximum allowable working pressure MPa	Over 7.5 up to and including 10		Over 10 up to and including 15		Over 15 up to and including 20		Over 20	
	Treatment	Volatile material treatment	By oxygen treatment	Volatile material treatment	By oxygen treatment	Volatile material treatment	By oxygen treatment	Volatile material treatment	By oxygen treatment
Feed water	pH (at 25℃) (23)	8.5 to 9.6 (9)	6.5 to 9.3 (24)	6.5 to 9.6 (9)	6.5 to 9.3 (24)	8.5 to 9.6 (9)	6.5 to 9.3 (24)	9.0 to 9.7 (9)	6.5 to 9.3 (24)
	Conductivity(mS/m) (10) (at 25℃) (μS/m) (10) (at 25℃)	Max. 0.03 Max. 30	Max. 0.02 Max. 20	Max. 0.03 Max. 30	Max. 0.02 Max. 20	Max. 0.03 Max. 30	Max. 0.02 Max. 20	Max. 0.025 Max. 25	Max. 0.02 Max. 20
	Dissolved oxygen (μgO/*l*)	Max. 7	20 to 200 (25)	Max. 7	20 to 200 (25)	Max. 7	20 to 200 (25)	Max. 7	20 to 200 (25)
	Iron (μgFe/*l*)	Max. 30 (13)	Max. 20	Max. 20	Max. 10	Max. 20	Max. 10	Max. 10	Max. 10
	Copper (μgCu/*l*)	Max. 18	Max. 18	Max. 5	Max. 10	Max. 3	Max. 5 (26)	Max. 2	Max. 2
	Hydrazine (μgN₂H₄/*l*) (27)	Min. 10	–	Min. 10	–	Min. 10	–	Min. 10	–
	Silica (μgSiO₂/*l*)	Max. 40 (28) Max. 20 (29)	Max. 20	Max. 30 (28) Max. 20 (29)	Max. 20	Max. 20	Max. 20	Max. 20	Max. 20

Note:

(23) Add ammonia or volatile amine to adjust pH.

(24) Preferable to adjust pH to 8.0 through 8.5, when copper alloy is used for the system.

(25) It should be made the value suitable to minimize iron and copper concentration of feed water in this treatment.

(26) Preferable to keep at 3μgCu/*l* or less.

(27) The hydrazine concentration shall be the value not to exceed the upper limit of pH, and can reduce in accordance with dissolved oxygen concentration at deaerator outlet.

(28) Applied to the boiler with separator.

(29) Applied to the boiler without separator.

Remark:

13. The water quality of the once-through boiler having a maximum allowable working pressure of over 15 MPa after the initial stat-up shall be as specified in (6), in principle.

(5) Quality of steam generated from boilers (30)

Item	Standard value
Electric Conductivity(mS/m) (10) (at 25℃) (μS/m) (10) (at 25℃)	Max. 0.03 Max. 30
Silica (μgSiO₂/*l*)	Max. 20

Note: (30) This applies to the boiler using the ion exchang water as feed water during the normal operation (except for start-up period) when steam is fed to the turbine.

(6) Water quality during the start-up of once-through boilers (when treatment by volatile substances is applied).

Classification		Process	Circulation before firing (boiler cold clean-up)		Circulation during increased temperature and pressure		Load operation (1/2MCR (35) or less)	
		Maximum allowable working pressure MPa	Over 15 up to and including 20	Over 20	Over 15 up to and including 20	Over 20	Over 15 up to and including 20	Over 20
Feed water	Economizer inlet	pH (at 25℃)	8.5 to 9.6 (9)	9.0 to 9.6	8.5 to 9.6 (9)	9.0 to 9.6	8.5 to 9.6 (9)	9.0 to 9.6
		Electric Conductivity(mS/m) (10) (at 25℃) (μS/m) (10) (at 25℃)	Max. 0.1 Max. 100	Max. 0.1 Max. 100	Max. 0.1 Max. 100	Max. 0.1 Max. 100	Max. 0.1 Max. 100	Max. 0.1 Max. 100
		Disolved oxygen (μgO/*l*)	Max. 40 (31)	Max. 20 (31)	Max. 10	Max. 10	Max. 7	Max. 7
		Iron (μgFe/*l*)	Max. 200	Max. 100	Max. 100	Max. 50	Max. 30	Max. 30
		Copper (μgCu/*l*)	Max. 20	Max. 20	Max. 20	Max. 10	Max. 5	Max. 5
		Hydrazine (μgN₂H₄/*l*)	Min. 20 (32)	Min. 20 (32)	Min. 20	Min. 20	Min. 10	Min. 10
		Silica (μgSiO₂/*l*)	Max. 30	Max. 30	Max. 30	Max. 30	Max. 30	Max. 30
	Furnace water wall outlet	Electric Conductivity(mS/m) (10) (at 25℃) (μS/m) (10) (at 25℃)	Max. 0.1 Max. 100	Max. 0.1 Max. 100	Max. 0.1 Max. 100	Max. 0.1 Max. 100	–	–
		Iron (μgFe/*l*)	Max. 300	Max. 300	Min. 200 (33)	Min. 100 (34)	–	–

Note:

(31) This may be the target for some boiler types.

(32) Preferable to adjust the hydrazine concentration at a higher value to promote formation of the protective film inside the system, when starting after long intervals stopping. In addition, hydrazine dissolves and exists as hydrazine ion ($N_2H_5^+$) in a water.

(33) The target of iron concentration is 100μgFe/*l* or less.

(34) The target of iron concentration is 50μgFe/*l* or less.

(35) An abbreviation for the maximum continuous rating.

17-24 Reactor Water Quality

(1) Example of standard values for water quality control of PWR secondary system

SG water

Item	Standard value
pH at 25 ℃	8.6 to 9.1
Cation conductivity (mS/m)	≦0.1
Na^+ 〔μg/ℓ〕	≦20
Cl^- 〔μg/ℓ〕	≦20
SO_4 〔μg/ℓ〕	≦20
Na/Cl molar ratio	0.5±0.2
SiO_2 〔μg/ℓ〕	≦500

Feed water

Item	Standard value
PH at 25℃	8.8 to 9.3
O_2 〔μg/ℓ〕	≦5.0
N_2H_4 〔μg/ℓ〕	≧5.0
Total Fe 〔μg/ℓ〕	≦20
Total Cu 〔μg/ℓ〕	≦5.0
Total Ni 〔μg/ℓ〕	≦5.0

(2) Example of standard values for water quality control of BWR reactor water and feed water

Reactor water

Measuring item	Standard value
Conductivity (mS/m)	≦0.1
pH	5.6 to 8.6
Chloride ion 〔μg/ℓ〕	≦100
Silica 〔μg/ℓ〕	≦1000

Feed water

Measuring item	Standard value
Conductivity (mS/m)	≦0.01
pH	6.5 to 7.5
Chloride ion 〔μg/ℓ〕	Max.200, Min.20
Total metallic impurities (as Fe, Cu, Ni, Cr) 〔μg/ℓ〕	≦15
Total copper (as Cu) 〔μg/ℓ〕	≦ 2

〔Source: Introductory couse "Chemical Management in Themal and Nuclear Power Plant," Thermal and Nuculer Power Engineering Society: Vol.43 (1992) p.1323 to p.1354〕

17-25 Condensate Demineralizer

(1) Purpose of installation

a. Removal of impurities and corrosion products carried into the system.

b. Removal of substance (sea water) leaked into condenser.

c. Removal of impurities in makeup water.

d. Prevention of free alkali production in the system (PWR).

(2) Comparison of condensate demineralizer system

	H-OH cycle	NH_4-OH cycle
Resin	H type strongly acid cation exchange resin OH type strongly basic anion exchange resin	NH_4 type strongly acid cation exchange resin OH type strongly basic anion exchange resin
Substances removed from condensate	All dissolved solids All suspended solids (corrosion products)	All dissolved solids except for NH_4 All suspended solids (corrosion products)
Applied plant	BWR, PWR, thermal power plant	Thermal power plant

(3) An example of water quality at condensate demineralizer outlet

a Thermal power

	H-OH cycle	NH_4-OH cycle
All dissolved solids	Max. 25μg/ℓ	Max. 25μg/ℓ (except forNH_4)
Suspended	Max. 20μg/ℓ	Max. 20μg/ℓ
Silica	Max. 10μg-SiO_2/ℓ	Max. 10μg-SiO_2/ℓ
Copper	Max. 2μg-Cu/ℓ	Max. 2μg-Cu/ℓ
Iron	Max. 5μg-Fe/ℓ	Max. 5μg-Fe/ℓ
Conductivity	Max. 0.01mS/m	Max. 0.01mS/m(acid conductivity)
Sodium	—	Max. 5μg-Na/ℓ

b PWR

	H-OH cycle
Conductivity	Max. 0.01mS/m
Sodium ion	Max. 0.06μg-Na/ℓ Goal Max. 0.02μg-Na/ℓ
Chloride ion	Max. 0.15μg-Cl/ℓ Goal Max. 0.02μg-Cl/ℓ
Na/Cl molar ratio	0.5±0.2
Silica	Max. 0.02mg-SiO_2/ℓ
Iron	Max. 0.005mg-Fe/ℓ
Copper	Max. 0.002mg-Cu/ℓ

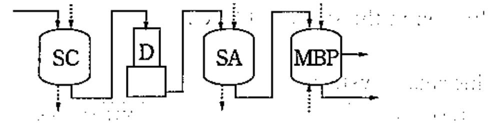
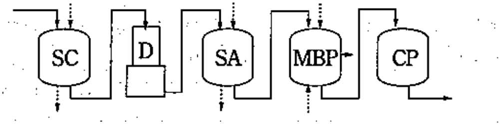
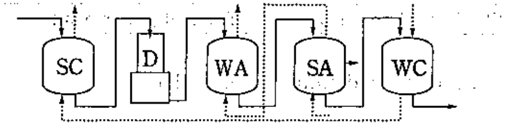
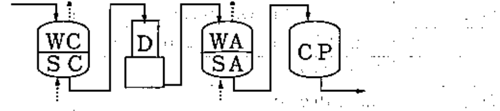
c BWR

	H-OH cycle
Conductivity	Max. 0.01mS/m
Silica	Max. 0.01mg-SiO_2/ℓ
Chloride ion	Max. 0.001mg-Cl/ℓ
pH	6.7 to 7.5
Total metallic impurities	Max. 10μg/ℓ Max. 2μg-Cu/ℓ

17-26 Water Purification System

(1) Resin type water purification system

The resin type water purification system is applied to various water purification systems. The examples of the system configuration are as shown below.

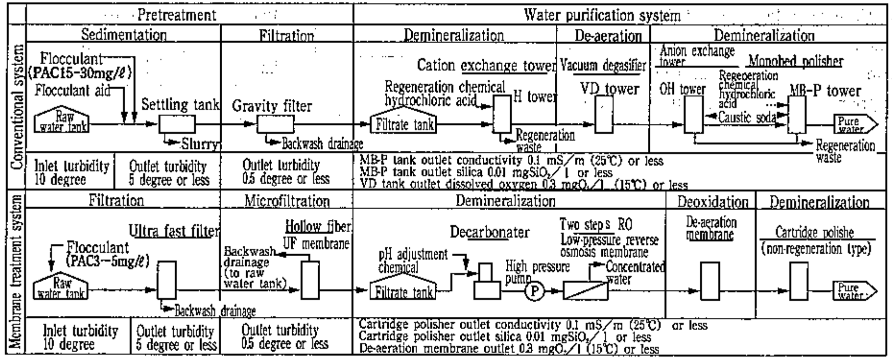
	System composition	Remarks
2B3T+ MBP		Most standard water purification system.
2B3T+ MBP+ CP		The system which attains the water quality of a condensate demineralizer system outlet level by installing non-regeneration type mixed bed
4B5T		The system obtained by the few regeneration chemicals in water quality equivalent to 2B3T+MBP.
Double bed method		The system which require minimum time and chemicals for regeneration, but produce high quality water.

Note:

—▶ : In service, ---▶: Chemical regeneration, SC: Strong acidic cation exchange resin, SA: Strong basic anion exchange resin, D: Decarboxylation tank, WC: Weak acidic cation exchange resin, WA: Weak basic anion exchange resin, MBP: Regeneration type mixed bed demineralizer, CP: Non regeneration type mixed bed demineralizer

(2) Membrane type water purification system

Membrane type water purification system is the equipment which use the ultra-filtration membrane and the reverse osmosis membrane, and has technology which attracts attention in recent years for the advantage as follows. (a) Strong acid and strong base drainage do not occur. (b) Processed water quality is stable. (c) Operation management is easy. (d) An installation space is small. The example of composition comparison with a conventional system is shown below.



〔Source: Yuuichi Yokomizo, Resent makeup water treatment equipment for power plant, Journal of water and waste, 39(1), 38-42 (1997)〕

17-27 Standards for Industrial Chemicals

(1) Hydrochloric acid (synthetic) HCl (JIS K 1310-1959) Molecular weight=36.46

Type Composition	NO.1	NO.2	NO.3
Hydrochloric acid (%)	Min. 37	Min. 35	Min. 35
Iron (as Fe) (%)	Max. 0.0005	Max. 0.002	−
Ignition residue (%)	Max. 0.005	Max. 0.01	−

(2) Sulfuric acid (concentrated sulfuric acid) H_2SO_4 (JIS K 1321-1994) Molecular weight=98

Type		Sulfuric acid content (H_2SO_4) %	Ignition residue %	Iron (Fe) %
Concentrated sulfuric acid	93% Sulfuric acid	Indicated Sulfuric acid content or more	Max. 0.05	Max. 0.03
	95% Sulfuric acid			
	98% Sulfuric acid			

(3) Caustic soda NaOH Molecular weight=40

(a) Solid caustic soda (JIS K 1202-1981)

Type	No.1	No.2	No.3	No.4
Sodium hydroxide (NaOH)	Min. 98%	Min. 97%	Min. 96%	Min. 94%
Sodium carbonate (Na_2CO_3)	Max. 2%	Max. 2%	Max. 2%	Max. 2%
Sodium chloride (NaCl)	Max. 0.15%	Max. 1.0%	Max. 2.8%	Max. 3.2%
Ferric oxide (Fe_2O_3)	Max. 0.005%	Max. 0.005%	Max. 0.008%	Max. 0.008%

(b) Liquid caustic soda (JIS K 1203-1981) containing 45% of sodium hydroxide (NaOH)

Type	No.1	No.2	No.3	No.4
Sodium carbonate (Na_2CO_3)	Max. 1%	Max. 1%	Max. 1%	Max. 1%
Sodium chloride (NaCl)	Max. 0.1%	Max. 0.5%	Max. 1.3%	Max. 1.6%
Ferric oxide (Fe_2O_3)	Max. 0.005%	Max. 0.01%	Max. 0.02%	Max. 0.03%

(4) Liquid chlorine Cl_2 (JIS K 1102-1959) Molecular weight=70.91

The quality of the liquid chlorine shall confirm to the following.

Chlorine(as Cl2) 99.4% or more

(5) Soda ash Na_2CO_3 (JIS K 1201-1950) Molecular weight=83

Type	Light ash	Heavy ash
Apparent specific gravity	less 1.0	Min. 1.0
Weight reduced by heating	Max. 1.0	Max. 1.0%
Total alkali (as Na_2CO_3)	Min. 99%	Min. 99%
Sodium chloride (NaCl)	Max. 0.5%	Max. 0.5%
Ferric oxide (Fe_2O_3)	Max. 0.01%	Max. 0.01%
Water insoluble contents	Max. 0.2%	Max. 0.2%

(6) Aluminum sulfate $Al_2(SO_4)_3 \cdot H_2O$ (JIS K 1423-1970)

Aluminum sulfate as industrial chemicals (solid and liquid)

Type / Item	Solid, special	Solid No.1		Solid No.2	Liquid
		Class 1	Class 2		
External appearance	—	—	—	—	Colorless or yellowish light brown liquid
pH	Min. 3.0	Min. 3.0	Min. 3.0	Min. 2.5	Min. 3.0
Aluminum oxide (Al_2O_3) (%)	Min. 17.0	Min. 15.0	Min. 14.0	Min. 14.0	Min. 8.0
Iron (Fe) (%)	Max. 0.01	Max. 0.01	Max. 0.01	Max. 1.5	Max. 0.02
Water insoluble content (%)	Max. 0.1	Max. 0.1	Max. 0.1	Max. 0.3	—

(7) Aluminum sulfate for waterworks $Al_2(SO_4)_3 \cdot xH_2O$ (JIS K 1450-1996)

Aluminum sulfate for waterworks (solid and liquid)

Type / Item		Solid	Liquid
External appearance		—	Colorlessness or yellowish light brown clear liquid
Aluminum oxide (Al_2O_3)	(%)	Min. 15.0	8.0 to 8.2
pH		Min. 3.0	Min. 3.0
Insoluble content	(%)	Max. 0.1	—
Ammonia nitrogen (N)	(mg/ℓ)	Max. 300	Max. 100
Arsenic (As)	(mg/ℓ)	Max. 4	Max. 2.0
Iron (Fe)	(mg/ℓ)	Max. 600	Max. 200
Manganese (Mn)	(mg/ℓ)	Max. 25	Max. 15
Cadmium (Cd)	(mg/ℓ)	Max. 2.0	Max. 1.0
Lead (Pb)	(mg/ℓ)	Max. 10	Max. 5
Mercury (Hg)	(mg/ℓ)	Max. 0.2	Max. 0.1
Chromium (Cr)	(mg/ℓ)	Max. 10	Max. 5

(8) Sodium phosphate (Orthosodium phosphate) (JIS K 1437-1956)

Type / Component		Sodium phosphate monobasic	Sodium phosphate dibasic	Sodium phosphate tribasic $Na_3PO_4 \cdot 12H_2O$	
		$NaH_2PO_4 \cdot 2H_2O$	$Na_2HPO_4 \cdot 12H_2O$	No.1	No.2
Pure component	(%)	Min. 98	Min. 98	Min. 97.5	Min. 98
Phosphoric anhydride (P_2O_5)	(%)	Min. 44.6	Min. 19.45	Min. 18.2	Min. 17.75
Water insoluble content	(%)	Max. 0.1	Max. 0.1	Max. 0.1	Max. 0.1
Iron	(%)	Max. 0.05	Max. 0.05	Max. 0.01	Max. 0.05
Methyl orange alkalinity (Na_2O)	(%)	—	8.2 to 8.9	16.0 to 17.9	15.5 to 18.0
Phenolphthalein alkalinity (Na_2O)	(%)	18.8 to 20.0	—	—	—
Arsenic (As)	(%)	Max. 0.005	Max. 0.005	Max. 0.005	Max. 0.01

(9) Sodium sulfite (crystal) (JIS K 1418-1958)
Sodium sulfite (anhydride) (JIS K 1419-1958)

(1) Molecular weight = 252.16
(2) Molecular weight = 126.05

Type / Component		Sodium sulfite (crystal) $Na_2SO_3 \cdot 7H_2O$ (1)		Sodium sulfite (anhydride) Na_2SO_3 (2)	
		No.1	No.2	No.1	No.2
Water soluble		Transparent or almost transparent	—	—	—
Sodium sulfite	(%)	Min. 95.0 ($Na_2SO_3 \cdot 7H_2O$)	Min. 90.0	Min. 97.0 (Na_2SO_3)	Min. 90.0
Sodium sulfate	(%)	Max. 1.25	—	Max. 2.5	—
Sodium chloride	(%)	Max. 0.05	Max. 0.25	Max. 0.1	Max. 0.5
Iron	(%)	Max. 0.001	Max. 0.02	Max. 0.003	Max. 0.02
Sodium carbonate	(%)	Max. 0.05	—	Max. 0.1	—

(10) Aluminum polychloride for waterworks $[Al_2(OH)_nCl_{6-n}]_m$ (JIS K 1475-1996)

Specific gravity (20℃)		Min. 1.19
Aluminum oxide (Al_2O_3)	(%)	10.0 to 11.0
Alkalinity	(%)	45 to 65
pH (10g/ℓ solution)		3.5 to 5
Sulfate ion (SO_4^{2-})	(%)	Max. 3.5
Ammonia nitrogen (N)	(mg/ℓ)	Max. 100
Arsenic (As)	(mg/ℓ)	Max. 1.0
Iron (Fe)	(mg/ℓ)	Max. 100
Manganese (Mn)	(mg/ℓ)	Max. 15
Cadmium (Cd)	(mg/ℓ)	Max. 1.0
Lead (Pb)	(mg/ℓ)	Max. 5
Mercury (Hg)	(mg/ℓ)	Max. 0.1
Chromium (Cr)	(mg/ℓ)	Max. 5

(11) Sodium hypochlorite for waterworks [NaClO] (JWWA K 120-1972)

Effective chlorine	(%)	Min. 5
Free alkali	(%)	Max. 2
Insoluble	(%)	Max. 0.01
Mercury	(mg/ℓ)	Max. 1
Arsenic	(mg/ℓ)	Max. 1
Lead	(mg/ℓ)	Max. 1

17-28 Chemical Resistant Materials

Chemical products	Pipe	Valve	Storage reservoir	Pump (compressor)	Strainer
Hydrochloric acid	Hard rubber, Polythylene lining steel	Rubber lining iron	Rubber lining steel, Polyethylene, FRP	Rubber lining steel, Teflon, Vinyliden fluoride	Rubber lining Teflon
Hydrogen fluoride	Lead, Rubber lining, Bakelite		Lead	Lead, Rubber lining	
Dilute sulfuric acid (Max. 20%)	Polyethylene lining steel	Rubber lining iron	Rubber lining steel	Vinyliden fluoride	
Concentrated sulfuric acid (95% to 98%)	Steel	Steel	Steel	Iron, Steel, 14% Silicon steel, 18-8 Nickel chromium steel, Vinyliden fluoride	
Nitric acid	14% Silicon steel, Chromium steel		Aluminum, Glass	Silicon iron, Chromium steel	
Phosphoric acid	Lead, Rubber lining steel		Lead lining, Nickel chromium steel, Rubber lining		
Chlorine (dry)	Steel, Silicon steel, Rubber lining steel	Monel, Steel	Steel cylinder	(Compressor) Cast iron steel	
Chlorine (wet)	Lead lining, Ceramics	Stellite			
Ammonia gas (dry)	Wrought steel, Steel, Chromium steel	Monel		Monel	
Hydrogen (cooled)	Carbon steel, Chromium steel, Chromium molybdenum steel	Carbon steel	Nickel steel	Chromium vanadium steel	
Oxygen (cooled)	Wrought steel	Bronze	Steel	Steel	
Ammonium water	Steel, Nickel		Steel, Rubber lining steel	SCS13	SUS304
Coal	Wrought steel, Steel	Cast ion	Steel	Cast iron	
Caustic soda	Steel	Cast ion	Steel, Rubber lining steel	Iron, Steel	Iron
Aluminum sulfate, PAC	Polyethylene lining steel		Rubber lining steel, Polyethylene	PVC	
Ammonia Solution	Polyethylene lining steel, Rubber lining steel		Rubber lining	Iron, Nickel iron, Steel	Iron
Sodium sulfite	SUS304, Polyethylene lining steel	Rubber lining iron	Polyethylene, Rubber lining steel, SUS304	SCS13	
Soda carbonate (10%)	Steel		Steel	Iron, Steel	Iron, Steel
Salt (Max. 20%)	Polyethylene lining steel	Rubber lining iron	Rubber lining steel, Cement	SCS14	
Sodium phosphate	Steel, Lead		Steel	Iron, Silicon steel	Iron
Sodium sulfate	Steel, Lead, Chromium nickel lining		Steel, Lead, Chromium nickel steel	Iron, Bronze	Cast iron

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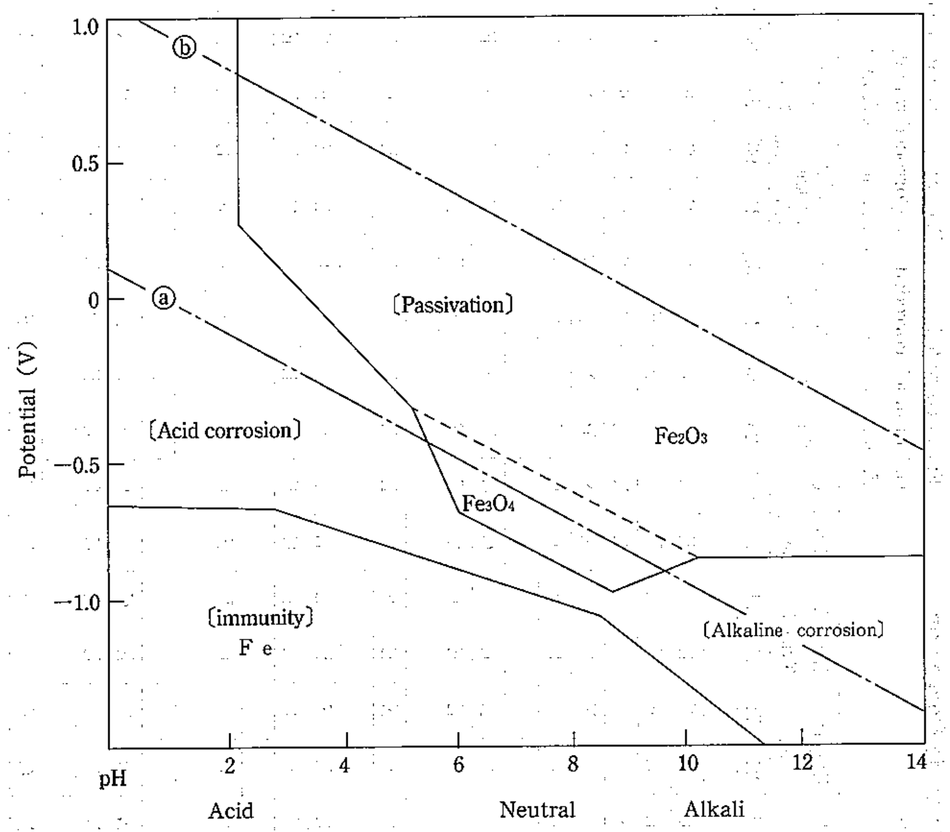
17-29 Chemical Resistance of Organic Corrosion Resistant Lining Materials

E: Not corroded P: Corroded, cannot be used
G: Not much corroded N: Corroded rapidly
F: Corroded to some extent but can be used, depending on the position

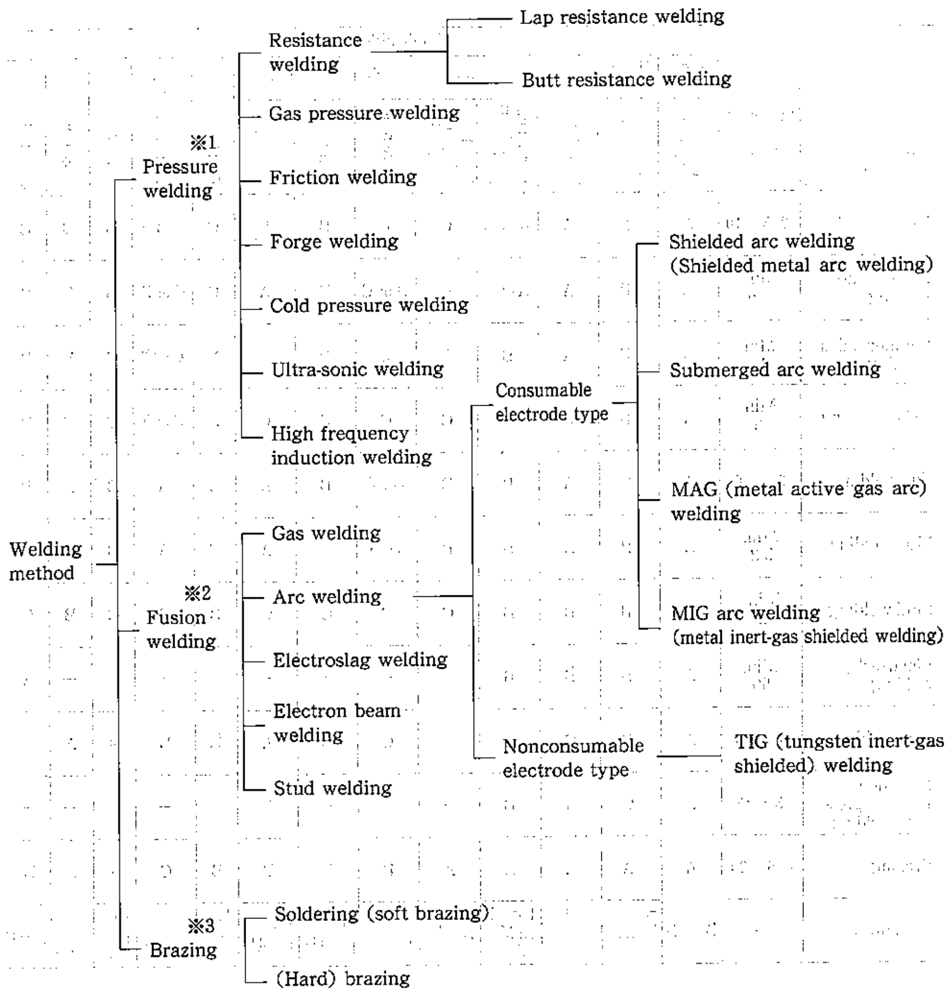
Material \ Chemicals \ Temperature (℃)	Ebonite lining		Soft rubber lining		Neoprene lining		Hard PVC Type I		Hard PVC lining		Saran sheet		Polyethylene sheet		Chemical resistant polyester FRP		Epoxy coating		Fluoro resin sheet	
	24°	66°	24°	66°	24°	71°	24°	71°	24°	66°	25°	66°	24°	52°	24°	93°	24°	93°	24°	121°
Acid																				
Hydrochloric acid 37%	E	E	E	E	N	N	E	E	E	N	E	E	E	E	E	G	E	E	E	E
Sulfuric acid 50%	E	E	E	E	E	F	E	E	E	F	E	E	E	E	E	G	E	E	E	E
〃 70%	F	N	F	N	N	N	E	E	N	N	E	E	E	F	G	P	F	N	E	E
〃 93%	N	N	N	N	N	N	E	F	N	N	P	N	F	N	F	N	N	N	E	E
Phosphoric acid 85%	E	E	E	E	F	E	E	E	E	E	E	E	E	E	E	G	E	E	E	E
Base																				
Ammonia solution 28%	E	F	G	F	E	E	E	E	G	G	N	N	E	E	G	F	E	E	E	E
Sodium hydroxide 25%	E	E	E	E	E	E	E	E	G	F	F	N	E	E	N	N	E	E	E	E
Acid salt																				
Ferric Cl, SO_4 10%	E	E	E	E	F	N	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Basic salt																				
Sodium carbonate	E	E	E	E	E	E	E	E	E	G	E	E	E	E	E	E	E	E	E	E
Sodium phosphate	E	E	E	E	E	E	E	E	G	F	E	E	E	E	G	F	E	E	E	E
Neutral salt																				
Ca, Mg, K, Na (Cl, NO_3, SO_4) 10%	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Gas																				
Chlorine (wet)	G	F	F	N	N	N	E	G	F	F	E	E	N	N	F	N	P	N	E	E
Chlorine (dry)	F	N	N	N	N	N	E	E	G	F	E	E	P	N	G	F	F	N	E	E
Organic compound																				
Gasoline	G	N	N	N	G	F	—	—	E	F	E	E	P	—	—	—	E	G	E	E

17-30 Potential-pH diagram of Iron Oxide (300℃)



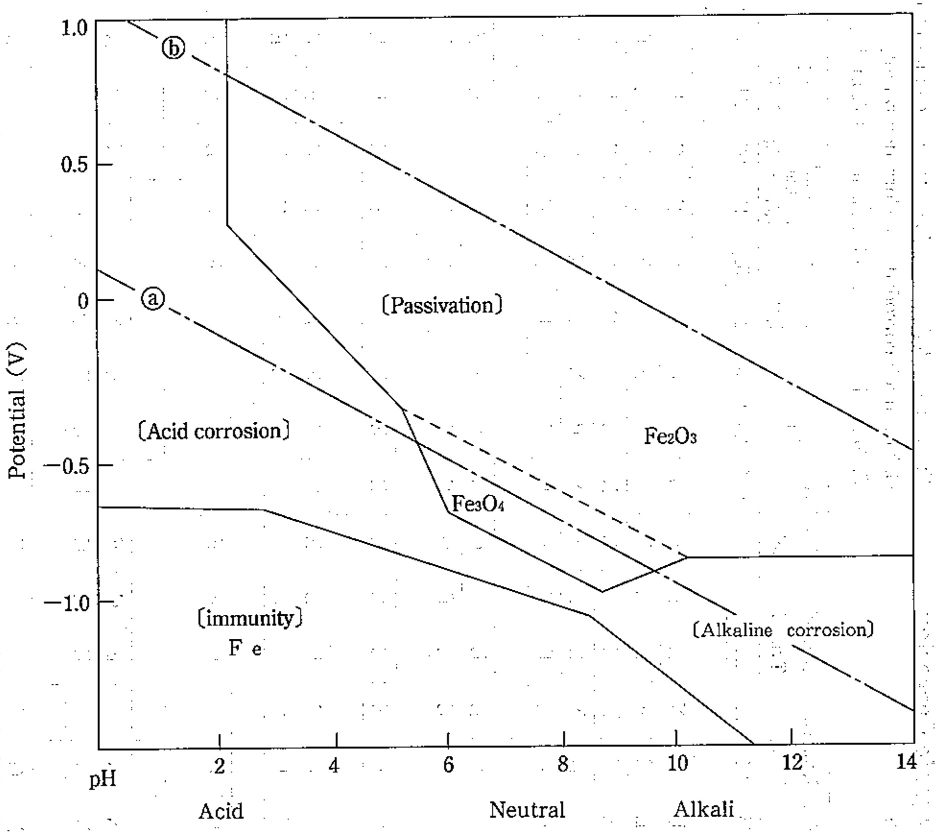
18-1 Types of Welding Methods

Welding Methods are divided into the following types according to their principles and procedures.



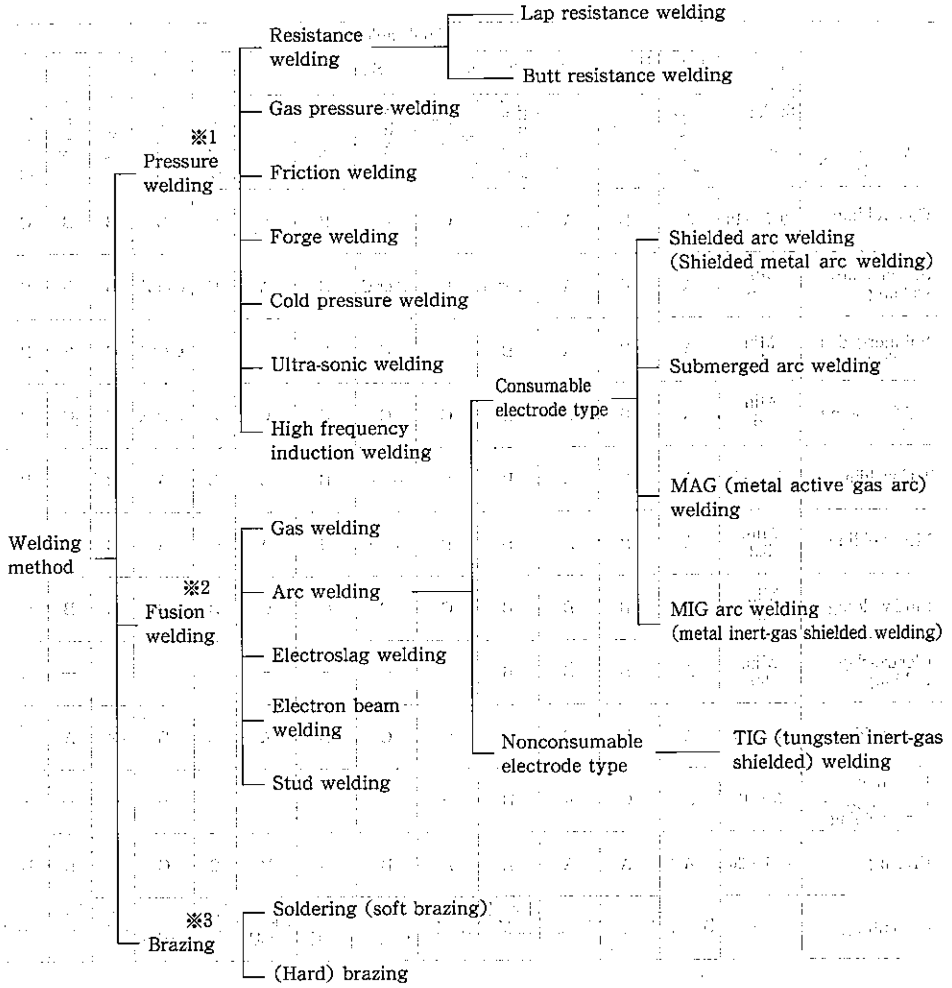
※1. The method of jointing by applying heat and pressure to a joint part.
※2. The method of jointing by melting a joint part without applying pressure.
※3. The method of jointing by permeating of filler metals (brazing materials) into a narrow crevice.

17-30 Potential-pH diagram of Iron Oxide (300℃)



18-1 Types of Welding Methods

Welding Methods are divided into the following types according to their principles and procedures.



※1. The method of jointing by applying heat and pressure to a joint part.
※2. The method of jointing by melting a joint part without applying pressure.
※3. The method of jointing by permeating of filler metals (brazing materials) into a narrow crevice.

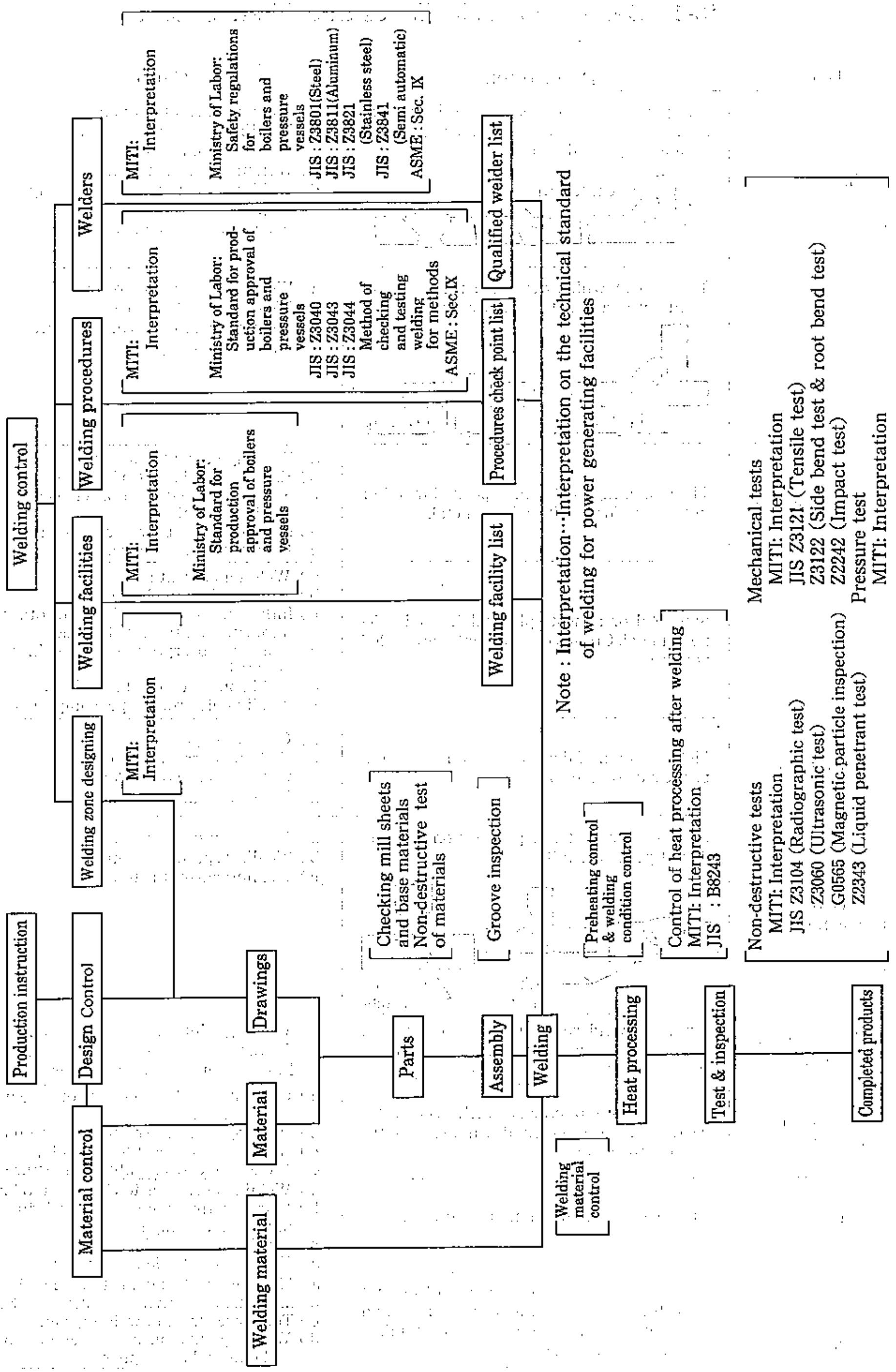
18-2 Selection of Welding Methods and Base Materials

As shown below, some welding methods are available. Materials, shapes, plate thickness, quantity of welded parts, etc. should be considered carefully to make full use of the features of these welding methods.

Welding methods	Applicable plate thickness mm	Applicable materials												
		Low carbon steel	Medium carbon steel	Low alloy steel			Stainless steel			Cast iron	Aluminum alloy	Copper alloy	Nickel alloy	Cast steel
		C: Max.0.30%	C: 0.30 - 0.45%	Molybdenum steel	Chromium -molybdenum steel	Nickel -chromium -molybdenum steel	Martensite	Ferrite	Austenite					
Gas welding	0.5～10	A	B	A	A or B	C	C	B	B	C	B	B	B	C
Shielded arc welding	Min. 1.6	A	B	A	A or B	B	B or C	B	A	C	C or X	B	B	B
Submerged arc welding	Min. 10	A	B	A	B	C	C	B	A	×	C or X	C	B	B
MAG welding	Min. 6	A	B	B	B	C	C	C	C	×	C or X	C	C	B
TIG welding	0.5～6	A	B	A	B	B	B or C	B	A	C	A	B	B	B
MIG welding	Min. 3.2	A	B	A	B	B	B or C	B	A	C	A	B	B	B
Stud welding	Min. 2	A	B	B	B	C	C	C	C	×	B	C	B	C
Electro-slag welding	Min. 50	A	B	B	B	—	—	—	—	—	—	—	—	A
Spot welding	0.5～6	A	B	C	C	C	C	B	A	×	B	×	A	—
Induction heating pressure welding	3～12	A	C	A	B	—	—	—	B	—	—	—	—	—
Brazing	0.5～20	A	A	A	A	A	B	B	B	B	C	A	B	B
Gas cutting	—	Possible	Possible	Possible	Possible for Max. 5Cr	Possible	Impossible	Impossible	Impossible	Impossible	Impossible	Impossible	Impossible	Possible

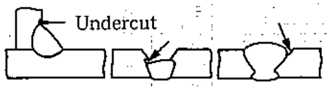
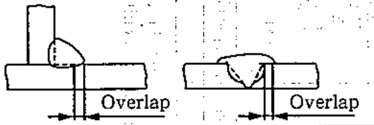
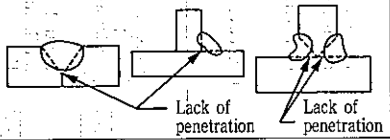
A: Excellent	Widely used. No problem for welding.
B: Good	Good skill or special processing is required. (Checking preheated layer temperature)
C: Fair	Hard to weld. It is impossible to weld materials of special components.
X: Failure	Welding is impossible.
–: Unknown	Not applicable at present.

18-3 Welding Control Chart



Note : Interpretation···Interpretation on the technical standard of welding for power generating facilities

18-4 Defects in Weld Zones and Their Causes

Defects	Descriptions	Causes
Undercut	The part at which a base material is hollowed along toes of welds and is grooved without deposited material 	a) Welding current is too high. b) Welding electrode type and electrode diameter are improper. c) Welding speed is too high. d) Welding electrode is held at improper angle. e) Arc length is too long.
Overlap	The part at which deposited metal is not fused with base metals and overlap 	a) Welding current is too small. b) Welding speed is too low. c) Welding electrode type or electrode diameter is improper.
Slag inclusion	The remaining of slag in deposited metal or in the part fused with a base metal.	a) Welding current is too small. b) Slag advances due to too low welding speed. c) Slag is removed from previous layer beads incompletely. d) Previous layer beads are defective. e) Groove shape is improper.
Blow hole	Spherical or almost spherical holes in deposit metal. Groups of small holes are called porosities.	a) Welding current is too high. b) Arc length is too large. c) Influences of water, oil, rust or other impurities on the bevel surface. d) Moisture absorption of the welding electrode. e) Weld zone is cooled too quickly. f) Welding electrode type is improper.
Burn through	Melting down of deposited metal on the opposite side of a groove	a) Groove shape is improper. b) Welding current is too large. c) Welding speed is too low. d) Base materials are overheated.
Lack of penetration	Some positions of full penetration welding do not penetrate fully. 	a) Groove angle is too small. b) Welding speed is too high. c) Welding current is too small.
High temperature cracks	Cracks in weld zones which occur at high temperature such as solidification temperature range of weld zones or just below it	a) Welding joints are restricted too much. b) Sulfur is segregated in base materials. c) Interval between the roots is excessive.
Low temperature cracks	A generic term of cracks which occur after weld zones are cooled down near to the room temperature.	a) Contents of alloy elements of base materials are too much. b) Welding joints are restricted too much. c) Weld zone is cooled too quickly. d) Welding electrodes absorb moisture.
Improper bead appearance	The surface and uranami of weld beads	a) Welding current is too high or too low. b) Slag covering condition is bad due to improper welding speed. c) Weld zone is overheated d) Welding electrode is improper
Stress corrosion cracking (SCC)	Cracking because of interaction of do not have fine appearance, material, stress, and environment for welding zone of stainless steels, nickel alloys, etc.,	a) Material sensitizing due to welding heat b) Inadequate resistivity of materials to SCC c) Too large stress in welding zones d) Water quality on inner welding zone and external atmosphere

18-5 Post-Weld Heat Treatment

Post-weld heat treatment is carried out for the purpose of improvement of the usability and the integrity of weld zones. The concrete purposes are mainly below.

(1) Release of welding residual stress and stabilization of sizes
(2) Softening of a heat affected zone
(3) Improvement of ductility and toughness
(4) Improvement and recovery of resistivities against stress corrosion cracking
(5) Emission of hydrogen

The condition of heat treatements is standardized in and outside the country. It is specified in JIS Z 3700 "Methods of Post Weld Heat Treatment", as follows;

Temperature and Time for Post Weld Heat Treatment (JIS Z 3700-1987)

Item		P－1	P－2	P－3	P－4	P－5	P－9
Type of base metals		Carbon steel	Quenched and tempered high tensile strength steel	C-0.3Mo steel C-0.5Mo steel 0.5Cr-0.5Mo steel	1Cr-0.5Mo steel 1.25Cr-0.5Mo steel	2.25Cr-1Mo steel 5Cr-0.5Mo steel 7Cr-0.5Mo steel 9Cr-1Mo steel	2-2.4Ni steel 3.5Ni steel
Minimum holding temperature, ℃		595	595	595	595	675	595
Minimum holding time (H) h	Thickness of weld zone, t mm	Under 6mm, $\frac{t}{4}$					
		Over 6 mm to 50mm, $\frac{t}{25}$		Over 6 mm to 125mm, $\frac{t}{25}$			
		Over 50mm, $2+\frac{t-50}{100}$		Over 125mm, $5+\frac{t-125}{100}$			

Remark:

1. Materials other than those given in Table 1 shall be as agreed on between the parties concerned.
2. The weld thickness (t) shall be as follows;
   (1) The thickness of base material, in the case of butt welding with complete penetration, the smaller thickness, in the case where the material has an uneven thickness.
   (2) The thickness of the base material on the beveled side, in the case of the complete penetration welding of T-joint and L-joint.
   (3) The beveling depth or the aggregate sum of the depths, in the case of the partial penetration welding.
   (4) The throat depth, in the case of fillet welding.
   (5) The depth of repaired portion, in the case of repair welding.
3. The temperature for the post weld heat treatment shall not exceed the tempering temperature for the quenched and tempered steel for P-2 and P-3 materials.

Typical Standards of Holding Temperature on Post Weld Heat Treatment (JIS Z 3700-1987Comments)

Unit ℃

P number	Materials	ASME(1) Ⅷ-1 1983	ASME(1) Ⅷ-2 1982	ASME(1) Ⅲ-1 1983	BS 5500 1982	BS 2633 1973(1984) (Tube)	ISO TC 11	HPIS 1981 E 107～112	AWS/ ANSI D1.1 1985
P 1	Carbon steel (C-steel)	≧595	≧595	595～675	600±20	(4) 580～620 630～670	550～600	≧550	(1) 590～650
P 2	Quenched and tempered high tensile strength steel	—	—	—	—	—	Below tempering temperature	Below tempering temperature	≧590(1)
P 3	C-0.3Mo steel	≧595	≧595	595～675	600±20	650～680	580～620	≧590	—
P 3	C-0.5Mo steel						580～620		
P 3	0.5Cr-0.5Mo steel						620～660		
P 4	1Cr-0.5Mo steel	≧595	≧595	595～675	(2) 630～670 650～700	630～670	620～660	(2) ≧590	—
P 4	1.25Cr-0.5Mo steel					—	—	≧620	
P 5	2.25Cr-1Mo steel	≧675	—	—	(2) 630～670 680～720 719～750	(2) 680～720 700～750	(3) 625～750	(2) ≧650 ≧675	—
P 5	5Cr-0.5Mo steel				—	710～760	(3) 670～740	(2) ≧675 ≧700 (除7Cr)	
P 5	7Cr-0.5Mo steel				—	710～760	—		
P 5	9Cr-1Mo steel				—	710～760	—		
P 9-A	2-2.4Ni steel	≧595	≧595	—	—	—	—	—	—
P 9-B	3.5Ni steel	≧595	≧595	595～635	580～620	590～620	550～590		
P11-A	9Ni steel	550～585	550～585	535～565	Not required	Not required	—	—	—

Remark: (1) The substitutional specification of the lower temperature and the longer holding time, regarding a part of materials.

(2) According to application conditions and environment or design conditions (strength, creep or softening).

(3) The temperature range 40℃ is specified in each case.

(4) In BS 2633, 580～620℃ for C-Mn steels (C≦0.25%), 630～670℃ for C-Mn steels (C>0.25%).

Typical Standards of Holding Time and Heating／Cooling Rate on Post Weld Heat Treatment (JIS Z 3700-1987 Comments)

			ASME Ⅷ-1 1983	ASME Ⅷ-2 1983	ASME Ⅲ 1983	BS 5500 1984	BS 2633 1973 (Tube)	ISO TC 11	HPIS 1983 E 107～112	AWS 1985 D1.1 (Tube)
Holding time	Carbon steel, h	Per thickness	$T/25$(1)	$T/25$(1)	$T/25$(1)	$T/24$	$T/24$	$T/30$, $T/25$	$T/25$(1)	$T/25.4$
		Minimum	0.25	1	0.5	1	0.5	0.5	1	0.25
	Alloy steel, h	Per thickness	$T/25$(1) (2)	$T/25$(1) (2)	$T/25$(1) (2)	$T/24$	$T/24$	$T/25$	$T/25$(2)	—
		Minimum	0.25	1	0.5	1～3	0.5～3	1.2	1	
Heating	Maximum furnace temperature at taking in, ℃		425	425	425	400	400(3)	400	400	315
	Maximum heating rate, ℃/h	Per thickness	224×25 /T	226×25 /T	220×25 /T	220×25 /T	220×25 /T	220×25.4 /T	220×25 /T	220×25.4 /T
		Minimum	55	56	55	55	55	55(3)	50	—
		Maximum	224	220	220	220	220	220	220	220
Cooling	Maximum furnace temperature at taking out, ℃		425	425	425	400	400	400	400	315
	Maximum cooling rate, ℃/h	Per thickness	280×25 /T	280×25 /T	220×25 /T	275×25 /T	275×25 /T	275×25.4 /T	275×25 /T	260×25.4 /T
		Minimum	55	56	55	55	55	55	55(3)	—
		Maximum	280	280	220	275	275	275	275	260
Maximum temperature difference during heating and cooling, ℃/m			150/5	140/5	140/4.5	150/4.5	—	150/4.57	130/4.5	140/4.6
Maximum temperature difference during holding, ℃			85	56	Setting temperature	Setting temperature	—	Setting temperature	(80)(4)	83
Minimum overlapping length in the case of division, m			1.5	1.5	1.5	$1.5\sqrt{R\times T}$ the larger value	$2.5\sqrt{R\times T}$ and the temperature at $T/2$(5)	1.5	1.5	—

Remark: (1) $2+(T-50)/100$ for $T\geqq 50$ (T: thickness mm)

(2) $5+(T-125)/100$ for $T\geqq 125$

(3) With complicated structure, more consideration is desirable.

(4) Specified in the procedure specification.

(5) Based on the way of partial heating treatment.

(6) R: inner radius of vessel or pipe, m

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Holding Time According to Temperature Range and Thickness of Weld Zone on Post-Weld Heat Treatment

(Referred to MITI "Interpretation on the technical standard of welding for power generating facilities")

Type of base metals	Temperature range (℃)	Holding time according to thickness of weld zone (hour)			
		The maximum thickness of 12.5mm	The maximum thickness of 50mm and over 12.5mm	The maximum thickness of 125mm and over 50mm	Over 125mm
P−1 (Carbon steel)	595 min. and 700 max.	0.5 min.	$\frac{t}{25}$ min.	$2+\frac{t-50}{100}$ min.	$2+\frac{t-50}{100}$ min.
P−3 (Molybdenum steel)	595 min. and 710 max.	0.5 min.	$\frac{t}{25}$ min.	$2+\frac{t-50}{100}$ min.	$2+\frac{t-50}{100}$ min.
P−4 (Chromium-molybdenum steel Standard alloying elements max. 2.75%)	595 min. and 740 max.	0.5 min.	$\frac{t}{25}$ min.	$\frac{t}{25}$ min.	$5+\frac{t-125}{100}$ min.
P−5 (Chromium-molybdenum steel Standard alloying elements max. 12%)	680 min. and 760 max.	0.5 min.	$\frac{t}{25}$ min.	$\frac{t}{25}$ min.	$5+\frac{t-125}{100}$ min.
P−6 (Martensitic stainless steel)	680 min. and 760 max.	0.5 min.	$\frac{t}{25}$ min.	$\frac{t}{25}$ min.	$5+\frac{t-125}{100}$ min.
P−7 (Ferritic stainless steel)	705 min. and 760 max.	0.5 min.	$\frac{t}{25}$ min.	$\frac{t}{25}$ min.	$5+\frac{t-125}{100}$ min.
P−9A and P−9B	595 min. and 680 max.	0.5 min.	$\frac{t}{25}$ min.	$\frac{t}{25}$ min.	$5+\frac{t-125}{100}$ min.
P−11A and P−11B	595 min. and 680 max.	0.5 min.	$\frac{t}{25}$ min.	$\frac{t}{25}$ min.	$\frac{t}{25}$ min.

Remark:

The value t is the following thickness (mm).

1. In the case of the complete penetration welding, the thinner thickness of the weld zone or the base metal (restricted to pressure boundary). In the case of different thickness, the thinner thickness.
2. In the partial penetration welding, the depth of a groove.
3. In the case of fillet welding, the depth of a throat
4. In the case of only clad welding, the thickness of weld zones.

P−9A ; Nickel steel. A standard content of nickel is 2.50%max..
P−9B ; Nickel steel. A standard content of nickel is over 2.50% and 3.50%max..
P−11A (group number 1); Nickel steel. A standard composition of nickel is over 3.50% and 9.0% max..
P−11A (group number 2); Alloy steel. The minimum tensile strength is 660 N/mm² or more and less than 730 N/mm².
P−11B ; Alloy steel. The minimum tensile strength is 730N/mm² or more.

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18-6 Application of Non-destructive Tests

(1) Major application fields of non-destructive tests

Non-destructive tests	Major application fields	Not applicable to
RT	Internal defects in weld zones and castings	Internal defects in steel plates, cracks not in parallel with irradiation direction
UT	Internal defects in steel plates, cast or forged steels and weld zones	Normal cast iron Cast autenitic stainless steels and weld zones
MT	Surface defects on cast or forged ferro-magnetic steels and weld zones	Non-magnetic metals and deep defects
PT	Defects openings on surfaces	Internal defects
ET	Surface defects simple-shaped objects	Deep defects and objects with complicated shape
AET	Initiation and growth of cracks in hydraulic pressure tests	Existing defects
ST	Strain or stress	Defect detection

〔Reference: JIS Z 3021-1987, The Handbook of Welding edited by The Japan Welding Society, published by Maruzen〕

(2) Applications of non-destructive tests to weld zones

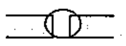
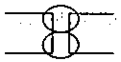
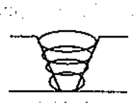
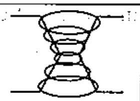
Applications	Non-destructive tests
Detecting defects on groove surfaces	VT, PT, MT
Investigating defect ranges on plate materials near grooves	UT
Detecting cracks on each layer in multi-layer welding	MT, PT
Detecting defects remaining on back surfaces with chipping	MT, PT
Detecting surface defects in weld zones	MT, PT
Detecting defects just below the surface (within 2mm) of weld zones	MT
Detection of internal detect at weld zones	RT, UT
Detecting defects in positions where jigs were temporarily set	MT, PT
Detecting a initiation and a growth of cracks on hydraulic pressure tests	AET
Measuring stress and strain on hydraulic pressure tests	ST

〔Reference: JIS Z 3021-1987, JIS Z 3021-1987 and The Handbook of Welding edited by The Japan Welding Society, published by Mazuzen co.〕

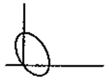
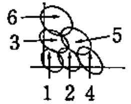
Remark:
RT : Radiographic examination
UT : Ultrasonic examination
MT : Magnetic particle testing
PT : Penetrating testing
ET : Eddy current testing
AET : Acoustic Emission testing
ST : Strain measuring test
VT : Visual testing

18-7 Examples of Welding Standards

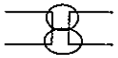
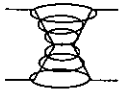
(a) Position: Flat, Joint: Butt

Plate thickness (mm)	Welding method	Number of layers	Current (A)	Welding electrode dia. (mm)
3.2		1	80~120	3
4		2	90~150	3~5
4		2	90~150	3~4
6		2	120~170	4
8		3	120~180	4
4		1	120~150	4
6		2	120~170	4
8		2	120~180	4
10		3	130~230	4~5
12		4	150~250	5
16		4~6	150~300	5~6
16		4	180~250	5
19		6	180~250	5
25		8	180~300	5~6

(b) Position: Flat, Joint: Horizontal

Plate thickness (mm)	Welding method	Number of layers	Current (A)	Welding electrode dia. (mm)
3.2		1	80~120	3
4		1	120~160	4
6		1	130~170	4
8		2	160~200	5
10		2	170~230	5
12		3	180~230	5
16		6	200~300	5~6
19		9	200~300	5~6

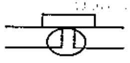
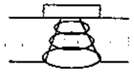
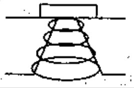
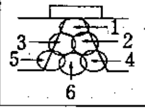
(c) Position: Vertical, Joint: Butt

Plate thickness (mm)	Welding method	Number of layers	Current (A)	Welding electrode dia. (mm)
3.2		1	80~120	3
4		2	90~150	3~5
4		1	90~150	3~4
6		2	100~150	4
8		2	100~150	4
10		3	120~160	4
12		3	150~200	5
16		5	150~200	5
16		4	150~200	5
19		6	150~200	5

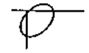
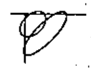
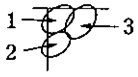
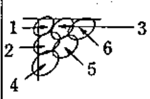
(d) Position: Vertical, Joint: Horizontal

Plate thickness (mm)	Welding method	Number of layers	Current (A)	Welding electrode dia. (mm)
3.2		1	80~120	3
4		1	90~150	3~4
6		2	100~150	4
8		2	100~150	4
10		3	120~160	4
12		3	150~200	5
16		4	150~200	5
19		6	150~200	5

(e) Position: Overhead, Joint: Butt

Plate thickness (mm)	Welding method	Number of layers	Current (A)	Welding electrode dia. (mm)
3.2		1	80~120	3
4		1	90~150	3~4
4		1	90~150	3~4
6		2	120~150	4
8		2	120~180	4
10		3	120~180	4
12		4	150~220	5
16		6	150~220	5
12		6	150~230	5
16		9	150~230	5

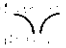
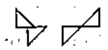
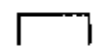
(f) Position: Overhead, Joint: Horizontal

Plate thickness (mm)	Welding method	Number of layers	Current (A)	Welding electrode dia. (mm)
3.2		1	90~120	3
4		1	90~150	3~4
6		2	120~170	4
8		2	120~170	4
10		3	120~180	4
12		4	150~220	5
16		7	150~220	5
19		10	150~230	5

18-8 Symbolic Representation of Welds (JIS Z 3021-1987)

The symbols for welds shall consist of basic symbols and supplementary symbols as specified in Tables 1 and 2.

Table 1 Basic Symbols

Shape of weld	Basic symbol	Remarks
Double-flange		
Single-flange		
Square-groove		Upset welds, flash welds, friction welds, etc. are included.
Single V groove and double V groove (X groove)		The X groove weld shall be represented by two figures of this symbol drawn symmetrically about the reference line of the explanatory line, hereinafter referred to as the "reference line". Upset welds, flash welds, friction welds, etc. are included.
Single bevel groove and double bevel groove (K groove)		The K groove weld shall be represented by two figures of this symbol drawn symmetrically about the reference line. The vertical line in the symbol shall be drawn on the left side. Upset welds, flash welds, friction welds, etc. are included.
Single J groove and double J groove		The double J groove weld shall be represented by two figures of this symbol drawn symmetrically about the reference line. The vertical line in the symbol shall be drawn on the left side.
Single U groove and double U groove (H groove)		The H groove weld shall be represented by two figures of this symbol symmetrically drawn about the reference line
Flare single V groove and flare X groove		The flare X groove weld shall be represented by two figures of this symbol drawn symmetrically about the reference line.
Flare single bevel groove and flare K groove		The flare K groove weld shall be represented by two figures of this symbol drawn symmetrically about the reference line. The vertical line in the symbol shall be drawn on the left side.
Fillet		The vertical line in the symbol shall be drawn on the left side. Parallel continual fillet weld shall be represented by this symbol drawn symmetrically about the reference line. However, in the case of staggered continual fillet welds, the symbols shown on the right may be used. 
Plug and slot		—
Bead and cladding		In the case of cladding by welding, two figures of this symbol shall be drawn side by side.
Spot, projection, and seam		This symbol represents a weld made by resistance welding, arc welding, electron beam welding or the like in lap joints. However, fillet welds are excluded. Seam welds shall be represented by two figures of this symbol drawn side by side.

Remark: The basic symbols shall represent the shapes of welds between two members, as a rule

Table 2. Supplementary Symbols

Division			Supplementary symbol	Remarks
Shape of weld surface	Flat		—	
	Convex		⌒	The symbol shall be drawn to be convex toward the outside of the reference line.
	Concave		‿	The symbol shall be drawn to be concave toward the outside of the reference line.
Finishing method for weld	Chipping		C	
	Grinding		G	In the case of grinder finishing
	Cutting		M	In the case of machine finishing
	Not specified		F	In the case where the finishing method is not specified.
Field welding			⚑	This symbol may be omitted when it is obvious that all-round peripheral welding is employed.
All-round peripheral welding			○	
Field all-round peripheral welding			⚑○	
Nondestructive test method	Radiographic test	General	RT	The category "general" is the case when only the method of each test such as the radiograph test and the like is shown and the content is not given. An appropriate marking can be used, as required, for tests not represented by the symbols shown here. (Example) Leakage test LT Strain measuring test ST Visual test VT Acoustic emission test AET Eddy current test ET
		Double wall photographing	RT-W	
	Ultrasonic flaw detecting test	General	UT	
		Vertical flaw detecting	UT-N	
		Bevel detecting	UT-A	
	Magnetic particle examination	General	MT	
		Fluorescence detecting	MT-F	
	Penetration test	General	PT	
		Fluorescence detecting	PT-F	
		Non-fluorescence detecting	PT-D	
	Whole test		○	These symbols shall be suffixed to each symbol of test.
	Partial test (sampling test)		△	

Remark: The supplementary symbols shall be used, as required.

18-9 Titles of JIS Standards on Welding

(1) Test and inspection

Standard number Title

JIS G 0565: 1982 Method for magnetic particle testing of ferromagnetic materials and classification of magnetic particle indication(c)

JIS Z 2343: 1982 Method for liquid penetrant testing and classification of the indication(c)
JIS Z 3001: 1999 Welding terms(c)
JIS Z 3021: 1987 Symbolic representation of welds(c)
JIS Z 3040: 1995 Method of qualification test for welding procedure(c)
JIS Z 3043: 1990 Method of welding procedure qualification test for stainless-clad steel
JIS Z 3044: 1991 Method of welding procedure qualification test for nickel and nickel alloy clad steels
JIS Z 3050: 1995 Method of nondestructive examination for weld of pipeline(c)
JIS Z 3060: 1994 Method of ultrasonic examination for welds of ferrite steel(c)
JIS Z 3062: 1996 Methods and acceptance criteria of ultrasonic examination for gas pressure welds of reinforcing deformed bars(c)
JIS Z 3080: 1995 Methods of ultrasonic angle beam examination for butt welds of aluminum plates(c)
JIS Z 3081: 1994 Methods of ultrasonic angle beam examination for welds of aluminum pipes and tubes(c)
JIS Z 3082: 1995 Methods of ultrasonic examination for T type welds of aluminum plates(c)

JIS Z 3101: 1990 Testing method of maximum hardness in weld heat-affected zone(c)
JIS Z 3103: 1987 Method of repeated tension fatigue testing for fusion welded joints(c)
JIS Z 3104: 1995 Methods of radiographic examination for welded joints in steel(c)
JIS Z 3105: 1993 Method of radiographic examination for fusion welded butt joints of aluminum plates(c)
JIS Z 3106: 1971 Methods of radiographic test and classification of radiographs for stainless steel welds (c)
JIS Z 3107: 1993 Methods of radiographic examination for titanium welds by X-ray(c)
JIS Z 3108: 1986 Methods of radiographic test for circumferential butt welds of aluminum pipes and tubes (c)
JIS Z 3109: 1988 Method of radiographic testing for aluminum T-welds
JIS Z 3111: 1986 Methods of tension and impact tests for deposited metal(c)
JIS Z 3113: 1975 Method of measurement of hydrogen content for deposited metal(c)
JIS Z 3114: 1990 Method of hardness test for deposited metal(c)
JIS Z 3115: 1973 Method of taper hardness test in weld heat-affected zone(c)
JIS Z 3118: 1992 Method of measurement for hydrogen evolved from steel welds(c)
JIS Z 3119: 1988 Methods of measurement for ferrite content in austenitic stainless steel? deposited metal
JIS Z 3120: 1980 Method of inspection for gas pressure welded joint of steel bars for concrete reinforcement(c)
JIS Z 3121: 1993 Methods of tensile test for butt welded joints(c)
JIS Z 3122: 1990 Methods of bend test for butt welded joint(c)
JIS Z 3128: 1996 Method of impact test for welded joint(c)
JIS Z 3131: 1976 Method of tension test for front fillet welded joint
JIS Z 3132: 1976 Method of shear test for side fillet welded joint
JIS Z 3134: 1965 Method of bend test for T type fillet welded joint(c)
JIS Z 3135: 1971 Method of soundness test for fillet welds(c)
JIS Z 3136: 1999 Specimen dimensions and procedure for shear testing resistance spot and embossed projection welded joints(c)
JIS Z 3137: 1999 Specimen dimensions and procedure for cross tension testing resistance spot and embossed projection welded joints(c)
JIS Z 3138: 1989 Method of fatigue testing for spot welded joints(c)
JIS Z 3139: 1978 Method of macro test for section of spot welded joints(c)

JIS Z 3140: 1989 Method of inspection for spot weld(c)
JIS Z 3141: 1996 Method of test for seam welded joints(c)
JIS Z 3143: 1996 Method of test for butt pressure welded joints(c)
JIS Z 3145: 1981 Method of bend test for stud welds
JIS Z 3153: 1993 Method of T-joint weld cracking test(c)
JIS Z 3154: 1993 Method of controlled thermal severity weld cracking test(c)
JIS Z 3155: 1993 Method of FISCO test(c)
JIS Z 3157: 1993 Method of U-groove weld cracking test(c)
JIS Z 3158: 1993 Method of y-groove weld cracking test(c)
JIS Z 3159: 1993 Method of H-type restrained weld cracking test(c)
JIS Z 3181: 1973 Method of test for fillet weld of covered electrode(c)
JIS Z 3182: 1991 Method of deposition rate measurement for covered electrodes(c)
JIS Z 3183: 1993 Classification and testing methods for deposited metal of submerged arc welding for carbon steel and low alloy steel
JIS Z 3184: 1992 Method of preparing deposited metal sample for chemical analysis(c)
JIS Z 3191: 1963 Method of spreading test for brazing(c)
JIS Z 3192: 1999 Methods of tensile and shear tests for brazed joint
JIS Z 3197: 1999 Testing methods for soldering fluxes(c)

(2) Welding materials (welding rods, wires for welds, blazing filler metals, solders and gases)

Standard number Title

JIS Z 3268: 1998 Precious brazing filler metals for vacuum service(c)
JIS Z 3317: 1991 MAG welding solid wires for molybdenum steel and chromium molybdenum(c)
JIS Z 3318: 1991 MAG welding flux cored wires for molybdenum steel and chromium molybdenum steel(c)
JIS Z 3319: 1991 Flux cored wires for electro-gas arc welding(c)
JIS Z 3320: 1993 Flux cored wires for CO2 gas shielded arc welding of atmospheric corrosion resisting steel(c)
JIS Z 3324: 1988 Stainless steel solid wires and fluxes for submerged arc welding
JIS Z 3325: 1990 MAG welding solid wires for low temperature service steel(c)
JIS Z 3326: 1991 Arc welding flux cored wires for hard-facing
JIS Z 3333: 1991 Submerged arc welding solid wires and fluxes for 9% nickel steel(c)
JIS Z 3334: 1988 Nickel and nickel alloy filler rods and solid wires for arc welding
JIS Z 3351: 1988 Submerged arc welding solid wires for carbon steel and low alloy steel(c)
JIS Z 3352: 1988 Submerged arc welding fluxes for carbon steel and low alloy steel(c)
JIS Z 3391: 1988 Types, dimensions and mass of wound steel wire for welding(c)
Ⓙ**JIS G 3503:** 1980 Wire rods for core wire of covered electrode(c)
Ⓙ**JIS G 3523:** 1980 Core wire for covered electrode(c)
JIS G 4316: 1991 Stainless steel wire rods for welding(c)
Ⓙ**JIS Z 3201:** 1990 Gas welding rods for mild steel
Ⓙ**JIS Z 3202:** 1983 Copper and copper alloy gas welding rods(c)
Ⓙ**JIS Z 3211:** 1991 Covered electrodes for mild steel(c)
Ⓙ**JIS Z 3212:** 1990 Covered electrodes for high tensile strength steel
JIS Z 3214: 1993 Covered electrodes for atmospheric corrosion resisting steel(c)
Ⓙ**JIS Z 3221:** 1989 Stainless steel covered electrodes(c)
Ⓙ**JIS Z 3223:** 1993 Molybdenum steel and chromium molybdenum steel covered electrodes
JIS Z 3224: 1991 Nickel and Nickel-alloy covered electrodes(c)
JIS Z 3225: 1990 Covered electrodes for 9% nickel steel(c)

JIS Z 3231: 1989 Copper and copper alloy covered electrodes(c)
Ⓙ**JIS Z 3232:** 1986 Aluminum and aluminum alloy welding rods and wires(c)
JIS Z 3233: 1990 Tungsten electrodes for inert gas shielded arc welding(c)
JIS Z 3234: 1999 Copper alloys for resistance welding electrode(c)
JIS Z 3241: 1993 Covered electrodes for low temperature service steel(c)
Ⓙ**JIS Z 3251:** 1991 Covered electrodes for hard-facing(c)
JIS Z 3252: 1992 Covered electrodes for cast iron
Ⓙ**JIS Z 3261:** 1998 Silver brazing filler metals(c)
JIS Z 3262: 1998 Copper and copper alloy brazing filler metals(c)
JIS Z 3263: 1992 Aluminum alloy brazing filler metals and brazing sheets(c)
Ⓙ**JIS Z 3264:** 1998 Copper phosphorus brazing filler metals(c)
JIS Z 3265: 1998 Nickel brazing filler metals(c)
JIS Z 3266: 1998 Gold brazing filler metals(c)
JIS Z 3267: 1998 Palladium brazing filler metals(c)
JIS Z 3281: 1996 Solders for aluminum and aluminum alloys
Ⓙ**JIS Z 3282:** 1999 Soft solders-Chemical compositions and forms(c)
Ⓙ**JIS Z 3283:** 1986 Resin flux cored solders(c)
Ⓙ**JIS Z 3312:** 1993 MAG welding solid wires for mild steel and high strength steel
Ⓙ**JIS Z 3313:** 1993 Flux cored wires for gas shielded and self-shielded metal arc welding of mild steel, high strength steel and low temperature service steel(c)
JIS Z 3315: 1993 Solid wires for CO2 gas shielded arc welding for atmospheric corrosion resisting steel(c)
JIS Z 3316: 1989 Tig welding rods and wires for mild steel and low alloy steel
Ⓙ**JIS Z 3321:** 1985 Stainless steel, welding rods and solid wires(c)
JIS Z 3322: 1996 Materials for stainless steel overlay welding with strip electrode(c)
Ⓙ**JIS Z 3323:** 1989 Stainless steel flux cored wires(c)
JIS Z 3331: 1988 Titanium and titanium alloy rods and solid wires for inert gas shielded arc welding(c)
JIS Z 3332: 1990 Filler rods and solid wires for TIG welding of 9% nickel steel(c)
JIS Z 3341: 1993 Copper and copper alloy rods and solid wires for inert gas shielded arc welding(c)
JIS K 6746: 1995 Plastic welding rods(c)
Ⓙ**JIS K 1101:** 1982 Oxygen(c)
Ⓙ**JIS K 1105:** 1995 Argon(c)

Symbols	Meaning
Ⓙ	The standard designated to specific products based on the Industrial Standardization Law Sec. 19
(c)	A original standard has comments.

19-1 History of the Maximum Unit Capacity of Steam Power Plants in Japan

Year of Commission	Capacity (kW)	Name of Plant		Main Steam Pressure MPa[gage]	Main/Reheat Steam Temperature (℃/℃)	Design Efficiency (%)	Boiler Type	Turbine-Generator		Historical Notes
		Company	Unit					Type	rpm	
1885	15	Tokyo Lighting Co.	—							The 1st Generator of Japanese Production (D.C. Generation and Moving Type)
1886	25	Osaka Spinning Co.	Sangenya Factory							
1887	25	Tokyo Lighting Co.	No.2 Lighting Office					Steam Engine		The 1st Plant for Utility Use
1889		Osaka Lighting Co.	Nishidoutonbori	0.412			Multi－tube type for land Lancashire	Steam Engine	200	The 1st A.C. Generating Unit
1894	30	Mitsui Mining Co.	Mitsui Mining					Steam Engine	250	
1895	200	Tokyo Lighting Co.	Asakusa No.1				a)	Steam Engine		Japanese Production
1897	265	Tokyo Lighting Co.	Asakusa No.2				a)	Steam Engine		
1901	300	Nagoya Lighting Co.	No.3							
1904	500	Tokyo City Railway	Fukagawa					SC		The 1st Steam Turbine (Vertical Curtis Type)
1905	500	Tokyo Lighting Co.	Senju					SC		The 1st Steam Turbine for Utility Use (Horizontal Parsons Type)
1905	1,500	Tokyo City Railway	Fukagawa					SC		Vertical Curtis Type
1908	500	Mitsubishi-Nagafune	Chuuou					SC		The 1st Steam Turbine of Japanese Production
1908	1,000	Osaka City Electric	Kujou No.1	1.098				SC		The 1st Steam Turbine in Kansai Area
1911	3,000	Osaka Lighting Co.	Ujigawa-West	1.030	185		a)	SC	1,800	Horizontal Parsons Type
1912	6,000	National Railway							3,000	
1913	5,000	Osaka Lighting Co.	Ujigawa-East	1.030	185		a)	SC	1,800	Horizontal Parsons Type
1918	12,500	Osaka Lighting Co.	Kasugade No.1	1.383	291			SC	1,800	The 1st Japanese Production Unit of 10 MW Class
1921	8,000	Kinugawa Electric Co.	Sumida						1,500	
1922	20,000	Osaka Lighting Co.	Kasugade No.2	1.383	291			SC	1,800	
1923	5,000	Kyushu Electric Co.	Namazuda	1.314	275		a)		3,000	
1924	25,000	Nippon Electric Co.	Amagasaki-East	1.726	317		a)	SC	1,800	
1925	35,000	Toho Electric Co.	Nagoya	2.177	371		a)	SC	1,800	Max. Capacity of 1,800 rpm Unit
1926	25,000	Tokyo Lighting Co.	Senju	1.549	314		a)	SC	1,500	Max. Capacity of 1,500 rpm Unit
1927	35,000	Tokyo Lighting Co.	Tsurumi No.1	2.412	382		a)	SC	1,500	Max. Capacity of 1,500 rpm Unit
1927	12,500	Kyushu Railway Co.	Daimon	2.403	371		a)	TC	3,000	Max. Capacity of 3,000 rpm Unit
1927	12,500	Hiroshima Electric Co.	Saka	2.069	361		a)		3,600	Max. Capacity of 3,600 rpm Unit
1928	40,000	Nippon Electric Co.	Amagasaki-East	1.726	317		a)	TC	1,800	
1931	27,000	Kyushu Railway Co.	Kokura	3.452	400		a)	TC	3,000	Max. Capacity of 3,000 rpm Unit
1933	18,000	Yamaguchi Electric Office	Ube No.2	3.452	415		a)	TC	3,600	Max. Capacity (in the world) of Japanese Production 3,600 rpm Unit
1933	53,000	Kansai Kyodo Karyoku	Amagasaki No.1	3.727	430		a)	TC	1,800	
1935	26,200	Hiroshima Electric Co.	Saka	3.040	410		a)	TC	3,600	Max. Capacity (in the world) of Japanese Production 3,600 rpm Unit
1936	53,000	Tokyo Lighting Co.	Tsurumi No.1	4.168	435		a)	TC	1,500	Max. Capacity of 1,500 rpm Unit

(Continued)

Year of Commission	Capacity (kW)	Name of Plant		Main Steam Pressure MPa[gage]	Main/Reheat Steam Temperature (℃/℃)	Design Efficiency (%)	Boiler Type	Turbine-Generator		Historical Notes
		Company	Unit					Type	rpm	
1937	75,000	Kansai Kyodo Karyoku	Amagasaki No. 2	3.727	430		a)	TC	1,800	Max. Capacity of 1,800 rpm Unit
1938	53,000	Seibu Kyodo Karyoku	Tobata−3	3.923	435		a)	TC	3,000	Max. Capacity of 3,000 rpm Unit
1939	30,000	Toho EPC.	Aiura−1	3.923	450		a)	TC	3,600	Max. Capacity of 3,600 rpm Unit
1952	35,000	Kyushu EPC.	Chikujo−1	5.884	482	29.0	a)	TC	3,600	Max. Capacity of 3,600 rpm Unit
1953	55,000	Tokyo EPC.	Ushioda−3	3.923	435		a)	TC	3,000	Max. Capacity of 3,000 rpm Unit and 1st hydrogen cooling Generator
1954	55,000	Chubu EPC.	Meiko−4	5.884	485	29.6	a)	TC	3,600	Max. Capacity of 3,600 rpm Unit
1955	66,000	Tokyo EPC.	Tsurumi No. 2−1	5.884	480	28.6	a)	TC	3,000	Max. Capacity of 3,000 rpm Unit
1955	66,000	Chubu EPC.	Meiko−5	5.884	485	31.0	a)	TC	3,600	Max. Capacity of 3,600 rpm Unit
1956	75,000	Kyushu EPC.	Karita−1	10.00	538/538	36.1	a)	TC	3,600	
1957	125,000	Tokyo EPC.	Chiba−1	12.45	538/538	37.2	a)	TC	3,000	Max. Capacity of 3,000 rpm Unit
1959	175,000	Tokyo EPC.	Chiba−3	16.57	566/538	38.8	a)	TC	3,000	Max. Capacity of 3,000 rpm Unit
1959	156,250	Chubu EPC.	Shinnagoya−1	16.57	566/538	39.1	b)	TC	3,600	Max. Capacity of 3,600 rpm Unit
1960	220,000	Chubu EPC.	Shinnagoya−2	16.57	566/538	39.2	b)	TC	3,600	Max. Capacity of 3,600 rpm Unit
1960	265,000	Tokyo EPC.	Yokosuka−1	16.57	566/566	39.8	b)	CC	3,000/3,000	
1963	250,000	The Kansai EPC.	Himeji No. 2−1	16.57	566/538	38.8	b)	TC	3,600	Tandem compound type, max. Capacity of 3,600 rpm Unit
1964	350,000	Tokyo EPC.	Yokosuka−3	16.57	566/566	39.8	b)	CC	3,000/3,000	Max. Capacity of 3,600 rpm Unit
1964	375,000	Chubu EPC.	Owasemita−1	16.57	566/538	39.1	b)	TC	3,600	Tandem compound type, max. Capacity of 3,600 rpm Unit
1967	265,000	*E.P.D.C.	Isogo−1	16.57	566/566	39.5	a)	CC	3,000	Max. Capacity of the coal fired Unit
1967	600,000	Tokyo EPC.	Anegasaki−1	24.12	538/566	40.3	c)	CC	3,000/3,000	Max. Capacity of 3,000 rpm Unit
1968	450,000	The Kansai EPC.	Himeji No. 2−4	24.12	538/552/566	40.2	c)	TC	3,600	Tandem compound type, max. Capacity of 3,600 rpm Unit
1968	500,000	Chubu EPC.	Chita−3	24.12	538/538	39.4	c)	TC	3,600	Tandem compound type, max. Capacity of 3,600 rpm Unit
1972	600,000	The Kansai EPC.	Kainan−3	24.12	538/552/566	40.3	c)	TC	3,600	Tandem compound type, max. Capacity of 3,600 rpm Unit
1973	450,000	Tokyo EPC.	Minamiyokohama−3	16.57	538/566	38.6	b)	CC	3,000/3,000	Max. Capacity of drum type Boiler Unit
1974	700,000	Chubu EPC.	Chita−4	24.12	538/566	39.5	c)	TC	3,600	Tandem compound type, max. Capacity of 3,600 rpm Unit
1974	1,000,000	Tokyo EPC	Kashima−5	24.12	538/566	40.9	c)	CC	3,000/1,500	
1975	1,000,000	Tokyo EPC.	Sodegaura−2	24.12	538/566	39.5	c)	CC	3,000/1,500	Max. Capacity of gas fired Unit
1981	500,000	*E.P.D.C.	Matsushima−1	24.12	538/538	40.1	c)	TC	3,600	Max. Capacity of the coal fired Unit
1983	700,000	*E.P.D.C.	Takehara−3	24.12	538/538	41.1	c)	CC	3,600/1,800	Max. Capacity of the coal fired Unit
1989	700,000	Chubu EPC.	Kawagoe−1	30.99	566/566/566	41.76	c)	TC	3,600	Ultra Super Critical Pressure Unit
1990	1,000,000	*E.P.D.C.	Matsuura−1	24.12	538/566	40.66	c)	TC	3,600	Max. Capacity of the coal fired Unit
1998	1,000,000	Haramachi−2 of Tohoku EPC., Misumi−1 of The Chugoku EPC.		24.52	600/600	43.0	c)	TC	3,000, 3,600	Max. Steam Temperature Unit

Note: EPC., Electric Power Co., Inc.
E.P.D.C., Electric Power Development Co., Ltd.

Remark: a) ···Natural Circulation Boiler, b) ···Forced Circulation Boiler, c) ···Once-through Boiler,
SC···Single Cylinder Type, TC···Tandem Compound Type, CC···Cross Compound Type.

19-2 Table of Typical Steam Power Units in Japan

Name of Plant		Commission Dates	Capacity (MW)	Fuel	Main Steam Pressure MPa〔gage〕	Main/Reheat Steam Temperature (℃/℃)	Boiler Type	Turbine Generator		Notes
Company	Unit							Type	rpm	
Hokkaido EPC.	Tomato-atsuma 2	Oct-85	600	Coal	24.12	538/566	a)	TC	3,000	
Hokkaido EPC.	Shiriuchi 2	Sep-98	350	Heavy oil emulsion	24.12	566/538	a)	TC	3,000	
Tohoku EPC.	Noshiro 2	Dec-94	600	Coal	24.12	566/593	a)	TC	3,000	
Tohoku EPC.	Haramachi 2	Jul-98	1,000	Coal	24.52	600/600	a)	CC	3,000	
Tokyo EPC.	Higashi ohgishima 2	Mar-91	1,000	LNG	24.12	538/566	a)	CC	3,000	
Tokyo EPC.	Hirono 4	Jan-93	1,000	Heavy, crude oil/ Natural gas	24.12	538/566	a)	CC	3,000	
Chubu EPC.	Kawagoe 2	Jun-90	700	LNG	30.99	566/566/566	a)	TC	3,600	
Chubu EPC.	Hekinan 3	Apr-93	700	Coal	24.12	538/593	a)	TC	3,600	
Hokuriku EPC.	Tsuruga 1	Oct-91	500	Coal	24.12	566/566	a)	TC	3,600	
Hokuriku EPC.	Nanao Ohta 2	Jul-98	700	Coal	24.12	593/593	a)	TC	3,600	
The Kansai EPC.	Nanko 2	Feb-91	600	LNG	24.12	538/566	a)	TC	3,600	
The Kansai EPC.	Nanko 3	Oct-91	600	LNG	24.12	538/566	a)	TC	3,600	
The Chugoku EPC.	Shin Onoda 2	Jan-87	500	Coal	24.12	538/566	a)	TC	3,600	
The Chugoku EPC.	Misumi 1	Jul-98	1,000	Coal	24.52	600/600	a)	CC	3,600	
Shikoku EPC.	Anan 4	Dec-76	450	Coal/Heavy oil	24.12	538/566	b)	TC	3,600	
Shikoku EPC.	Tachibanawan	Jun-00	700	Coal	24.12	566/593	a)	TC	3,600	
Kyushu EPC.	Matsuura 1	Jun-89	700	Coal	24.12	538/566	a)	TC	3,600	
Kyushu EPC.	Reihoku 1	Dec-95	700	Coal	24.12	566/566	a)	TC	3,600	
*E.P.D.C.	Tachibanawan 1	Jul-00	1,050	Coal	25	600/610	a)	CC	3,600	
*E.P.D.C.	Matsuura 2	Jul-97	1,000	Coal	24.12	593/593	a)	CC	3,600	

Note: a) Variable pressure and once-through boiler
b) Once-through boiler
EPC., Electric Power Company
E.P.D.C., Electric Power Development Co., Ltd.

19-3 Outline of Combined Cycle Power Generation Facilities

(1) Outline of combined cycle power generation facilities

Name of Company	Name of Plant	Name of Prefecture	Plant Output (kW)	Group Number	Gas turbine						Heat recovery steam generator			Steam turbine				Commission Dates	Notes
					Type	Capacity (kW)	Number	Turbine inlet pressure (MPa)	Turbine inlet temperature (℃)	Fuel	Type	Capacity (t/h)	Number	Capacity (kW)	Number	Turbine inlet pressure (MPa)	Turbine inlet temperature (℃)		
Tohoku EPC.	Higashi Niigata	Niigata	1,090,000 (Ambient temperature at 15℃)	Group No. 3 Steam power 3-1~2 Gas turbine 3-1~6	Single-shaft Open cycle	137,000 (Ambient temperature 1℃)	6	1.37	1,154	LNG	a)	High pressure 194 Low pressure 57	6	203,000 (Ambient temperature 1℃)	2	6.37/0.49	500/Saturated	Oct-85	•Dec-84 Half capacity in commission •Oct-85 Full capacity in commission
			1,610,000	Group No. 4 Steam power 4-1~2 Gas turbine 4-1~4	Open simple cycle Single-shaft type	270,000 (Ambient temperature 5℃)	4	1.86	1,420	LNG	a)	High pressure 310 Intermediate pressure 57 Low pressure 47	4	265,000	2	High pressure13.73 Reheat 4.12 Low pressure 0.49	High pressure 566 Reheat 566 Low pressure 253	4-1GT,4-2GT, 4-1ST:Jul-99 4-3GT,4-4GT, 4-2ST:Dec-06	
Tokyo EPC.	Futtsu	Chiba	2,000,000	Group No. 1	Open cycle Single-shaft type	112,823 (Ambient temperature 8℃)	7	1.14	1,145	LNG	b)	220	7	52,177	7	64.6/1.38	531/198	Nov-86	•Stage after stage in commission Dec-85 First stage in commission
				Group No. 2	Open cycle Single-shaft type	112,823 (Ambient temperature 8℃)	7	1.14	1,145	LNG	b)	220	7	52,177	7	64.6/1.38	531/198	Nov-88	•Stage after stage in commission Dec-87 First stage in commission
	Yokohama	Kanagawa	1,400,000	Group No. 7	Open simple cycle Single-shaft type	225,000 (Ambient temperature 5℃)	4	1.38	1,429	LNG	a)	High pressure 281 Intermediate pressure 62 Low pressure 39	4	125,000	4	High pressure10.13 Reheat 2.28 Low pressure 0.32	High pressure 538 Reheat 536 Low pressure 260	7-2:Oct-97 7-1:Jan-98 7-4:Jun-96 7-3:Jan-97	
			1,400,000	Group No. 8	Open simple cycle Single-shaft type	225,000 (Ambient temperature 5℃)	4	1.38	1,429	LNG	a)	High pressure 283 Intermediate pressure 57 Low pressure 43	4	125,000	4	High pressure10.19 Reheat 2.26 Low pressure 0.32	High pressure 539 Reheat 537 Low pressure 253	8-3:Oct-97 8-4:Jan-98 8-1:Jul-96 8-2:Feb-97	
	Chiba	Chiba	1,440,000	Group No. 1	Open simple cycle Single-shaft type	241,900	4	1.56	1,350	LNG	a)	High pressure 252 Intermediate pressure 59 Low pressure 56	4	118,100	4	High pressure10.30 Intermediate pressure 2.87 Low pressure 0.40	High pressure 532 Intermediate pressure 533 Low pressure 250	1-4:Dec-98 1-3:Apr-99 1-2:Jul-99 1-1:Dec-99	
			1,440,000	Group No. 2	Open simple cycle Single-shaft type	233,000	4	1.40	1,429	LNG	a)	High pressure 286 Intermediate pressure 63 Low pressure 38	4	127,000	4	High pressure10.26 Intermediate pressure 2.39 Low pressure 0.33	High pressure 535 Intermediate pressure 537 Low pressure 262	2-1:Feb-99 2-2:May-99 2-3:Aug-99 2-4:Feb-00	
Chubu EPC.	Yokkaichi	Mie	560,000	Group No. 4	Open cycle Single-shaft type	79,440 (Ambient temperature 9℃)	5	1.14	1,206	No.1~3 stages LNG No.4~5 stages LNG LPG	b)	High pressure 145 Low pressure 35	5	40,750 (Ambient temperature 27℃)	5	6.28/0.67	549/177	Jul-88	•Stage after stage in commission Feb-88 First stage in commission
	Kawagoe	Mie	1,650,000	Group No. 3	Open cycle	158,000 (Ambient temperature 5℃)	7	1.43	1,288	LNG	a)	High pressure 196 Intermediate pressure 35 Low pressure 31	7	85,000 (Ambient temperature 5℃)	7	High pressure10.03 Intermediate pressure 2.18 Low pressure 0.25	High pressure 538 Intermediate pressure 538 Low pressure 258	Dec-96	•Stage after stage in commission Jun-96 First stage in commission
			1,650,000	Group No. 4	Open cycle	158,100 (Ambient temperature 5℃)	7	1.36	1,260	LNG	a)	High pressure 191 Intermediate pressure 36 Low pressure 36	7	84,900 (Ambient temperature 5℃)	7	High pressure 8.73 Intermediate pressure 2.35 Low pressure 0.16	High pressure 538 Intermediate pressure 538 Low pressure 250	4-1:Jun-97 4-2,3:Aug-97 4-4,5:Oct-97 4-6,7:Dec-97	

(Continued)

Name of Company	Name of Plant	Name of Prefecture	Plant Output (kW)	Group Number	Gas turbine						Heat recovery steam generator			Steam turbine				Commission Dates	Notes
					Type	Capacity (kW)	Number	Turbine inlet pressure (MPa)	Turbine inlet temperature (℃)	Fuel	Type	Capacity (t/h)	Number	Capacity (kW)	Number	Turbine inlet pressure (MPa)	Turbine inlet temperature (℃)		
Chubu EPC.	Shin Nagoya	Aichi	1,458,000	Group No. 7	Open cycle	158,200	6	1.42	1,288	LNG	a)	High pressure 180 Intermediate pressure 30 Low pressure 30	6	84,800	6	High pressure10.87 Intermediate pressure 2.22 Low pressure 0.43	High pressure 538 Intermediate pressure 538 Low pressure 270	Dec-98	•Stage after stage in commission Aug-98 First stage in commission
The Kansai EPC.	Himeji No.1	Hyogo	670,000	Group No. 5	Open simple cycle Single-shaft type	157,000	3	1.37	1,350	LNG	a)	High pressure 193 Intermediate pressure 36 Low pressure 36.7	3	258,600	1	High pressure 14.89 Reheat 4.47 Low pressure 0.52	High pressure 538 Reheat 538 Low pressure 262	Apr-95	
			670,000	Group No. 6	Open simple cycle Single-shaft type	154,300	3	1.49	1,418	LNG	a)	High pressure 206 Intermediate pressure 31 Low pressure 37	3	250,100	1	High pressure 14.70 Reheat 4.36 Low pressure 0.52	High pressure 538 Reheat 538 Low pressure 272	May-96	
The Chugoku EPC.	Yanai	Yamaguchi	700,000	Group No. 1	Open simple cycle Single-shaft type	82,780 (Ambient temperature 5℃)	6	1.22	1,104	LNG	a)	158.8	6	42,220 (Ambient temperature 5℃)	6	5.58/0.55	481/161.8	Dec-92	•Stage after stage in commission Nov-90 First stage in commission
			700,000	Group No. 2	Open simple cycle Single-shaft type	125,400 (Ambient temperature 5℃)	4	1.13	1,260	LNG	a)	231.6	4	72,600 (Ambient temperature 5℃)	4	6.87/0.55	577/158.1	Jan-96	•Stage after stage in commission Mar-94 First stage in commission
Kyushu EPC.	Shin Oita	Oita	1,560,000	Group No. I	Open cycle Single-shaft type	76,300 (Ambient temperature 7℃)	6	1.18	1,085	LNG	a)	High pressure 123.0 Low pressure 28.7	6	38,700	6	5.67/0.52	511/0.160	Jun-91	•Stage after stage in commission Nov-90 First stage in commission
				Group No. 2	Open cycle Single-shaft type	144,400 (Ambient temperature 7℃)	4	1.30	1,260	LNG	a)	High pressure 226.0 Low pressure 43.7	4	73,100	4	7.60/0.53	538/161	Feb-94 Feb-95	•No. 1~2 stages in commission •No. 3~4 stages in commission
			735,000	Group No. 3-1	Open cycle Single-shaft type	160,200	3	1.52	1,288	LNG	a)	High pressure 200 Intermediate pressure 35 Low pressure 34	3	84,800	3	High pressure10.12 Reheat 2.21 Low pressure 0.30	High pressure 538 Reheat 538 Low pressure 268	Jul-98	
Mizu-shima	Mizu-shima	Oka-yama	149,000	New No. 1 Unit	Open cycle Single-shaft type	88,800	1	1.16	1,250	Enhanced heat value blast furnace gas	a)	218	1	60,200	1	7.46/0.66	538/210	Jun-94	
Fuku-yama	Fuku-yama	Hiro-shima	145,000	New No. 1 Unit	Open cycle Single-shaft type	86,500	1	1.16	1,250	Enhanced heat value blast furnace gas	a)	210	1	58,500	1	7.44/0.58	538/195	Jul-95	

Notes: a) Natural circulation type b) Forced circulation type

(2) Outline of pressurized fluidized bed combined cycle power generation facilities

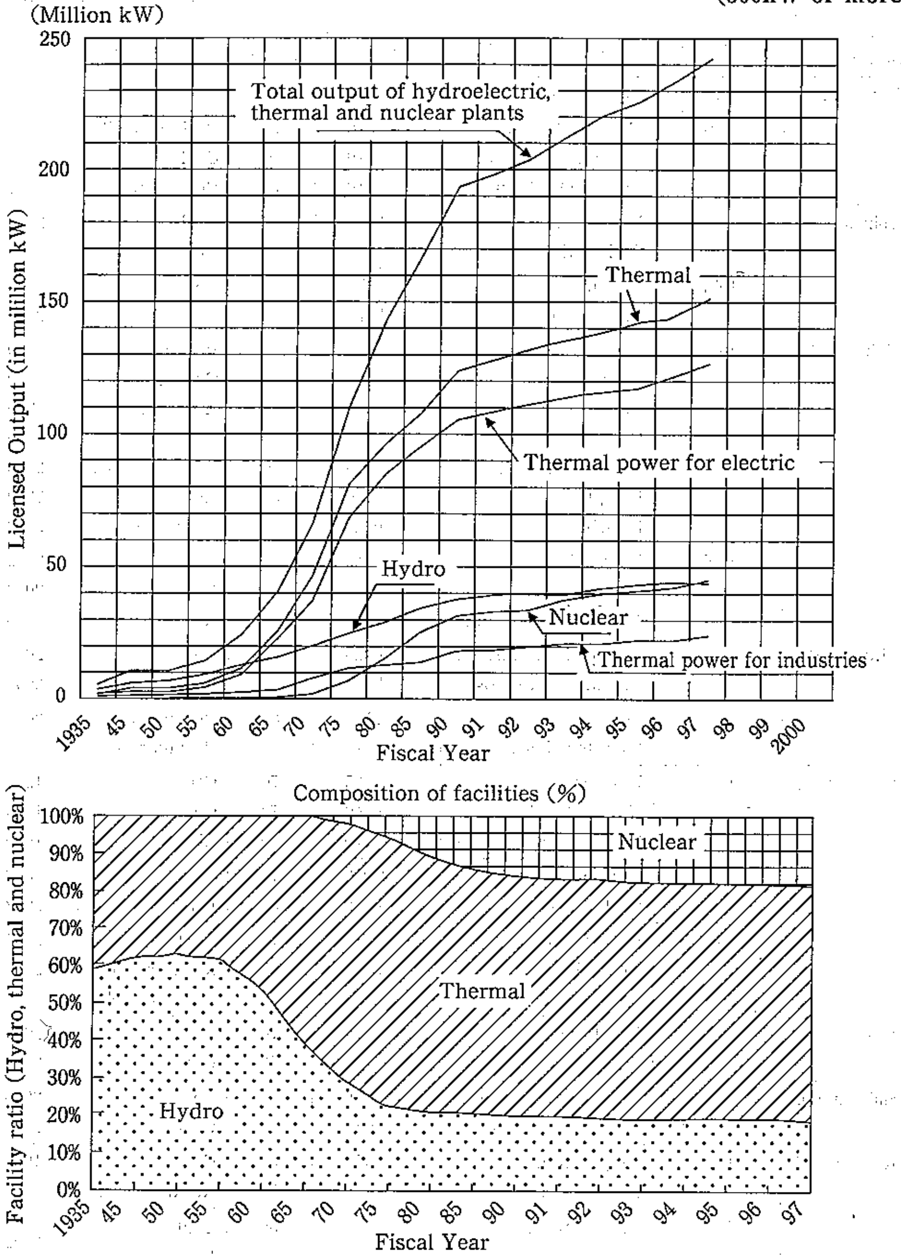
Name of Company	Name of Plant	Name of Prefecture	Plant Output (kW)	Group Number	Pressurized fluidized bed boiler				Gas turbine					Steam turbine				Commission Dates	Notes
					Type	Fuel system	Capacity (t/h)	Fuel	Type	Capacity (kW)	Number	Turbine inlet pressure (MPa)	Turbine inlet temperature (℃)	Capacity (kW)	Number	Turbine inlet pressure (MPa)	Turbine inlet temperature (℃)		
Hokkaido EPC.	Tomato-atsuma	Hokkaido	85,000	Group No. 3	Pressurized fluidized bed/reheat/ forced circulation type	Bubbling type	195	Coal	Open simple cycle Single-shaft type	13,600	1	0.95	831	75,300	1	High pressure16.57 Reheat 3.65	High pressure 566 Reheat 538	Mar-98	

19-4 Table of IPP Plants

(As of November 30, 1999)

Name of Electric Power Company	Fiscal year	Name of Company	Plant output (MW)	Utilization factor	Main fuel	Commission year (Fiscal)
Hokkaido EPC.	1996	Nippon Steel	100.0	70	Coal	2001
	1997	Idemitsu Kosan	15.0	70	Residuary oil	2004
		Nippon Paper Industries	80.0	70	Coal	2004
		Nippon Oil Refining	50.0	70	Residuary oil	2004
Tohoku EPC.	1996	Nippon Steel	136.0	30	Coal	2000
		Pacific Metals	44.0	30	Heavy oil	2000
	1997	Nichimen	5.3	50	Coal	2000
		Nihon Cement	134.0	40	Coal	2001
Tokyo EPC.	1996	Showa Denko	124.2	70	Residuary oil	1999
		Ebara	64.0	30	City gas	1999
		Tomen	65.5	30	Kerosene	1999
		Hitachi Zosen	102.7	30	Heavy oil	1999
		Nippon Oil Refining	48.5	50	Cracked light oil	2000
		Polyplastics	47.0	50	Heavy oil	2000
		Hitachi	100.5	30	Kerosene	2000
	1997	Kawasaki Steel	392.6	30	LNG	2002
		Toa Oil	238.0	80	Excessive gas	2003
		Nippon Oil Refining	342.0	80	Residuary oil	2003
Chubu EPC.	1996	Nakayama Kyoudou Hatuden	135.5	90	Coal	2000
		Akemi Electric Power	135.0	85	Coal	2000
	1997	Cosmo Oil	200.0	80	Residuary oil	2003
		Idemitsu Kosan	225.6	80	Residuary oil	2004
The Kansai EPC.	1996	Kobe Steel	54.5	70	Others	1999
		Nippon Steel	133.0	70	Coal	1999
		Nakayama Kyoudou Hatuden	136.0	30	LNG	1999
		Kobe Steel	659.0	70	Coal	2002
		Osaka Gas	140.0	30	LNG	2002
	1997	Kobe Steel	659.0	70	Coal	2004
		Koa Oil	132.3	70	Residuary oil + Petroleum coke	2004
The Chugoku EPC.	1997	Ube Industries	195.0	70	Coal	2003
		Mitsubishi Rayon	40.0	50	Coal	2003
Shikoku EPC.	1998	Sumitomo Osaka Cement	65.0	70	Coal	2005
		Taiheiyo Cement	150.0	70	Coal	2005
Kyushu EPC.	1996	Nippon Steel	137.0	50	Coal	1999
		Kyushu Oil	137.0	50	Residuary oil	1999
	1997	Nippon Steel	300.0	50	Coal + Excessive gas	2002

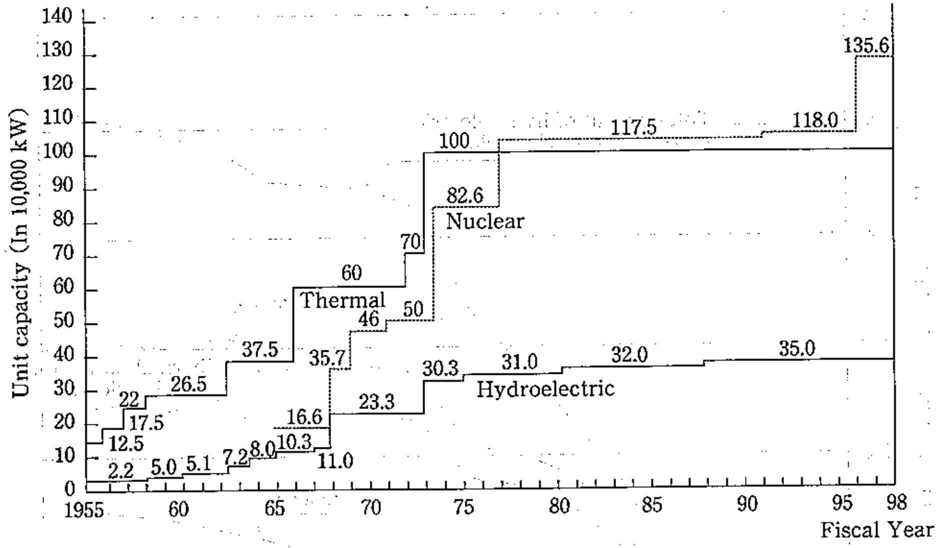
19-5 Historical Change of Power Generation Facilities in Japan (500kW or more)



〔Source: Hand Book of Electric Power Industry by The Federation of Electric Power Companies Statistics Committee, editions from 1992 to 1998〕

Note: Data are plotted in every year from 1990.

19-6 Histories of Maximum Capacities of Hydro, Thermal and Nuclear Units in Japan



19-7 Electric Power Generation Produced by Thermal Power Plant in Major Countries

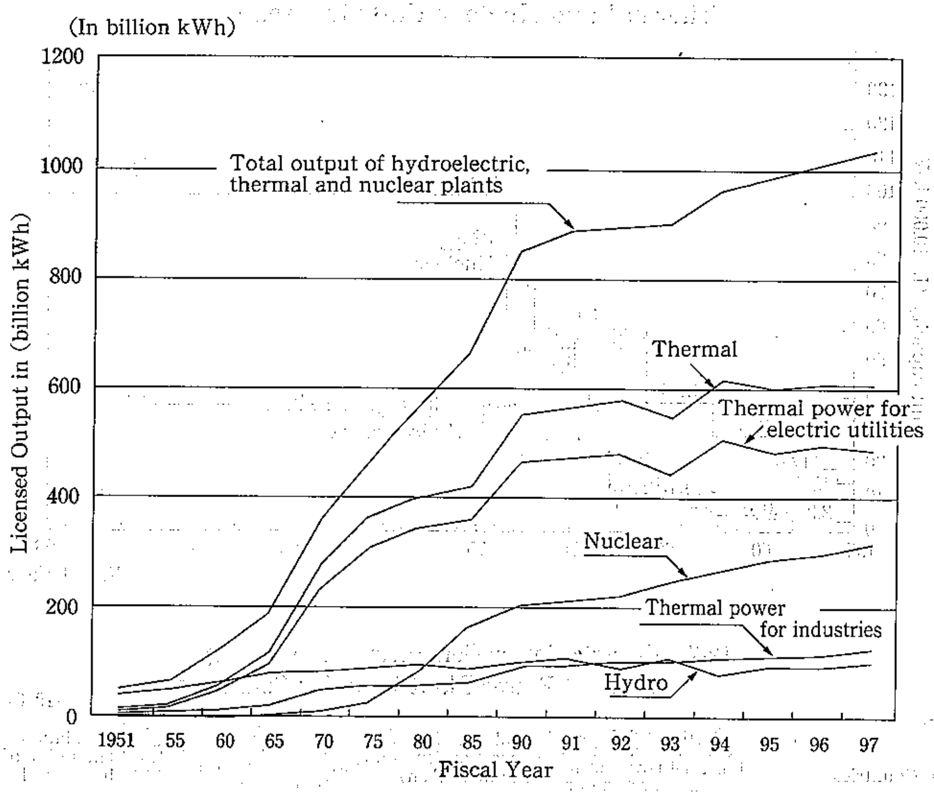
(-1996)

Item / Countries	Electric power generation produced by thermal power plant (In units of million kWh)	Total electric power generation (In units of million kWh)	Ratio of electric power generation produced by thermal power plant to total electric power generation (%)	Population (In units of 10,000 people)
U.S.A.		3,473,369		26,545
Russia	583,000	847,000	68.8	14,747
Japan	614,014	1,009,349	60.8	12,576
Germany	367,030	550,309	66.7	8,190
China	878,101	1,079,358	81.4	123,208
U.K.	245,103	347,369	70.6	5,878
Italy	197,313	244,424	80.7	5,738
France	41,681	484,003	8.6	5,837
Canada	111,111	547,858	20.3	2,997
Australia	* 157,164	* 173,404	90.6	* 1,807
Spain	78,208	176,242	44.4	3,927
Sweden	14,875	139,686	10.6	884
Total	* 8,249,317	* 13,097,664	63.0	5,716 (million people)

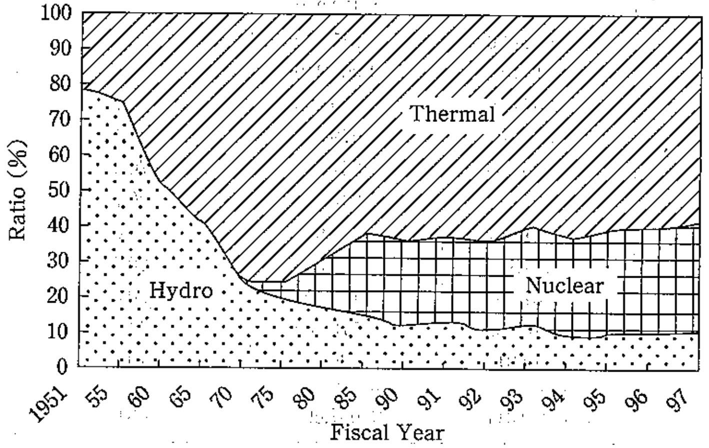
* Actual result data in 1995

〔Source: Overseas Electric Utilities Industry Statistics by Japan Electric Power Information Center, Inc. (1998 edition)〕

19-8 Historical Change of Electric Power Generation in Japan



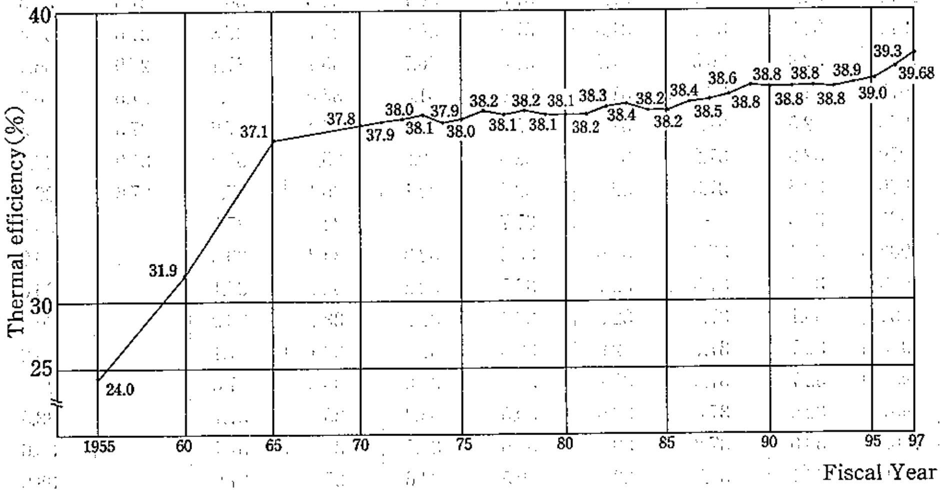
Composition of facilities (Hydro, thermal and nuclear)



〔Source: Hand Book of Electric Power Industry by The Federation of Electric Power Companies Statistics Committee, editions from 1992 to 1998〕

Note: Data are plotted in every year from 1990.

19-9 History of Gross Thermal Efficiency of Thermal Power Plants (Average of 9 Electric Power Companies)



〔Source: Hand Book of Electric Power Industry by The Federation of Electric Power Companies Statistics Committee, editions from 1970 to 1998〕

19-10 History of Average Net Thermal Efficiency per Year of Thermal Power Plants in Major Countries

(In units of %)

	U.S.A.	U.S.S.R	U.K.	Ex West Germany	Canada	France	Italy	Ex East Germany	Japan
1965	32.9	29.0	27.4	34.1	—	33.6	35.1	—	34.8
1970	32.5	33.5	28.4	35.7	30.8	34.9	36.3	25.1	35.9
1971	32.4	34.2	29.2	37.1	31.2	35.2	36.8	25.4	36.1
1972	32.6	34.7	29.4	37.7	31.0	35.4	36.8	25.8	36.3
1973	32.7	35.3	29.9	37.8	30.6	35.4	36.9	26.6	36.5
1974	32.6	35.7	30.3	37.3	30.7	35.5	36.8	27.3	36.3
1975	32.9	36.1	31.3	37.2	30.8	35.7	36.8	27.6	36.4
1976	32.9	36.5	31.7	37.8	30.7	35.7	37.1	27.9	36.4
1977	32.7	36.1	31.5	37.9	31.8	35.0	37.2	27.5	36.5
1978	32.5	37.1	32.1	38.8	32.1	35.4	37.6	27.3	36.5
1979	32.6	37.2	31.8	38.8	32.2	35.1	37.2	31.0	36.4
1980	32.5	37.5	32.1	38.6	32.1	35.1	37.3	27.6	36.3
1981	32.5	—	—	37.7	—	34.7	37.0	—	36.5
1982	32.4	37.6	32.6	35.8	32.3	34.3	39.3	—	36.6
1983	32.4	37.5	32.7	36.5	32.2	34.1	37.1	—	36.6
1984	33.1	37.1	32.9	36.4	32.2	33.7	36.9	—	36.2
1985	32.7	37.7	32.9	39.3	32.2	33.1	37.1	—	38.2
1986	32.7	37.6	33.1	39.5	32.0	33.6	37.6	—	38.4
1987	32.9	37.8	33.5	39.5	34.3	33.0	37.7	—	38.5
1988	33.0	37.8	33.7	39.5	34.7	34.7	37.7	—	38.6
1989	33.1	37.7	33.7	39.5	34.6	35.7	37.9	—	38.8
1990	32.9	37.8	33.9	39.8	34.5	35.8	37.7	—	38.8
1991	33.1	39.1	34.0	39.8	33.2	36.0	37.7	—	38.8
1992	33.0	39.6	34.4	39.6	35.0	35.7	38.0	—	38.8
1993	33.0	39.9	36.6	39.8	34.4	34.7	38.3	—	38.8
1994	32.7	39.6	36.2	39.8	31.7	34.4	38.3	—	38.9
1995	33.5	39.4	36.4	39.9	32.6	34.5	38.6	—	39.0
1996	33.5	35.6	37.4	—	—	35.2	38.8	—	39.3

Note:※1 The thermal efficiencies in ex West Germany are measured at the generator terminal.

※2 The thermal efficiencies in Canada and Japan from 1990 to 1996 are measured at the generator terminal.

※3 The thermal efficiencies in U.S.S.R from 1990 to 1996 are those measured in Russia.

※4 The thermal efficiencies in ex West Germany in and after 1991 are those measured in Unified Germany.

Sources: Overseas Electric Utilities Industry Statistics by Japan Electric Power Information Center, Inc. (1998 edition)
Hand Book of Electric Power Industry by The Federation of Electric Power Companies Statistics Committee (1998 edition)

19-11 History of Units having Maximum Yearly Thermal Efficiencies in Japan

(Steam power plants) (Those having maximum thermal efficiencies of units operating 250 days or more a year)

Fiscal Year	Unit name	Output (MW)	Steam condition (MPa-℃/℃)	Generating days	Utilization factor (%)	Thermal efficiency	
						Gross(%)	Net(%)
1960	Chiba No.4	175	16.57−566/538	362	92.6	38.15	35.74
1961	Shin-minato No.1	156	16.57−566/538	318	81.2	38.95	36.59
1962	Shin-minato No.1	156	16.57−566/538	292	72.4	39.14	36.69
1963	Yokohama No.2	175	16.57−566/538	311	65.7	39.47	37.13
1964	Himeji Daini No.1	250	16.57−566/538	306	72.7	38.98	37.89
1965	Kudamatsu No.1	156	16.57−566/538	318	77.6	39.14	37.29
1966	Goi No.4	265	16.57−566/566	302	61.5	39.86	37.31
1967	Yokohama No.2	175	16.57−566/538	355	70.3	39.86	37.60
1968	Anegasaki No.1	600	24.12−538/566	295	67.0	39.80	38.80
1969	Anegasaki No.1	600	24.12−538/566	313	74.0	39.85	38.84
1970	Anegasaki No.2	600	24.12−538/566	297	72.3	40.11	39.13
1971	Anegasaki No.3	600	24.12−538/566	341	73.0	40.06	38.98
1972	Kashima No.2	600	24.12−538/566	278	57.2	39.99	39.08
1973	Kashima No.3	600	24.12−538/566	312	72.5	40.48	39.29
1974	Shin-Sendai No.2	600	24.12−538/566	302	70.0	40.34	38.29
1975	Kashima No.5	1,000	24.12−538/566	256	49.2	40.29	38.60
1976	Tomakomai No.1	250	24.12−566/538	321	78.4	39.69	38.60
1977	Kainan No.3	600	24.12−538/552/566	323	66.7	39.74	38.40
1978	Kainan No.3	600	24.12−538/552/566	291	62.9	39.89	38.55
1979	Kudamatsu No.3	700	24.12−538/566	286	58.4	39.92	38.69
1980	Anan No.4	450	24.12−538/566	266	51.6	40.21	39.06
1981	Hirono No.1	600	24.12−538/566	296	59.4	40.36	39.03
1982	Hirono No.1	600	24.12−538/566	291	59.4	40.26	38.93
1983	Hirono No.1	600	24.12−538/566	291	59.5	40.38	39.08
1984	Chita Daini No.2	700	24.12−538/566	324	73.0	39.99	38.88
1985	Chita Daini No.2	700	24.12−538/566	300	67.0	40.06	38.95
1986	Tomato-atsuma No.2	600	24.12−538/566	299	75.1	41.37	38.88
1987	Tanagawa Daini No.1	600	24.12−538/552/566	262	49.9	40.30	38.80
1988	Tanagawa Daini No.1	600	24.12−538/552/566	282	51.9	40.27	38.89
1989	Hirono No.3	1,000	24.12−538/566	328	62.2	40.61	39.34
1990	Kawagoe No.1	700	30.99−566/566/566	287	64.4	41.05	39.61
1991	Kawagoe No.2	700	30.99−566/566/566	290	66.3	41.13	39.77
1992	Kawagoe No.2	700	30.99−566/566/566	316	69.3	41.03	39.62
1993	Noshiro No.1	600	24.52−538/566	340	70.3	41.22	38.99
1994	Shinchi No.1	1,000	24.12−566/593	299	70.6	41.33	38.74
1995	Noshiro No.2	600	24.12−566/593	262	49.8	40.96	38.64
1996	Ishikawa (coal) No.1	156	18.63−566/566	309	71.9	41.03	36.96
1997	Haramachi No.1	1,000	24.52−566/593	336	74.1	42.39	40.08

〔Reference: Power Generation Performances Survey Table by Reheat Type Electric Utility Thermal Power Units, from 1960 to 1997 (fiscal)〕

(Combined cycle power plants) (Those having maximum thermal efficiencies of units operating 250 days or more a year)

Fiscal Year	Unit name	Output (MW)	Generating days	Utilization factor (%)	Thermal efficiency	
					Gross (%)	Net (%)
1985	Higashi niigata Group NO. 3	1,090	345	53.0	43.32	42.63
1986	Higashi niigata Group NO. 3	1,090	365	62.4	43.97	43.33
1987	Higashi niigata Group NO. 3	1,090	364	58.4	43.94	43.28
1988	Higashi niigata Group NO. 3	1,090	358	63.7	44.06	43.43
1989	Higashi niigata Group NO. 3	1,090	365	75.6	43.95	43.34
1990	Higashi niigata Group NO. 3	1,090	365	77.5	44.20	43.57
1991	Higashi niigata Group NO. 3	1,090	366	79.5	44.31	43.67
1992	Higashi niigata Group NO. 3	1,090	365	73.5	44.36	43.72
1993	Higashi niigata Group NO. 3	1,090	365	80.6	44.17	43.54
1994	Yanai Group NO. 2	1,050	344	77.3	45.69	44.60
1995	Himeji Daiichi Group NO. 5	670	332	62.4	47.49	46.60
1996	Kawagoe Group NO. 3	1,650	330	46.4	48.34	47.29
1997	Kawagoe Group NO. 3	1,650	356	55.0	48.54	47.46

〔Reference: Power Generation Performances Survey Table by Reheat Type Electric Utility Thermal Power Units, from 1985 to 1997 (fiscal)〕

19-12 Thermal Efficiency and Utilization Factor of Power Plants

1. Thermal efficiency and heat consumption rate

(1) Gross thermal efficiency η_G

(a) Plants for power generating only

$$\eta_G = \frac{P \times 3600}{G_F \times H_h} \times 100 \quad (\%)$$

or,

$$\eta_G = \frac{\eta_B}{100} \times \frac{\eta_T}{100} \times \left(1 - \frac{L}{100}\right) \times 100 \quad (\%)$$

(b) Plants for power generating and heat supply (Dual purpose power plants, Cogenerating plants)

$$\eta_G = \frac{P \times 3600 + W_e h_e + W_b h_b}{G_F \times H_h} \times 100 \quad (\%)$$

(2) Gross heat consumption rate HR_G

$$HR_G = \frac{3600}{\eta_G/100} \quad (kJ/kWh)$$

(3) Net thermal efficiency η_N

(a) Plants for power generating only

$$\eta_N = \frac{(P - P_H) \times 3600}{G_F \times H_h} \times 100 \quad (\%)$$

(b) Plants for power generating and heat supply (Dual purpose power plants, Cogenerating plant)

$$\eta_N = \frac{(P - P_H) \times 3600 + W_e h_e + W_b h_b}{G_F \times H_h} \times 100 \quad (\%)$$

(4) Net heat consumption rate HR_N

$$HR_N = \frac{3600}{\eta_N/100} \quad (kJ/kWh)$$

(5) Auxiliary power ratio R_H

$$R_H = \frac{P_H}{P} \times 100 \quad (\%)$$

Where, P: Generated electric power (kW)

G_F: Fuel consumption (Dry coal for coal fired plants) (kg/h)

H_h: Heating value of fuel (Higher heating value) (kJ/kg)

η_B: Thermal efficiency of boiler (By input and output heat method: Using equation (1)-(a) in 11-3) (%)

η_T: Thermal efficiency of turbine (Using equation (3) in 14-5) (%)

L: Plant loss. The plant loss L is found as shown below: (%)

$$L = = \frac{[(Q_1)_B - (Q_1)_T] + [(Q_0)_T - (Q_0)_B] - Q_{MU}}{G_F \times H_h \times \eta_B} \times 100$$

$(Q_1)_B$: Quantity of heat flow out of boiler (kJ/h)

$(Q_0)_B$: Quantity of heat flow into boiler (kJ/h)

$(Q_1)_T$: Quantity of heat flow into turbine (kJ/h)

$(Q_0)_T$: Quantity of heat flow out of turbine (kJ/h)

Q_{MU}: Quantity of heat of make-up water (kJ/h)

($[(Q_1)_B - (Q_1)_T] + [(Q_0)_T - (Q_0)_B]$) is the sum of the quantities of heat discharged from the piping between the boiler and turbine, leak steam from the cycle, heat removed by water, etc.

We: Turbine extraction steam quantity used for supplying heat (kg/h)
he: Enthalpy of extraction steam used for supplying heat (kJ/kg)
Wb: Turbine exhaust steam quantity used for supplying heat (kg/h)
hb: Enthalpy of exhaust steam used for supplying heat (kJ/kg)
PH: House power (kW)

2. Indices for operations

(1) Maximum power (kW)

The maximum electric power generated in a certain period (Normally, average of electric power generated in an hour)

(2) Average power (kW)

$$\text{Average power} = \frac{\text{electric energy in certain period}}{\text{total hours in the same period}}$$

(3) Load factor (%)

$$\text{Load factor} = \frac{\text{average power in certain period}}{\text{maximum power in the same period}} \times 100$$

The load factor is a ratio representing the characteristics of the load. It also shows the practical service based on the maximum power if there is great difference between the approved power and maximum power like in a hydroelectric power plant.

(4) Utilization factor (%)

$$\text{Utilization factor} = \frac{\text{average power in certain period}}{\text{approved power of unit}} \times 100$$

The utilization factor is a ratio indicating what percent is used of the maximum capacity of the facility.

(5) Availability factor (%)

$$\text{Availability factor} = \frac{\text{operation hours in certain period}}{\text{total hours in the same period}} \times 100$$

The availability factor indicates a ratio of duty which the facility achieves in a certain period.

Note: 1. The period shown above is on a day, month or year basis.

19-13 Change of Fuel Costs (CIF)

Item / Fiscal Year	Coal (Normal)		Crude oil		LNG		Exchange rate
	Dollar/ton	Yen/ton	Dollar/barrel	Yen/kl	Dollar/ton	Yen/ton	Yen/dollar
1975	35.99	10,700	12.05	22,654	88.90	26,634	298.91
1976	33.53	9,840	12.69	23,382	97.90	28,652	292.89
1977	34.80	9,000	13.69	22,182	111.53	28,378	257.60
1978	38.37	7,624	13.89	17,633	124.62	25,141	201.91
1979	42.05	9,724	23.07	33,518	170.51	39,344	231.00
1980	56.59	12,100	34.62	47,508	287.56	62,681	218.23
1981	67.09	15,190	36.94	52,432	303.28	68,665	225.68
1982	64.07	16,005	34.07	53,485	296.62	73,975	249.57
1983	52.88	12,522	29.66	44,117	256.15	60,529	236.44
1984	48.43	11,787	29.14	44,558	254.97	62,149	243.09
1985	44.88	10,017	27.30	38,283	260.68	58,181	222.90
1986	43.42	7,009	13.81	13,967	176.05	28,377	160.77
1987	41.32	5,687	18.15	15,829	178.98	24,789	138.62
1988	43.84	5,652	14.79	11,896	160.76	20,592	127.84
1989	49.84	7,097	17.86	15,975	172.92	24,587	142.22
1990	51.02	7,197	23.34	20,296	204.86	28,652	138.23
1991	49.62	6,601	18.89	15,769	191.86	25,578	132.68
1992	47.81	5,985	19.29	15,196	187.28	23,463	125.27
1993	45.05	4,878	16.73	11,407	174.70	18,899	108.36
1994	43.56	4,345	17.32	10,855	167.98	16,754	99.63
1995	49.58	4,777	18.27	11,057	179.20	17,235	96.23
1996	48.73	5,452	21.63	15,298	198.62	22,355	112.46
1997	44.36	5,432	18.82	14,504	192.21	23,545	122.52

〔Source: Hand Book of Electric Power Industry by The Federation of Electric Power Companies Statistics Committee (editions from 1983 to 1998)〕

19-14 Approximate Site Areas, Utility Water and Fuels for Steam Power Plants

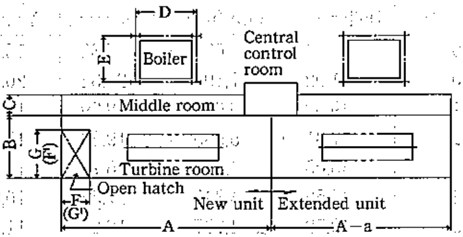
(per 1 MW)

		Oil	LNG	Coal	Remarks
Site areas(m²)	Total area	400～800	350～500	500～900	Tree planting rate: 40%
	Main building and chimney	30～60	25～30	40～110	
	Fuel storage yard	100～150	50～100	150～200	Storage period: 20 days or so
	Others	200～600	250～350	350～600	
Utility water (tons/day)	Normally required water quantity	1.9～2.4	1.9～2.4	2..4～4.4	MCR×0.5%
	Make-up water for boiler	0.4	0.4	0.4	
	Bearing cooling water, etc.	1.5～2.0	1.5～2.0	2～4.0	
	During silica purging or cleaning up	3.5～5.5			
	During construction or periodical inspection	3.4～4.0			
	Condenser cooling water quantity	3.8～4.1 (×10²t/s)			Seawater: 21℃
Fuel (per year)		Heavy oil: 1,400kℓ Crude oil: 1,500kℓ Naphtha: 1,800kℓ	LNG 1,100t	Coal: 2,300t	Utilization factor: 70% Thermal efficiency: 38%

Note: 1. Power plants using oil or LNG as fuel shall be equipped with denitration facilities of 1/2 or so.
2. Power plants using coal as fuel shall be equipped with desulfuration and denitration facilities for full quantity.

19-15 Example of Areas of Main Station Buildings of Steam Power Plants

(1) For Tandem compound type turbine generators



Item \ Unit capacity	150MW class	250MW class	350MW class	500MW	700MW	Remark
A (m)	50~66	62~78	67~82	88	103＊	Note: 2
a (m)	8~20	8~18	6~21	11	18＊	
B (m)	18~22	21~24	20~25	21~23	23	
C (m)	6~11	5~15	10~20	10~20	12~20	
D (m)	26~27	27~32	30~40	33~41	42	
E (m)	22~26	24~30	22~32	32~44	32	
F(F') (m)	about 8	8~10	6~10	7	9＊	
G(G') (m)	13~20	13~18	10~15	13	18＊	

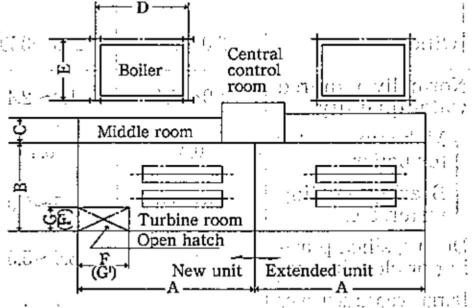
(Length: in m)

Note: 1. ＊The values marked with asterisks, ＊, are estimated from examples of extended units.

2. Dimensions A depend on the turbine types (including the number of casings) and the sizes and positions of large object entrances. (See Note 3.)

3. Dimensions F and G are marked with dashes if F>G, which is influenced by dimensions a.

(2) For Cross compound type turbine generators



Item \ Unit capacity	265MW	350MW	600MW	1,000MW	Remark
A (m)	53	60	72	90	Note: 1
B (m)	31	31	33	33	
C (m)	11~20	11~20	11~20	11~20	
D (m)	23~35	32~38	34~53	40~55	
E (m)	22~31	20~31	28~55	37~65	
F(F') (m)	14	14	16	17	
G(G') (m)	9	9	9	10	

(Length: in m)

Note: 1. Dimensions A are the same whether the building is constructed newly or extended.

2. Dimensions F and G are marked with dashes if F>G.

19-16 Standard Construction Schedule of Steam Power Plants

(In units of months)

Process \ Unit capacity / Type	156MW		250MW		375MW		500MW		600MW		700MW		1,000MW	
	Oil or gas	Coal	Oil or gas	Coal	Oil or gas	Coal	Oil or gas	Coal	Oil or gas	Coal	Oil or gas	Coal	Oil or gas	Coal
Start-Setting up	5.0	5.5	6.0	7.0	6.5	7.0	7.5	8.0	7.5	9.0	8.0	9.0	9.0	11.0
Setting up-Firing	13.0	17.0	15.0	18.0	17.0	20.0	19.0	23.0	21.0	24.0	21.0	25.0	24.0	30.5
Firing-Steaming	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Steaming-Commissioning	4.0	5.5	4.0	6.0	4.0	6.0	4.5	6.5	4.5	6.5	5.0	7.0	5.0	7.0
Total (Preparation period not included)	23.5	29.5	26.5	32.5	29.0	34.5	33.0	39.5	35.0	41.5	36.0	43.0	40.0	50.5
Delay in starting construction of second and subsequent units (Months)	4.5	6.5	4.5	7.0	5.0	7.0	6.5	8.0	6.5	8.0	6.5	8.5	6.5	8.5

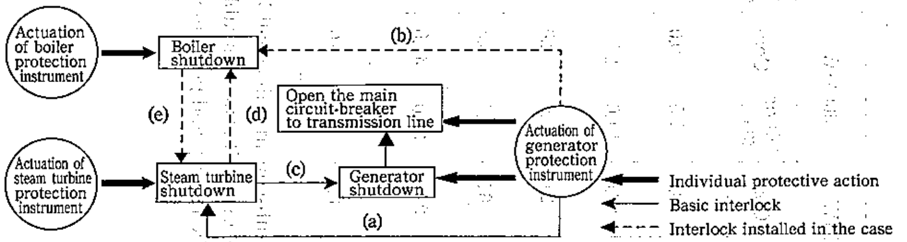
Note: If two or more units are to be constructed, the construction of the second and subsequent units shall be delayed for the months shown in "Delay in starting construction of second and subsequent units" above, since it is not desirable that the process from firing to commissioning, the busiest process in construction, is duplicated from the facility and personnel standpoints.

19-17 Classification of Trip Interlock Systems

1. Total Interlock between facilities of thermal power plant is called as unit interlock, and as for this interlock, the various methods are taken according to the point of view of facility operation and feature of facility. Here we explain the basic unit interlock of the steam power plant facilities, the gas turbine power plant facilities and the combined cycle power plant facilities.

(1) Unit Interlock of Steam Power Plant Facilities

The basic unit interlock between boiler, steam turbine and generator is shown below.



a. It is very general to shutdown steam turbine automatically (Note 1) when generator protection instrument is actuated.

(Note 1) By the article 15 of interpretation of the technical standards for thermal power plant facilities, it is a general rule to install the equipment automatically cut-off the inlet steam of steam turbine, when failure occurs inside the generator which capacity is over 10,000 kVA.

b. There is a system to shutdown the boiler automatically when generator protection instrument is actuated.

c. When the protection instrument of steam turbine is actuated, it is very general to shutdown generator and to open main circuit breaker (Note 2), after confirmation of each turbine valve closed condition (driving steam source cut-off) or driving oil pressure failure of each turbine valve after shutdown of the turbine. In this case, there is a case that motoring for a certain time is permitted, or another case it is not permitted.

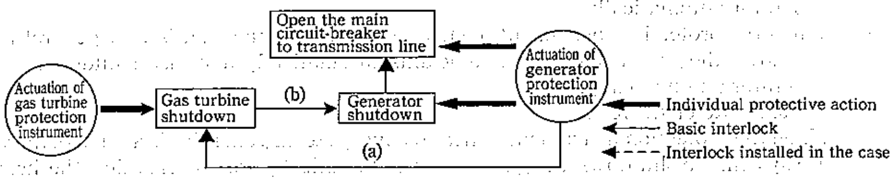
(Note 2) By the article 44 of interpretation of the technical standards for electrical facilities, it is a general rule to install the equipment cutting-off automatically the transmission line when the thrust bearing is worn remarkably or the temperature of it rises remarkably in a steam turbine which rated output is over 10,000 kW.

d. When the protection instrument of steam turbine is actuated, one system is to shutdown automatically the boiler immediately after steam turbine shutdown, and another system is to shutdown automatically the boiler only when required conditions are satisfied. The latter system is adopted in general, in case that the boiler can continue the independent operation after shutdown of turbine (in case that there is no possibility of reheater burnout, etc.), or that the steam of boiler is supplied to another facility.

e. When the protection instrument of boiler is actuated, one system is to shutdown automatically the steam turbine immediately, and another system is to shutdown the steam turbine when required conditions are confirmed as per the status of facilities. In general, the former system is adopted when the retaining heat capacity is small as once-through boiler, and the latter system is adopted when the retaining heat capacity is large as drum boiler or plural boilers are installed.

(2) Unit Interlock of Gas Turbine Power Plant Facilities

The basic unit interlock between gas turbine and generator is shown below.



a. It is very general to shutdown gas turbine automatically (Note 1) when generator protection instrument is actuated. In this case, one system is to shutdown automatically the gas turbine immediately according to the actuation items, and another system is to continue no-load operation by decreasing the fuel injection to gas turbine and to shutdown the turbine at the proper timing after cooling down.

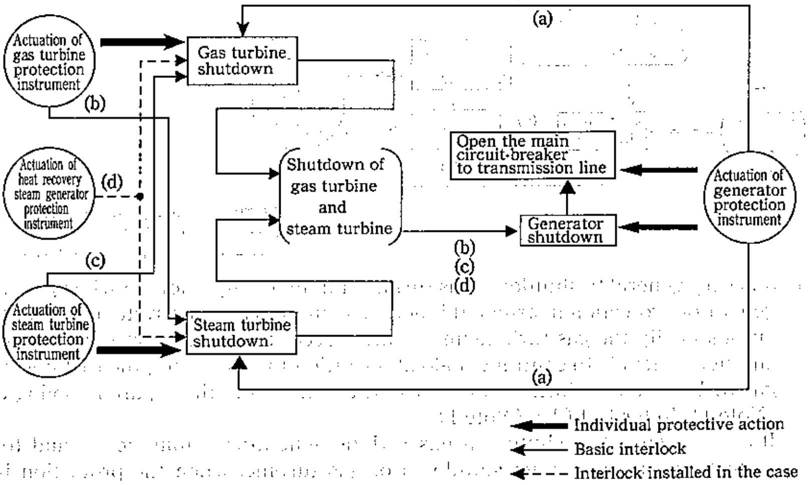
(Note 1) By the article 33 of interpretation of the technical standards for thermal power plant facilities, it is a general rule to install the automatic cut-off equipment of gas turbine inlet fuel, when failure occurs inside the generator which capacity is over 10,000 kVA.

b. It is very general to shutdown generator automatically and to open main circuit breaker, after shutdown of gas turbine, when the protection instrument of gas turbine is actuated.

(3) Unit Interlock of Combined Cycle Power Plant Facilities

a. Unit interlock of single-shaft combined cycle power plant facilities

Single-shaft combined cycle power plant facilities are composed by gas turbine, heat recovery steam generator using the gas turbine exhaust gas, steam turbine and generator, and are featured that gas turbine, steam turbine and generator are located on the same axis.



(a) It is very general to shutdown the gas turbine and the steam turbine as drivers automatically when the protection instrument of generator is actuated.

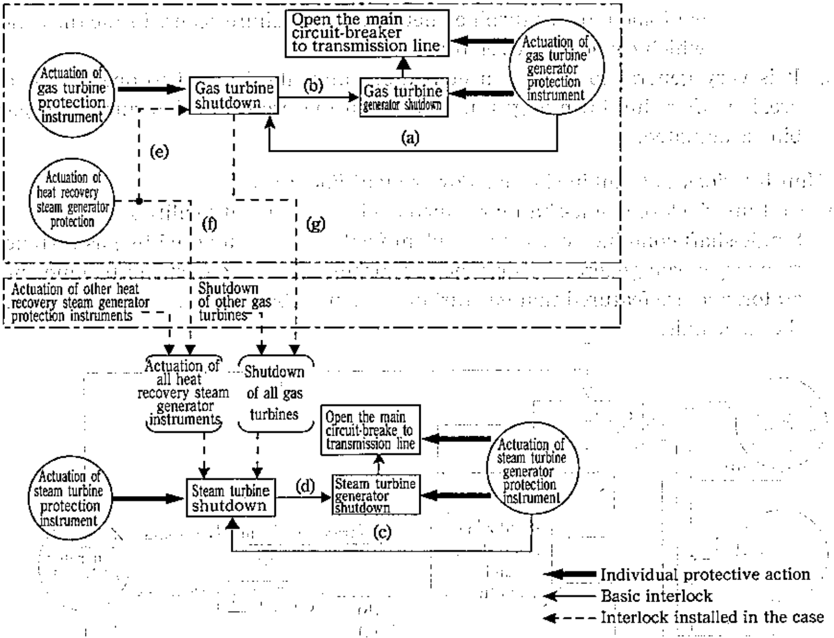
(Note 1) Refer to 1.(1)a (Note 1) and 1.(2)a (Note 1)

(b) When the protection instrument of gas turbine is actuated, it is very general to shutdown the steam turbine on the same axis automatically and also shutdown the generator automatically.

(c) When the protection instrument of steam turbine is actuated, it is very general to shutdown the gas turbine on the same axis automatically and also shutdown the generator automatically.
(Note 2) Refer 1.(1)c (Note 2)

(d) When the protection instrument of heat recovery steam generator is actuated, there are systems to shutdown the gas turbine automatically for interrupting the heat input to the heat recovery steam generator, and also shutdown the steam turbine automatically for preventing the wet-steam flow to the steam turbine.

b. Unit interlock of multi-shaft combined cycle power plant facilities
Multi-shaft combined cycle power plant facilities are composed by gas turbine and its generator, heat recovery steam generator using the gas turbine exhaust gas, and steam turbine and generator. In many cases, gas turbines and its generators and waste heat recovery boilers are installed plural.
The basic unit interlock is shown below.



(a) It is very general to shutdown gas turbine automatically (Note 1) when gas turbine generator protection instrument is actuated. In this case, one system is to shutdown automatically the gas turbine immediately according to the actuation items, and another system is to continue no-load operation by decreasing the fuel injection to gas turbine and to shutdown the turbine at the proper timing after cooling down.
(Note 1) Refer to 1.(2)a (Note 1)

(b) It is very general to shutdown gas turbine generator automatically and to open main circuit breaker, after shutdown of gas turbine, when the protection instrument of gas turbine is actuated.

(c) It is very general to shutdown steam turbine automatically (Note 2), when the protection instrument of steam turbine generator is actuated.
(Note 2) Refer to 1.(1)a (Note 1)

(d) It is very general to shutdown steam turbine generator and to open main circuit breaker (Note 3), after shutdown of steam turbine, when the protection instrument of steam turbine is actuated.
(Note 3) Refer to 1.(1)c (Note 2)

(e) When the protection instrument of heat recovery steam generator is actuated, there is a system to shutdown the gas turbine automatically for interrupting the heat input to the heat recovery steam generator. Besides, when the gas turbine exhaust gas can be emitted bypassing the heat recovery steam generator, it is not always necessary to shutdown the gas turbine automatically.

(f) When the protection instrument of heat recovery steam generator is actuated, there is a system to shutdown steam turbine immediately and automatically, and there is another system to shutdown it automatically after required conditions are confirmed as per the status of facilities. In general case of multi-shaft combined cycle power plant facilities, plural heat recovery steam generators are installed, so it is not necessary to shutdown the steam turbine automatically by the actuation of one heat recovery steam generator protection instrument. In other case of retaining heat capacity of heat recovery steam generator is large, it is not necessary to shutdown the steam turbine immediately and automatically by the actuation of one heat recovery steam generator protection instrument.

(g) When the protection instrument of gas turbine is actuated and the shutdown of gas turbine occurs, there is a system to shutdown steam turbine immediately and automatically, and there is another system to shutdown it automatically after required conditions are confirmed as per the status of facilities. In general case of multi-shaft combined cycle power plant facilities, plural gas turbines are installed, so it is not necessary to shutdown the steam turbine immediately and automatically by shutdown of one gas turbine.

〔Source: JEAC3201-1998 "Regulations for the Instrumentation and Control of Thermal Power Plant", issued by Japan Electric Association〕

19-18 Time Necessary for Start-up and Shutdown of Steam Power Plants

(In units of minutes)

Unit capacity	Steam conditions	Status before starting	Necessary time for starting up				Shout down time Full loading -parallel off
			Ignition-startup	Startup-parallel in	Parallel in-full loading	Ignition-full loading	
125 MW class	12.45MPa 538/538℃	① Midnight shut down ② Weekend shutdown ③ Long-term shutdown	50～90 120～210 180～520	20～35 40～45 30～300	75～120 110～180 110～450	145～245 275～435 357～1,080	60～157
150 MW class (150～200)	16.57MPa 566/538℃	① Midnight shut down ② Weekend shutdown ③ Long-term shutdown	30～180 60～240 170～580	15～50 15～60 15～345	75～180 100～240 110～410	140～410 215～540 410～1,125	60～150
250MW class (220～300)	16.57MPa 566/538℃ (566/566℃)	① Midnight shut down ② Weekend shutdown ③ Long-term shutdown	25～65 120～420 240～1,275	14～30 15～60 15～360	75～120 140～480 180～530	150～185 285～930 560～1,680	60～290
350MW class (300～400)	16.57MPa 566/538℃ (566/566℃)	① Midnight shut down ② Weekend shutdown ③ Long-term shutdown	25～75 50～360 85～405	10～30 15～70 20～360	50～180 75～370 135～675	75～260 170～605 245～1,095	41～160
500 MW class (400～550)	24.12MPa 538/538℃ (538/552/566℃)	① Midnight shut down ② Weekend shutdown ③ Long-term shutdown	40～120 100～360 100～400	20～45 25～70 60～430	75～280 105～300 139～480	165～365 245～590 510～1,100	72～195
600 MW class	24.12MPa 538/566℃ (538/538℃) (538/552/566℃)	① Midnight shut down ② Weekend shutdown ③ Long-term shutdown	27～75 55～360 120～370	13～35 15～100 20～370	50～148 87～410 160～570	100～600 167～800 450～1,160	40～175
700MW class	24.12MPa (30.99MPa) 538/538℃ (538/566℃) (566/566/566℃)	① Midnight shut down ② Weekend shutdown ③ Long-term shutdown	35～150 110～180 180～420	20～35 34～60 115～140	93～300 145～370 180～440	140～430 275～560 608～850	54～125

1,000MW class	24.12MPa 538/566℃	① Midnight shut down ② Weekend shutdown, ③ Long-term shutdown	30～65 47～81 199～540	18～29 23～40 23～330	105～160 156～220 223～770	167～243 226～331 500～1,330	55～272

Note: 1. The above table shows the time from firing to full loading. (Preparation before startup: Clear-up not included)
2. Midnight shutdown means shutdown of the plant for 8 to 12 hours or so, weekend shutdown means shutdown for 12 to 36 hours or so, and long-term shutdown means shutdown for 72 hours or more.
3. The above table shows the minimum and maximum required time of utility power plants in Japan (ten power companies).

19-19 Permissible Limits of Voltages in Thermal Power Plants

The Permissible fluctuations of voltages for electric equipment used in thermal power plants are specified by the standards as shown below.

Equipment names	Permissible voltage fluctuations	Standards
Generator	Rated voltage ±5%	JEC 37、54、114
Induction motor	Rated voltage ±10%	JEC 37
DC motor	Rated voltage ±5%	JEC 54
Semiconductor rectifier	Rated voltage ±5%	JEC 155、178
Transformer	Rated voltage ±5%	JEC 204
Electromagnetic contactor and relay	Rated voltage +10 to −15%	JEM 1,460、JEC 2,500
Automatic controller	Rated voltage ±10%	

[Descriptions]

1. The values shown above guarantee that any equipment can be used with the load for the rated output even if the voltage at the equipment terminal varies in the shown range during normal operation.
2. Note that the startup time of an induction motor increases and the protection relay may cause the motor to trip when the induction motor is started up on low voltage, even though the terminal voltage is the rated voltage −10% or less. In general, however, a motor may be started up even if the voltage drops by 15 to 25% from the rated voltage.
3. The stopping torque of an induction motor is approx. 150% of the maximum load torque. Thus, the motor may stop if the terminal voltage lowers below 70% of the rated voltage.
4. If a large motor is started on low voltage, its electromagnetic contactor or relay may be dislocated since the attraction is reduced due to voltage drop. JEM specifies that such voltage is the rated voltage −15% or less. In general, the voltage may drop by 30% or more.
5. The permissible line voltage fluctuation for instruments, recorders and controllers is ±10 %, in general. Devices whose performances are influenced by voltage fluctuation should be equipped with automatic voltage regulators (AVRs).
6. In general, overheat due to excessive excitation and deterioration of insulation are the problems when the equipment voltage exceeds the upper limit. However, overheat is not a serious problem since it may be reduced by decreasing the load current.

19-20 Minimum Load Operations and Quick Start of Steam Power Plants

(1) Boiler and turbine conditions

Boilers

Type: Radiation non-reheating or reheating boilers

Capacity: 100 to 3,200 t/h

Fuel: Heavy oil, crude oil, gas, or pulverized coal

Turbines

Steam condition: 24.12 MPa or less, 566℃ or less

Capacity: 66,000 to 1,000,000 kW or so (Non-reheating or reheating turbine)

Combination with boilers: Unit system (One turbine, one boiler)

Speed: 3,000 or 3,600 rpm

(2) Minimum load

(a) Minimum load limit of boiler

Boilers especially designed for heavy oil, crude oil or gas: 10 to 25% of the rated boiler capacity

Boilers especially designed for coal: 15 to 35% of the rated boiler capacity

Cautions of limits of minimum boiler load

(i) Minimum load of furnace
Pulverized coal only: 104,670 to 167,472 kJ/m^3/h
Mixed with heavy oil: 41,868 kJ/m^3/h
Heavy or crude oil only: Not restricted, in particular.
Natural gas only: Not restricted, in particular.
Blast furnace gas only: Not restricted, in particular.

(ii) Minimum velocity in fuel pipe (Pulverized coal mixture) 15 to 20m/s

(iii) Mimimum capacity of burner
Pulverized coal burner: 25 to 50%
Heavy or crude oil burner (Straight type) : 33 to 50%
Heavy or crude oil burner (Return flow type) : 10 to 20%
Heavy or crude oil burner (Steam spray type) : 5 to 20%
Blast furnace gas burner: 25 to 50%
Natural gas burner: 10 to 30%

(iv) Mimimum capacity of mill 25 to 50%

(v) Mimimum exhaust gas temperature
The gas temperature and air temperature should be so regulated that the air temperature of the air preheater is higher than the dew point of gas. (See 11-7.)

(vi) Auxiliary equipment Within the range causing no problems in low load performances.

(vii) Controller Within the range where the accuracy of the flow meters may be maintained in automatic control of the boiler.

(viii) Others Pay attention to the following:
Tube wall temperature of superheater and reheater. Right and left balance of water level in drum. Minimum flow of feed water (for once-through boiler).

(b) Limit of minimum turbine load

In general, the turbine load may be reduced to a value corresponding to the minimum boiler load, in general.

Cautions for limits of minimum turbine load

(i) Exhaust chamber temperature 55 or less to 120℃ or less (Depends on manufacturers.)

(ii) Moisture in exhaust steam 12% or less

(iii) Air separator The air separator should be protected against drop of the extraction pressure.

(iv) Feed water heater The feed water heater should be protected against drain discharge, penetration of air into the vacuum section, etc.

(v) Condenser and pump The condenser and pump should be protected against excessive cooling (condenser) and cavitation (condensate pump).

(3) Quick start

(a) Precautions for quick start of boiler

(i) Temperature rise rate of boiler water

Natural circulation boiler: 55℃/h (May be allowed up to 65℃/h in quick starting.)
Forced circulation boiler: 110℃/h
Once-through boiler: 220℃/h

(ii) Temperature rise of superheater and reheater tubes

The temperature of the superheater and reheater tubes should be maintained below the maximum allowable temperature of the tube material. (Lower the gas temperature if no steam or little steam flows inside when starting up and sufficient cooling effect is not expected. The gas temperature limits differ with the materials of the superheater and reheater. In general, the gas temperature at the furnace outlet should be maintained below 540℃ by controlling the fuel feed).

(iii) Others

Care should be taken to horizontal and vertical elongation of furnace water wall, spilling caused by quick heating of refractory material, boiling out of the superheater and reheater, etc.

(b) Precautions for quick start of turbine

(i) Differential expansion of rotor and casing

The differenial expansion of the rotor and casing should be limited below the allowable limit of the turbine.

(ii) Increasing rate of rotor temperature

Below the allowable limits concerning the rotor diameter and increasing rate of metal temperature of the turbine.

(iii) Increasing rate of steam temperature

Turbines with steam chambers integrated with casings: 167℃/h (WH type)
Turbines with separate type steam chambers, nozzle chambers, and independent dual-wall cylinders: 278℃/h (WH type)

(iv) Temperature difference between outside and inside of casing

Below the allowable limits concerning the temperature difference between the inner and outer surfaces of the steam control valve chamber, first stage steam chamber, reheated steam chamber and main stop valve as well as the inner wall temperature (GE type) The temperature difference between the inner and outer metal surfaces of the steam control valve chamber, intercept valve and inner and outer turbine chamber should be limited below 83℃. (WH type)

(v) Temperature difference between casing flange and bolts

The temperature difference between the inner surface of the turbine cylinder flange and bolts should be limited between −30 and +110℃. (WH type)

(vi) Temperature difference between main steam and reheated steam (for H.P. or I.P. turbine in integrated cylinder) (GE type)

When the steam temperature is close to the rated temperature:
Reheat steam temperature +28℃≧main steam temperature≧reheat steam temperature −42℃.
When steam flows with no load:
Main steam temperature≧reheated steam temperature≧main steam temperature −165℃.

(vii) Rotor eccentricity and vibrations during starting up

The rotor eccentricity and vibrations during starting up should be limited below the specified values of the turbine.

(viii) Temperature difference between steam and steam chamber

The steam temperature when starting up the turbine should desirably be 28 to 55℃ above the steam chamber temperature.

(ix) Exhaust chamber temperature

The exhaust chamber temperature should be 55℃ or less to 120℃ or less. (It depends on turbine manufacturers.)

19-21 Explosive Protection against Explosive Gases

1. Types of explosion-proof electrical apparatus, explosion grades and ignition temperatures (construction standard)

	Classes	Symbols	Definitions		
Types of explosion-proof constructions	Flameproof construction	d	Fully closed enclosure which can withstand the pressure developed during an internal explosion of an explosive gas, and which prevents the transmission of the explosion to the explosive gas surrounding the enclosure.		
	Oil-immersed explosion-proof construction	o	Construction in which the parts of the electrical apparatus generating electric sparks or arcs are immersed in oil in such a way that an explosive gas which may be above the oil cannot be ignited.		
	Pressurized explosion-proof construction	f	Enclosure filled with protective gas (clean air or inert gas) maintained at a pressure above that of the external atmosphere in order to keep out explosive gases.		
	Increased safety explosion-proof construction	e	Construction applied to the electrical apparatus that does not produce electric sparks or overheat in normal operation in which additional measures about the construction and temperature raise are applied so as to give increased security against the possibility of the occurrence of electric sparks or overheat.		
	Intrinsically safe explosion-proof construction	i	Construction which is certified by public organization's examinations that it does not cause combustion of explosive gases due to electric sparks or overheat in normal operation or in case of accidents		
	Special explosion-proof construction	s	Constructions not falling under above-shown categories which are certified by public organization's examinations and other means that they are free from combustion of explosive gases		
Explosion grades	Grade 1	1	Minimum gap causing fire leaping at clearance depth of 25 mm	Min. 0.6 mm	
	Grade 2	2		Min. 0.4 mm, Max. 0.6 mm	
	Grade 3	3a		Max. 0.4 mm	Water gas and hydrogen
		3b			Carbon disulfide
		3c			Acetylene
		3d			Other explosive gases and vapors
Ignition temperature	Ignition temperature G_1	G_1	Ignition temperature over 450℃		
	Ignition temperature G_2	G_2	Ignition temperature over 300℃, not more than 450℃		
	Ignition temperature G_3	G_3	Ignition temperature over 200℃, not more than 300℃		
	Ignition temperature G_4	G_4	Ignition temperature over 135℃, not more than 200℃		
	Ignition temperature G_5	G_5	Ignition temperature over 100℃, not more than 135℃		
	Ignition temperature G_6	G_6	Ignition temperature over 85℃, not more than 100℃		

2. Types of explosion-proof electrical apparatus, grouping and temperature classification (technical standard)

	Classes	Symbols	Definitions
Types of explosion-proof constructions	Flameproof construction	d	The concept of flameproof construction is that the enclosure of electrical apparatus with the source of actual or potential ignition is so designed that the enclosure prevents the transmission of the explosion generated inside it to the explosive atmosphere surrounding the enclosure by providing a special performance to it. In the design of the enclosure of flameproof construction, the fire leaping limit of the explosive gas concerned is required as basic data.
	Oil-immersed explosion-proof construction	o	The concept of oil-immersed explosion-proof construction is that the electrical apparatus which has the source of actual or potential ignition is so designed that the portion which may serve as the source of ignition is isolated from a surrounding explosive atmosphere with oil in order to prevent existing an explosive atmosphere and the source of ignition together.
	Pressurized explosion-proof construction	p	The concept of pressurized explosion-proof construction is that the electrical apparatus which has the source of actual or potential ignition is so designed that the portion which may serve as the source of ignition is isolated from a surrounding explosive atmosphere with protective gas in order to prevent existing an explosive atmosphere and the source of ignition together.
	Increased safety explosion-proof construction	e	The concept of increased safety explosion-proof construction is that the electrical apparatus which has only the source of potential ignition is so designed that additional measures are applied mechanically and electrically so as to give increased security against the possibility of the occurrence of the failure which produces the source of actual ignition.
	Intrinsically safe explosion-proof construction	ia or ib	The concept of intrinsically safe explosion-proof construction is that the electrical apparatus is so designed that not only in the normal condition but also in the estimated abnormal condition the consumption energy in an electric circuit is controlled so that electric sparks or a high temperature part may not become the source of actual and potential ignition to an explosive atmosphere. In the design of the electric circuit of intrinsically safe explosion-proof construction, the minimum ignition current of explosive gas concerned is required as basic data.
	Special explosion-proof construction	s	Constructions not falling under above-shown categories which are certified by public organization's examinations and other means that they are free from combustion of explosive gases.
Grouping of explosion-proof electrical apparatus		Ⅰ	For coal mines
		Ⅱ	For factories and working fields
	Subgroup of the electrical apparatus classified to flameproof construction and intrinsically safe explosion-proof construction	ⅡA	Fire leaping limit 0.9mm or more, Minimum ignition current ratio 0.8 over
		ⅡB	Fire leaping limit over 0.5mm, less than 0.9mm, Minimum ignition current ratio 0.45 or more, not more than 0.8
		ⅡC	Fire leaping limit not more than 0.5mm, Minimum ignition current ratio less than 0.45
Temperature classification of explosion-proof electrical apparatus	Temperature class T1	T1	Ignition temperature over 450℃
	Temperature class T2	T2	Ignition temperature over 300℃, not more than 450℃
	Temperature class T3	T3	Ignition temperature over 200℃, not more than 300℃
	Temperature class T4	T4	Ignition temperature over 135℃, not more than 200℃
	Temperature class T5	T5	Ignition temperature over 100℃, not more than 135℃
	Temperature class T6	T6	Ignition temperature over 85℃, not more than 100℃

3. Explosion grades, ignition index, groups, temperature classes and major risks of explosive gases

Gases	Explosion grades	Ignition index	Groups	Temperature classes	Ignition temperatures (℃)	Flash points (℃)	Explosion limits (Vol. %)		Vapor concentrations (Concentration of air: 1)
							Lower limits	Upper limits	
Acetylene	3	G_2	ⅡC	(T2)	305		2.5	100.0	0.9
Ammonium	1	G_1	ⅡA	(T1)	651		16.0	25.0	0.6
Carbon monoxide	1	G_1	ⅡB	(T1)	609		12.5	74.0	1.0
Ethanol	1	G_2	ⅡA	T2	363	13	3.3	19.0	1.6
Ethane	1	G_1	ⅡA	T1	472		3.0	12.5	1.0
Ethylene	2	G_2	ⅡB	(T2)	450		2.7	36.0	1.0
Hydrogen	3	G_1	ⅡC	(T1)	500		4.0	75.0	0.1
Butane	1	G_2	ⅡA	T2	365	−72	1.6	8.5	2.0
Propane	1	G_1	ⅡA	T1	432		2.1	9.5	1.6
Methanol	1	G_1	ⅡA	T2	385	11	6.0	36.0	1.1
Methane	1	G_1	ⅡA	(T1)	537		5.0	15.0	0.6
Hydrogen sulfide	2	G_3	ⅡA	(T3)	260		4.0	44.0	1.2
Gasoline	1	G_3			257.2	−43	1.4	7.6	3∼4
Water gas	3	G_1	ⅡC	(T1)			7.0	72.0	0.6

〔Source: Guideline for Users for Explosion Protection of Electrical Equipment at New Plants (Gas explosion protection 1994), by Industrial Safety Research Institute, Ministry of Labor〕

* Symbols with parenthesis in "Temperature class" show the classification by chemical similarity, etc.

4. Classification of hazardous area

4-1 In the case of construction standard

Classes	Definitions	Examples of possible areas	Recommended explosion-proof constructions	Applicable wiring methods
Zone 0	Areas where explosive atmosphere exists continuously or for long time in normal condition.	(a) Space above the surface of combustible liquid in a vessel or tank (b) Near the surface of combustible liquid in an open vessel or equivalent place	Intrinsically safe explosion-proof construction (Approved zone 0 apparatus …ia)	Intrinsically safe circuit (Circuit not having igniting capability intrinsically or having suppressed igniting capability in case of accidents)
Zone 1	Areas where explosive atmosphere may be produced in normal condition.	(a) Near openings which discharge explosive gas when product take-out covers are opened or safety valves function in normal operation. (b) Near openings which discharge explosive gas in inspection or repair works (c) Rooms or poorly ventilated places where explosive gas may be discharged (d) Pits, etc. subject to collection of explosive gas in places where such gas may possibly leaks	Intrinsically safe explosion-Flameproof construction, explosionproof construction, and pressurized explosion-proof construction (Devices having parts which may always serve as ignition sources and electrical apparatus carrying high voltage must not be used.)	Intrinsically safe circuit, low voltage wiring for zone 1 (Wiring in explosion-proof metal tubes or cabling)
Zone 2	Areas where explosive atmosphere may be produced in abnormal condition.	(a) Areas where explosive gas may leak if containers or vessels are broken due to corrosion or deterioration. (b) Places where dangerous substances may be discharged due to malfunction, excessively high temperature or pressure caused by abnormal reaction (c) Areas where explosive gas may produce hazardous atmosphere due to defects of forced ventilation. (d) Near zone 1 or rooms adjacent to zone 1 where explosive gas may rarely leak in and its concentration may reach to the hazardous level.	Intrinsically safe explosion-proof construction, explosionproof construction, and pressurized explosion-proof construction, Oil-immersed explosion-proof construction	Intrinsically safe circuit, Low voltage wiring for zone 2 (Wiring in explosion-proof metal tubes or cabling) High voltage cabling for zone 2

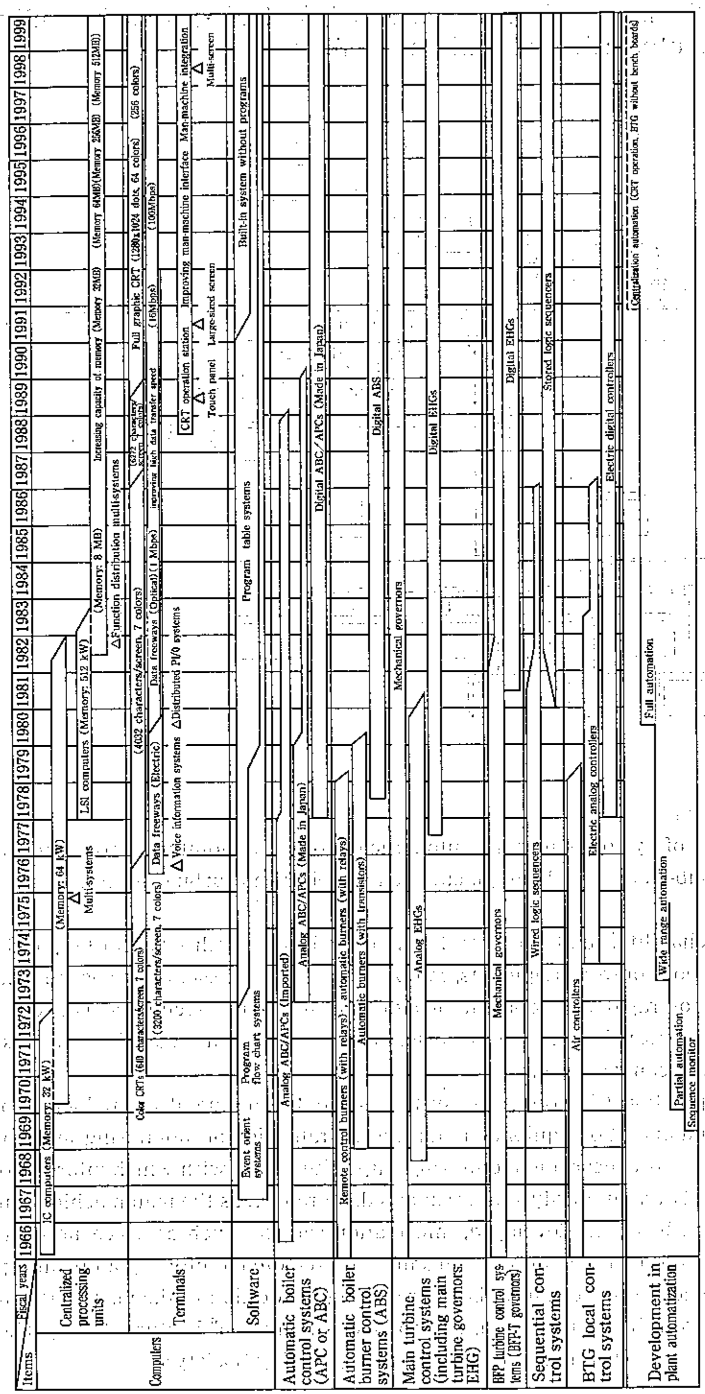
4-2 In the case of technical standard

Classes	Definitions	Examples of possible areas	Recommended explosion-proof constructions	Applicable wiring methods
Zone 0	Zone 0 means where explosive atmosphere exists continuously or for long time in normal condition.	Near the surface of combustible liquid in the vessel with which the lid is opened. However, in the ventilated areas the range as zone 0 may become narrow and the other areas may be decided as zone 1 or 2.	ia apparatus is selected among the electrical apparatus which conforms to intrinsically safe explosion-proof construction.	The wiring system to conform to the wiring of intrinsically safe circuit is selected.
Zone 1	Zone 1 means where explosive atmosphere may be produced periodically or some times in normal condition.	(a) Near openings which discharge explosive gas when product take-out covers are opened and so on in usual operation. (b) Near openings which often discharge explosive gas in inspection or repair works. (c) Rooms or poorly ventilated areas where explosive gas may pile up. However, in the ventilated areas the range as zone 1 may become narrow and the other areas may be decided as zone 2 or non-hazardous areas.	The electrical apparatus is selected among those which conform to flame-proof construction, pressurized explosion-proof construction, increased safety explosion-proof construction, intrinsically safe explosion-proof construction (ia apparatus and ib apparatus), or oil-immersed explosion-proof construction.	The wiring system is selected among those to conform to explosion-proof metal tubes, cabling, high voltage cabling, or the wiring of intrinsically safe circuit.
Zone 2	Zone 2 means where explosive atmosphere may be produced in abnormal condition.	(a) Areas where explosive gas may leak if containers or vessels are broken due to corrosion or deterioration. (b) Areas where explosive gas may be discharged due to malfunction, excessively high temperature or pressure caused by abnormal reaction. (c) Areas where explosive gas may pile up and may produce hazardous atmosphere due to defects of forced ventilation. (d) Near zone 1 or rooms adjacent to zone 1 where explosive gas may rarely leak in and its concentration may reach to the hazardous level.	The electrical apparatus is selected among those which conform to flame-proof construction, pressurized explosion-proof construction, increased safety explosion-proof construction, intrinsically safe explosion-proof construction (ia apparatus and ib apparatus), or oil-immersed explosion-proof construction, and the explosion-proof electrical apparatus which is indicated as approved zone 2 apparatus.	The wiring system is selected among those to conform to explosion-proof metal tubes, increased safety explosion-proof metal tubes, cabling, high voltage cabling, or wiring of intrinsically safe circuit.

5. Laws and regulations related to explosion-proof facilities

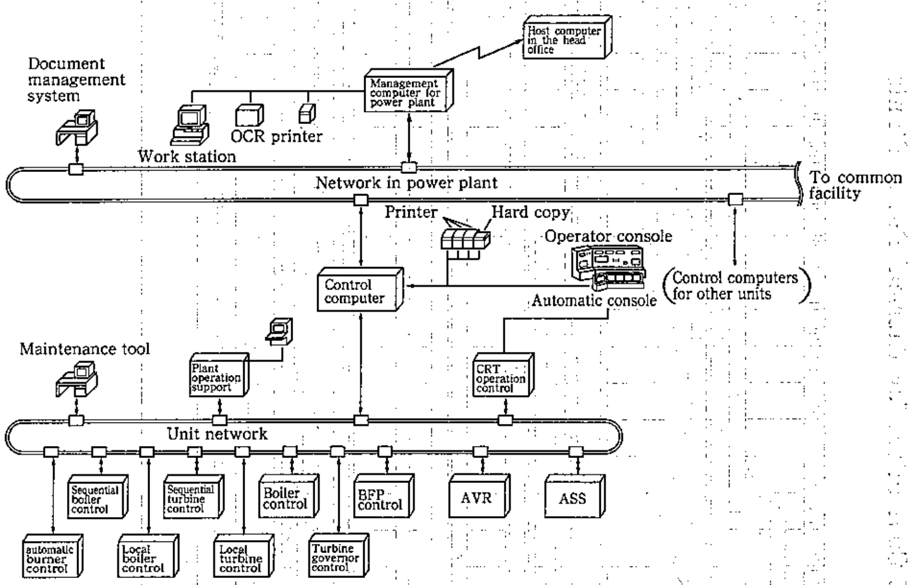
Ministry of Health, Labour and Welfare	Industrial Safety and Health Law (Set up in 1972; Amended in September 1998) Ordinance for the Enforcement of Industrial Safety and Health Law (Set up in 1972; Amended in September 1993) Rules for Industrial Safety and Health (Set up in 1972; Amended in January 1999) Inspection Rules for Machinery (Set up in 1972; Amended in January 1999) Standard of Explosion-Proof Construction of Electric Appliances and Machinery (Set up in 1969; Amended in 1988) Technical Standard of Electric Appliances and Machinery having sufficient Explosion-Proof Performance equivalent to those to conform to Standard of Explosion-Proof Construction concerning combustible gas or vapor of ignitable substance as provided in Standard of Explosion-Proof Construction of Electric Appliances and Machinery (Direction by Director-General in April 1988) Guide to Explosion-Proof Construction of Electric Facilities in Factories (Explosion-proof construction against gas and vapour-1979) Guideline for Users for Explosion Protection of Electrical Equipment at New Plants (Gas explosion protection 1994) New Guide to Explosion-Proof Construction of Electric Facilities in Factories (Explosion-proof construction against gas: 1985) Guide to Explosion-Proof Construction of Electric Facilities in Factories (Explosion-proof construction against dust: 1982)
Electricity Utilities Industry Law	Electricity Utilities Industry Law (Set up in 1964; Amended in April 1995) Engineering Standard of Electric Facilities (Set up in 1965; Amended in March 1997) Interpretation of Engineering Standard of Electric Facilities (Set up in March 1997) Electric Engineering Standard JEAC8001-1995 "Internal Wiring" established by Electric Engineering Standard Examination Committee of Japan Electric Association Electric Engineering Standard JEAC3708-1994 "Combustion Facilities" established by Electric Engineering Standard Examination Committee of Japan Electric Association
Fire Fighting	Fire Service Law (Set up in 1948; Amended in June 1994) Ordinance for the Enforcement of Fire Service Law (Set up in 1961; Amended in March 1998) Rules for the Enforcement of Fire Service Law (Set up in 1961; Amended in March
Dangerous Goods	Cabinet Order concerning the Regulations for Dangerous Goods (Set up in 1959; Amended in February 1998) Rules concerning the Regulations for Dangerous Goods (Set up in 1959; Amended in February 1998)
High Pressure Gas	High Pressure Gas Safety Law (Set up in 1951; Amended in November 1997) Ordinance for the Enforcement of High Pressure Gas Safety Law (Set up in 1951; Amended in March 1998) Rules for General High Pressure Gas Safety (Set up in 1966; Amended in March 1998)
Japanese Industrial Standards	JIS C 0903 General Rules of Explosion-Proof Construction of General-Purpose Electrical Apparatus (1983) JIS C 0904 Method of Testing for Explosion-Proof Construction of General-Purpose Electrical Apparatus (1983) JIS C 0905 Explosion-Proof Construction of Power Electrical Apparatus (1983) JIS C8001 General Rules of Explosion-Proof Lighting Apparatus (1991) JIS C8004 General Rules of Explosion-Proof Portable Lamps (1985)
Reference standards in overseas countries	API Standards, NEPA, IEC, VDE, etc.

19-22 History in Computers and Controllers for Thermal Power Plants



CRT : Cathode ray tube displays
PI/O : Process input and output units
kW : k words (10^3 words)
MB : Megabytes (1 bytes=8 bits)
Mbps: Megabit per second (transfer speed)

19-23 Examples of Construction of Control System for Fully Automatic Thermal Power Plants



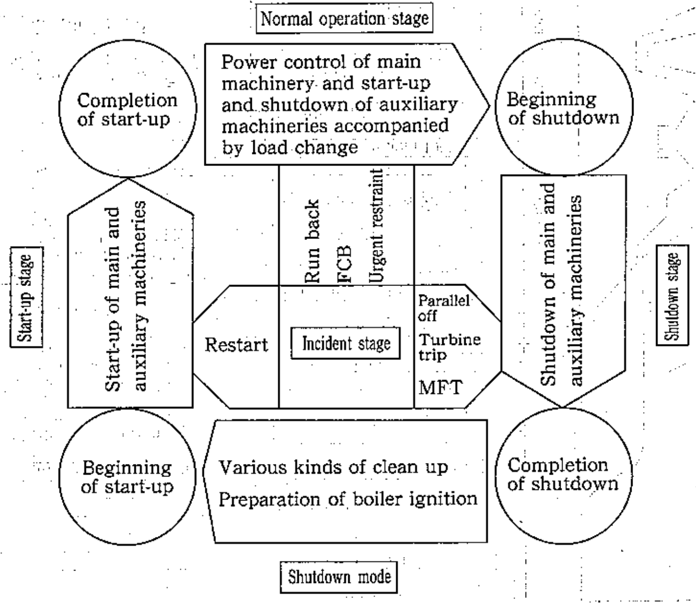
Features of System

1. It is composed of by combining the automatic control and monitoring computers and the subordinate sub-loop control equipment such as boiler and turbine control in a unit network.
2. To improve reliability, sub-loop control equipment is decentralized according to the function, and sub-loop control equipments, computers and transmission systems are redundant.
3. As the result of rapid development of signal transmission technique between digital Computers, in almost all cases, the construction of transmission system has been taken into consideration in control systems.
4. Concerning operation, CRT operation system is adopted aiming at the reduction of plant monitoring and operation equipment and the centralization of monitoring and operation function. And also, concerning monitoring, large size screen with which information is offered intensively and unitarily, etc. are adopted. Moreover, as the man-machine communication function has been developed, information services such as voice notification of start-up and shutdown of plant main machineries, remote monitoring of operating sound of auxiliary machineries, etc. have been prevailing in addition to the visual measures.

〔Source: "Instrumentation, Control and Automation" Lecture (21) by Thermal Power and Nuclear Power Engineering Society〕

19-24 Operation Stage and Scope of Automation (In Case of Full Automation)

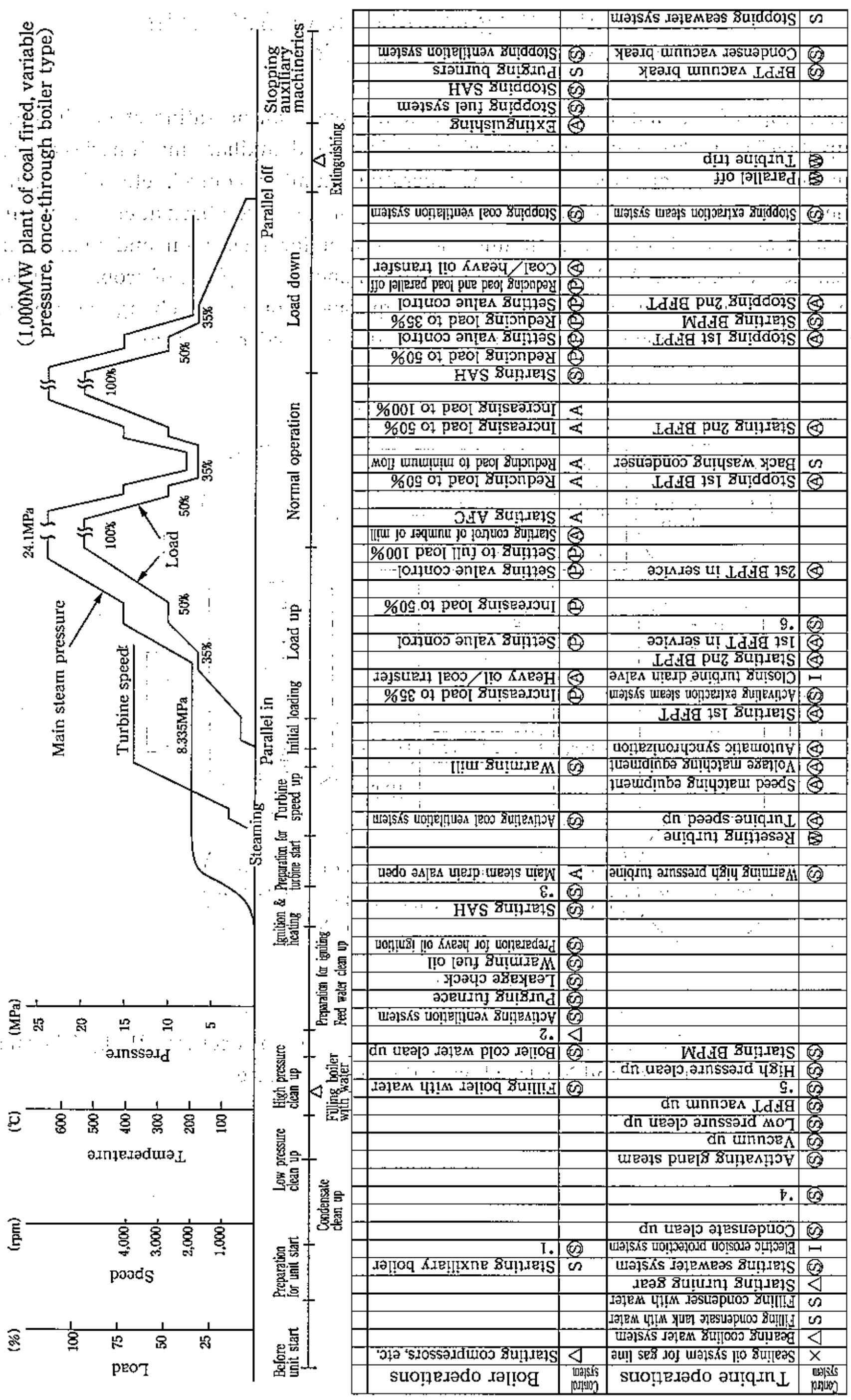
The latest scope of automation of control equipments covers all operating stages including "start-up stage" and" shutdown stage" of main machinery and auxiliary machineries of boiler and turbine, "normal operation stage" as operating number control, etc. of auxiliary machineries accompanied by load change and "incident stage" as run back at emergency incident, restart or parallel off, etc., excluding the operation for inspection and maintenance (maintenance work), etc. As the operation for maintenance work of out of scope of automation, there are periodic inspection of facilities and equipment, operation change of auxiliary machineries and inspection and operation after shutdown or before start-up.



〔Source: "Instrumentation, Control and Automation" Lecture (21) by Thermal Power and Nuclear Power Engineering Society〕

19-25 Automatic Operation and Control Methods

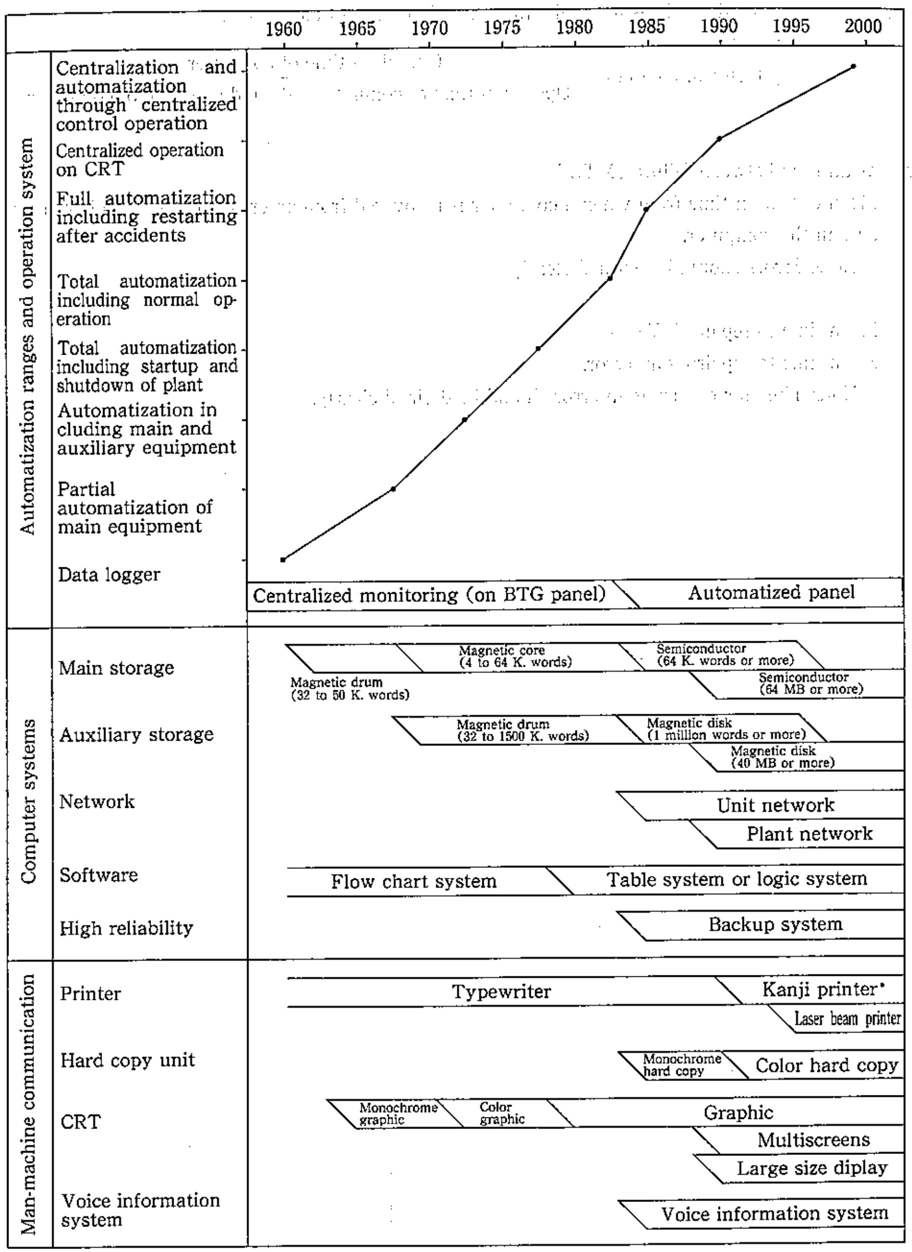
(1,000MW plant of coal fired, variable pressure, once-through boiler type)



<Symbols> Ⓟ : Set point control with computer Ⓐ : Analog sub-loop KIC with computer Ⓢ : Sequence master KIC with computer
Ⓦ : Wired logic KIC with computer A : Manual KIC or interlock KIC of analog sub-loop S : Manual KIC or interlock KIC of sequence master
I : Interlock △ : Remote control from center panel × : Remote control from local panel

*1 : Activating auxiliary steam system header
*2 : Starting EP ash processing system with ammonium injection
*3 : Controlling number of heavy oil burners to be ignited
*4 : Activating gland steam system
*5 : De-aerator vacuum up and heating for de-aeration
*6 : Transfer switching over of auxiliary power system

19-26 Progress of Computer Systems According to Automatization Levels



19-27 Evaluate Methods for Reliability of Computers

The following show the indices for evaluating the reliabilities of computers:

(1) Availability factor

$$\text{Availability factor of computer} = \frac{\text{Operation time of computer}}{\text{Operation time of computer} + \text{Breakdown time of computer}}$$

(2) Mean time between failure (MTBF)

Mean operation time from when a computer is recovered from an error to when another error occurs in the computer.

Note: Errors should be defined clearly.

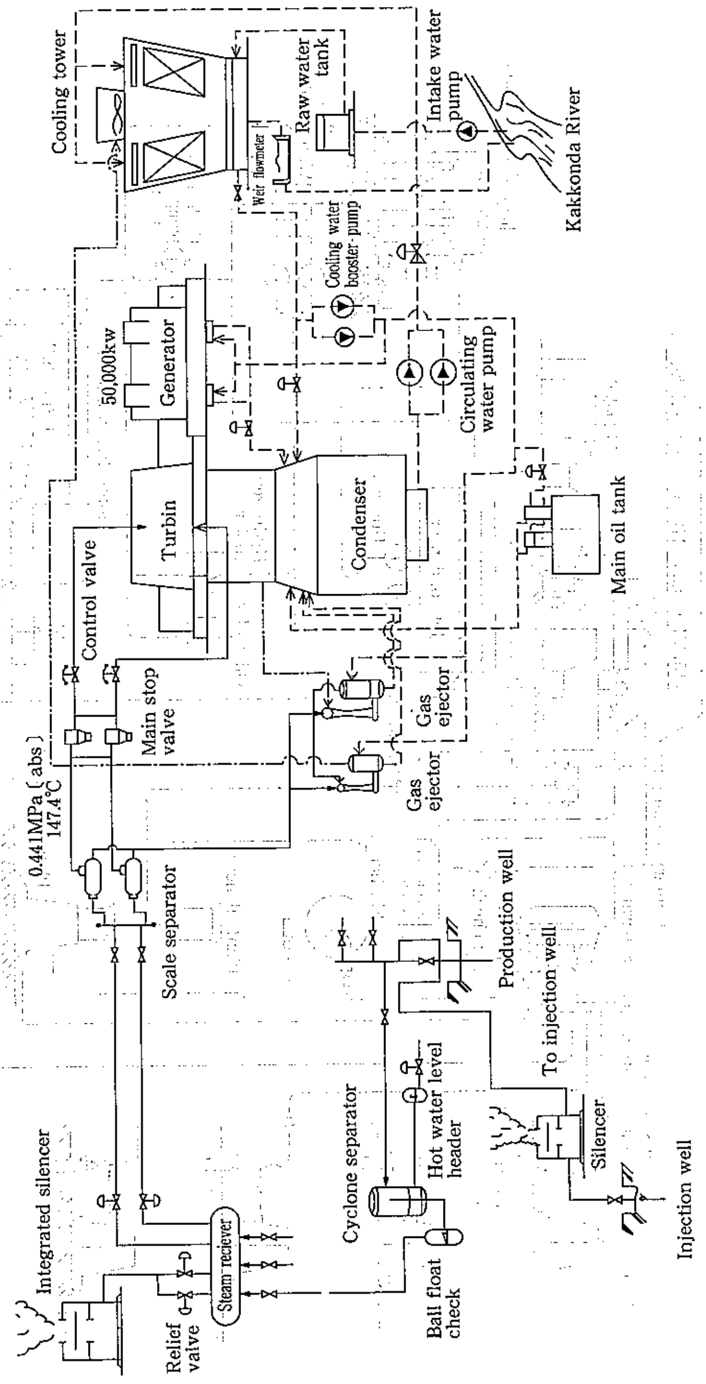
(3) Mean time to repair (MTTR)

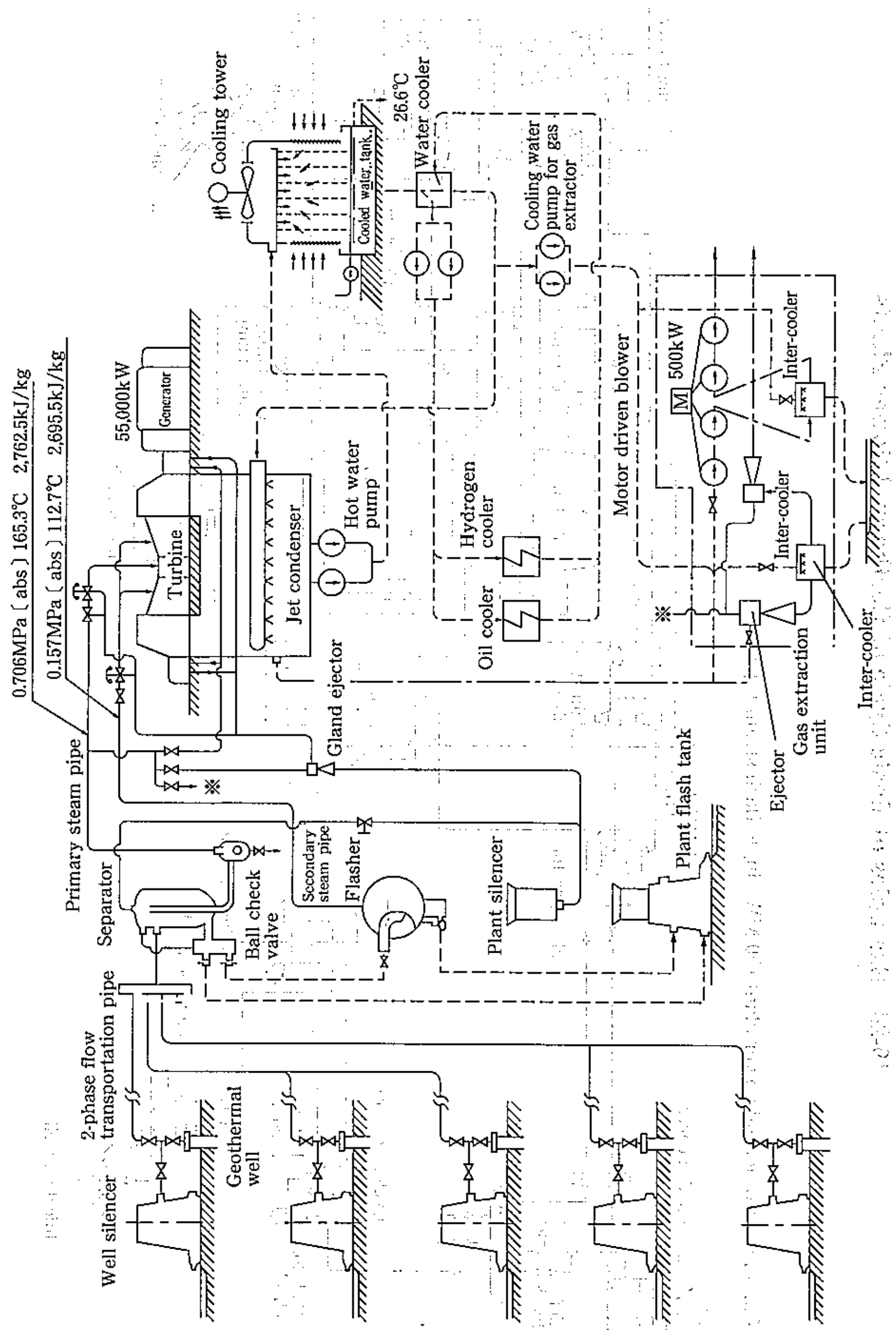
Mean time to repairing an error.

Note: Time for repairing an error should be defined clearly.

19-28 Examples of Basic Cycle of Geothermal Power Plants

(1) Kakkonda geothermal power plant (50 MW single flash steam type)

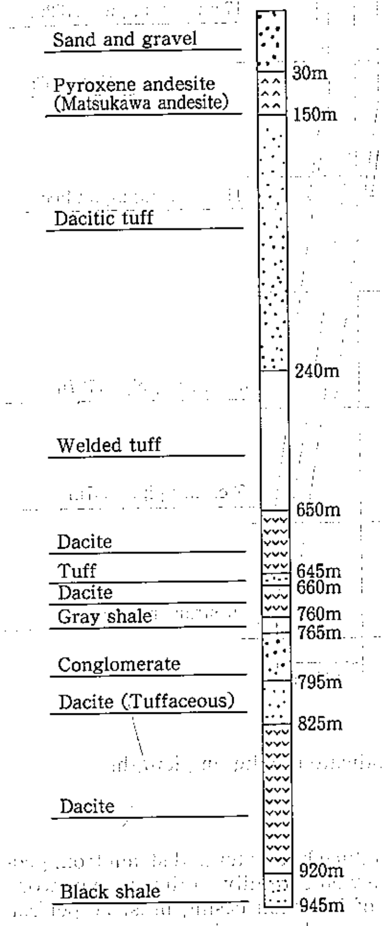




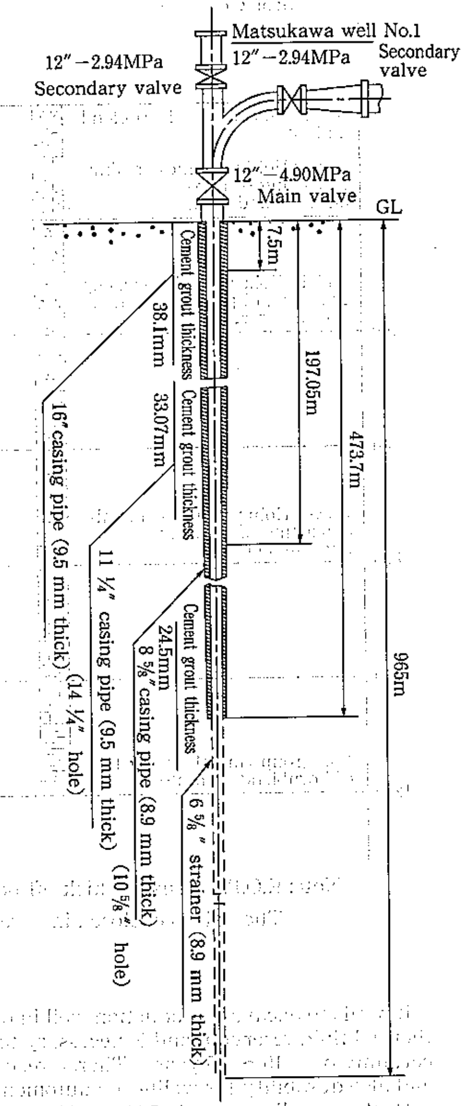
(2) Hatchobaru geothermal power plant

19-29 Examples of Production Well of Geothermal Power Plants

(1) Matsukawa geothermal power plant



Geologic colum of Matsukawa well No.1



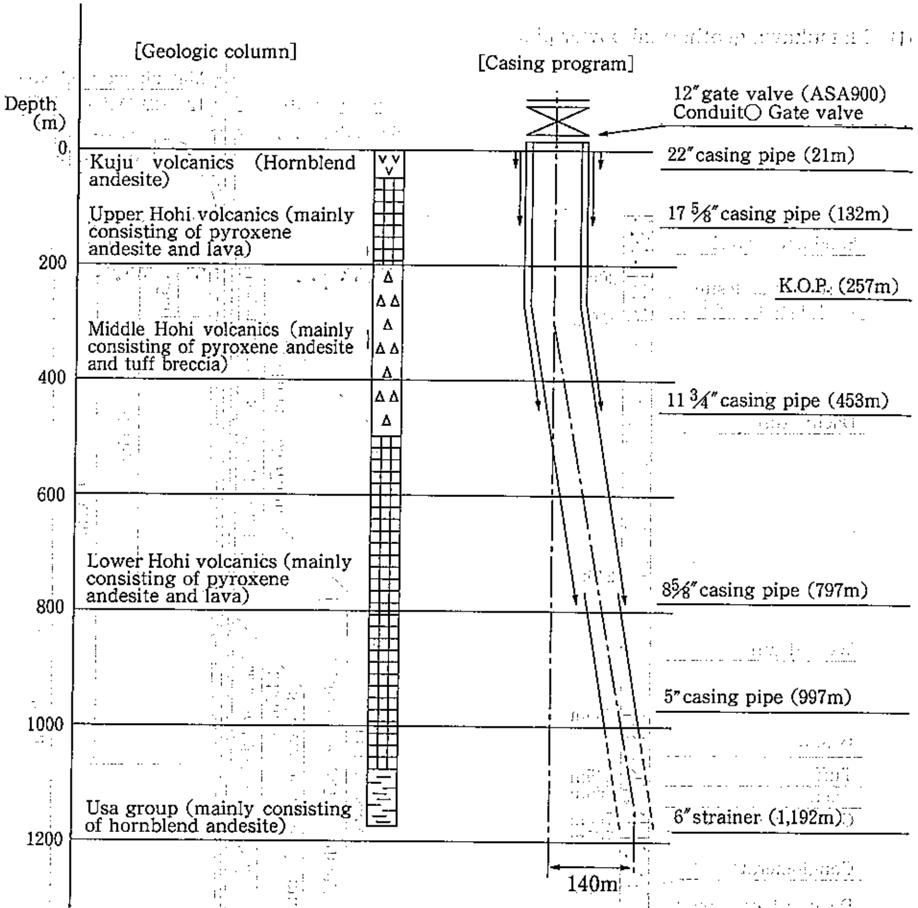
Casing program

Generally the fluid produced from geothermal well is 2-phase flow with which the gaseous phase (gas) of steam and non-condensable gas, and liquid phase (liquid) of hot water are mixed.

There are 2 types of geothermal well according to the characteristic of geothermal fluid reservoir, which are vapour-dominated fluid well and water-dominated fluid well. Vapour-dominated fluid well produces superheated steam, dry saturated steam and non-condensible gas that scarcely contain hot water, and water-dominated fluid well produces mainly steam and hot water.

In case of Matsukawa, it is the former vapour-dominated type and in Hatchobaru it is the latter water-dominated tvpe.

(2) Hatchobaru geothermal power plant



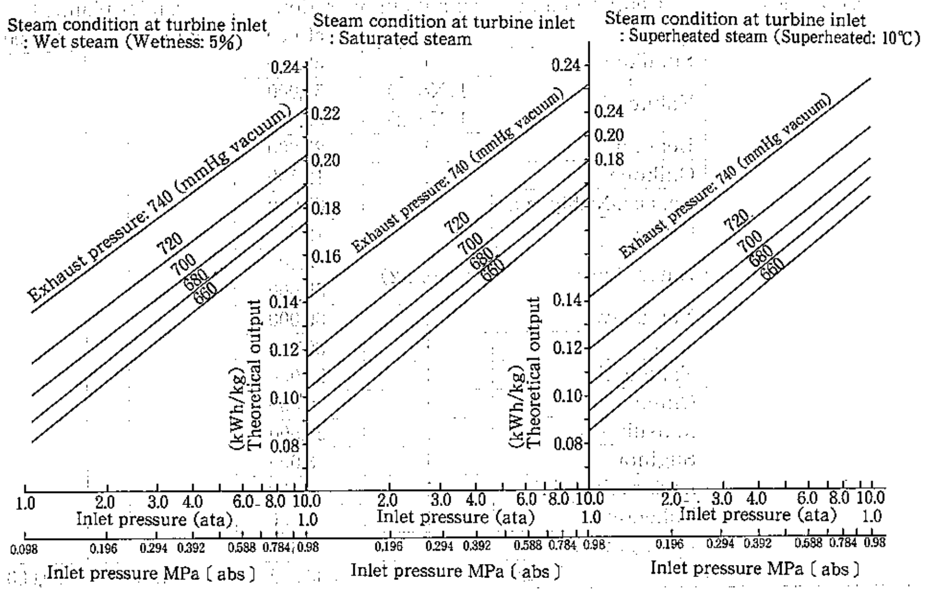
Note: K.O.P. means the kick off point.
The values enclosed in parentheses indicate the digging lengths.

It needs to excavate production well in order to produce hot water and steam from geothermal fluid reservoir, and is necessary to finish the well carefully so that it may work certainly over 10 ～ 15 years. Therefore, cementing of insertion casing must be perfect, and also durability for wellhead equipment must be enough secured.

Depth of well is usually 1,000～2,000m, and in special case it reaches to about 3,000m. Although diameter of last insertion casing is enlarged as much as possible in order to reduce pressure loss inside casing and to raise productive capacity, generally it is set to 8 5/8 inch (219.1mm) or 8 ½ inch (215.9mm).

Casing programs of production well are shown in front page figure and this page figure, and there are 2 types of casing programs. In the first type, intake portion of steam and hot water is open hole, and in the other type it is furnished with strainer (slot is cut to steel pipe and hot water and steam flow in a pipe through this slot). In case of Matsukawa and Hatchobaru, the latter type is adopted.

19-30 Theoretical Output Chart of Geothermal Turbines



〔Source: "Ground Equipment of Geothermal Power Plants" by Japan Geothermal Energy Association, 1971 edition〕

19-31 Major Geothermal Power Plants in the World

(1) Japan

(In units of kW)

Countries	Geothermal power plants in operation			Under planned		
Japan	Mori	1	50,000	Oguni	1	20,000
	Sumikawa	1	50,000			
	Kakkonda	1(No. 1)	50,000			
		1(No. 2)	30,000			
	Uenotai	1	28,800			
	Onikobe	1	12,500			
	Yanaizu-Nishiyama	1	65,000			
	Otake	1	12,500			
	Hatchobaru	2(No. 1,2)	55,000 55,000			
	Yamagawa	1	30,000			
	Ogiri	1	30,000			
	Takigami	1	25,000			
	Onuma	1	9,500			
	Matsukawa	1	23,500			
	Suginoi	1	3,000			
	Kirishima Kokusai Hotel	1	100			
	Takenoyu	1	50			
	Hachijojima	1	3,300			
	Total		533,250	Total		20,000

(2) World

(As of December 1998) (In units of MW)

Countries	Geothermal power plants in operation		Sum total for each country
United States	The Geysers	1, 896	2, 849.8
	Coso	240	
	Imperial Valley	402.8	
	Others	311	
Philippine	Leyte	700.87	1, 852.6
	Tiwi	330	
	Mak-Ban	425.73	
	Palimpinon	194	
	Bac-Man	150	
	Mindanao	52	
Italy	Pomarance	341	822.2
	Castelnuovo	133.7	
	Monterotondo	106	
	Monteverdi	40	
	Radicondoli	90	
	Monte Amiata	111.5	
Mexico	Cerro Prieto	650	773
	Los Azufres	88	
	Los Humeros	35	
Indonesia	Kamojang	140	589.5
	Salak, etc.	337.5	
	Darajat	55	
	Sibayak	2	
	Dieng	55	
New Zealand	Wairakei	157.2	358.76
	Ohaaki	116.2	
	Kawerau-Tarawera	6.36	
	Mclachlan	55	
	Rotokawa	24	
El Salvador	Ahuachapan	95	130
	Berlin	35	
Iceland	Krafla	60	140.8
	Svartsengi	17.1	
	Nesjavellir, etc.	63.7	
Costa Rica	Miravalles	125	125
Nicaragua	Momotombo	70	70
Kenya	Olkaria	45	45
China	Yangbajang	25.18	28.78
	Others	3.6	
Turkey	Kizildere	20.4	20.4
Russia	Pauzhetskya	11	11
France	Guadeloupe	4.2	4.2
Greece	Milos	2	(Out of operation)
Taiwan	PortugalTu-Chang	3.3	(Out of operation)
Portugal	Pico Vermelho	8.2	8.2
Thailand	Fang	0.3	0.3
Zambia	Kapisya	0.2	0.2
Australia		0.17	0.17
	Total		7, 829.91

(Continued)

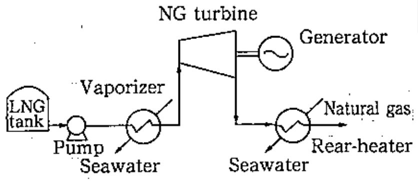
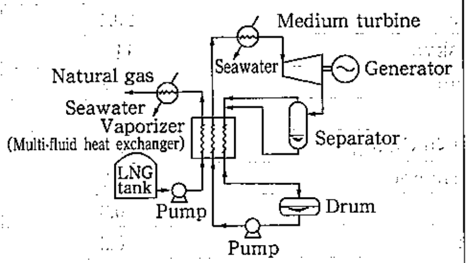
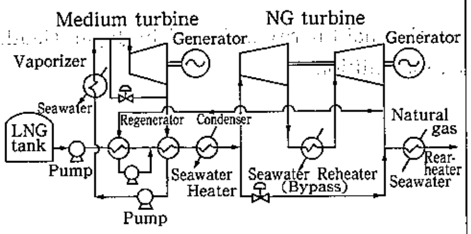
[Source: "Trend of Geothermal Energy in Japan" by Japan Geothermal Energy Association, 1999 editions]

19-32 LNG Cryogenic Power Generation Facilities

LNG cryogenic power generation facilities use LNG (very cold) as the low temperature source and sea water, etc. as the high temperature source, which have enthalpy difference of approx. 800kJ/kg.

LNG cryogenic power generation facilities can generate electric power of approx. 10,000 kW when vaporizing energy of LNG fuel for one million kW class thermal power plant uses fully for cryogenic power generation.

LNG cryogenic power generation facilities are roughly divided into some types: LNG direct expansion type, medium type using propane, Freon, etc. as medium, and combination of these types.

Type	System	Features
LNG direct expansion type		• In this type, heat recovery ratio is generally low, and especially when feed gas pressure is high, it is necessary to combine with regenerative type or reheating and regenerative type. • This type is technically easy, and is reliable and practical. • This type is profitable when feed gas pressure is low, and when feed gas pressure is high, economical efficiency becomes bad since generating output becomes small and auxiliary power ratio also becomes large.
Medium type		• In case that a mixture is used for secondary medium, heat recovery efficiency becomes larger than a single ingredient medium type. • Generating output per unit LNG flow is large. • A multi-fluid heat exchanger is required. • The equipment which separates ethane from LNG is required.
Combination of direct expansion reheating regenerative type and Rankine medium cycle type		• Even if high efficient medium system is combined, don't pass over the increase of an output to about 10%, but economical efficiency of system becomes low because of the increase of cost and the decrease of the scale effect. • In order to increase cryogenic heat recovery ratio, LNG direct expansion type and medium type are combined.

〔Source: The Thermal and Nuclear Power, Vol. 35, No. 11〕

19-33 Energy Saving for Thermal Power Plants

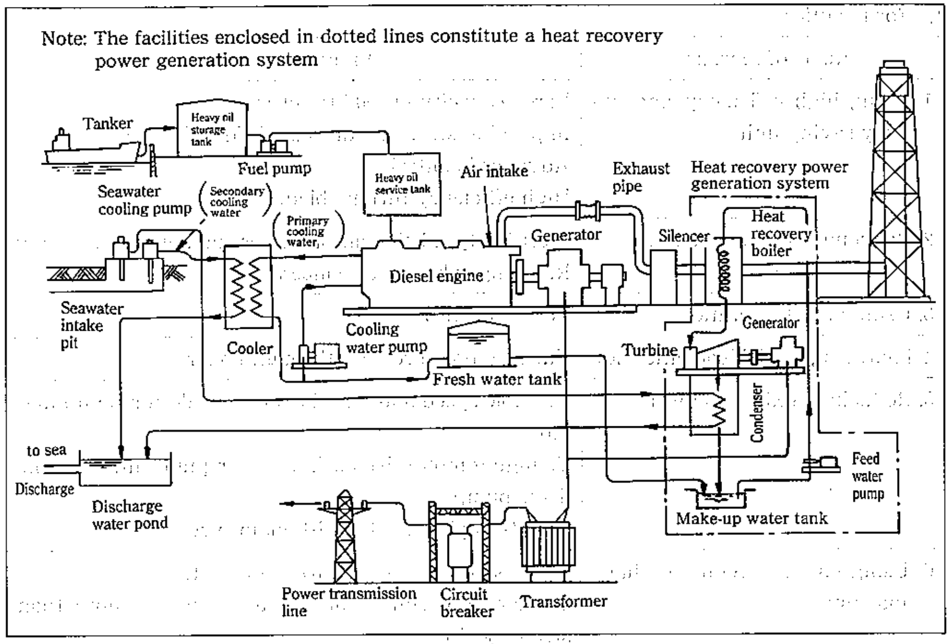
1. For facilities

Items of Measure	Practical means
1. Using high efficiency and energy saving unit	Large capacity (1,000 MW class) Improving steam conditions (24.52 MPa, 600/600 ℃) Advanced control High efficiency turbine blades
2. Reducing exhaust gas loss	Precision type boiler air preheater and improving sealing Reducing exhaust gas temperature
3. Using low O_2 operation	Forced draft boiler
4. Improving partial load efficiency	Variable pressure once-through boiler
5. Reducing auxiliary power	Variable speed and variable pitch blade for pump and blower Changing motor driven feed water pump into turbine drive pump Direct-coupled exciter with main turbine
6. Using energy saving auxiliary machine	Gas-gas heater at desulfurization system Condenser vacuum pump (Saves energy more than steam ejector.)
7. Using new power generation system	Combined cycle power generation system LNG-cryogenic power generation system

2. For operations

Items of Measure	Practical means
1. Giving priority to high efficiency and energy saving unit	Priority operation by suppressing high cost machine • More flexible and versatile operation between electric power companies • Shutting down plant at week ends and at night Reducing minimum load of unit Increasing load changing rate
2. Improving partial load efficiency	Reducing running auxiliary machines Reducing starting time (by improving water quality control technology) Securing operation at standard values (through precision control) Variable pressure operation of drum boiler AFC operation

20-1 Structure of Internal Combustion Engine Power Plants



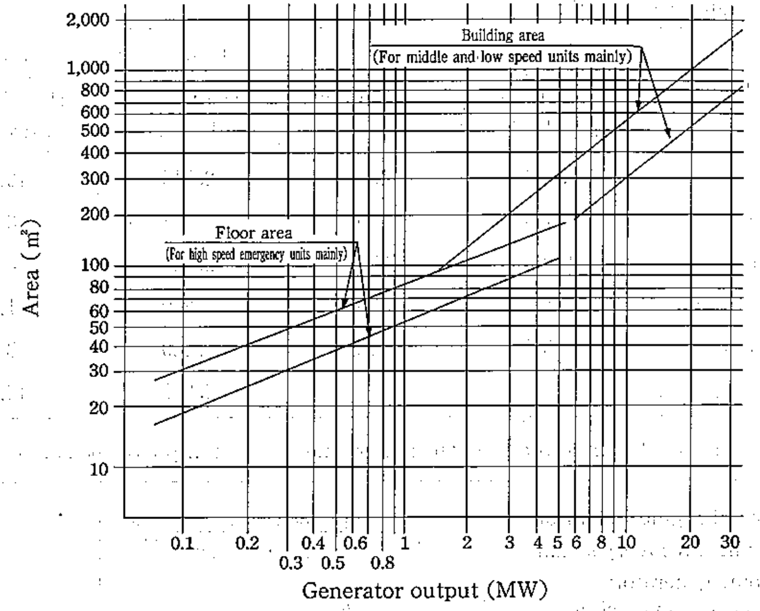
Note: The facilities enclosed in dotted lines constitute a heat recovery power generation system

20-2 Specifications and Performances of 4 Cycle Diesel Engines for Power Generation

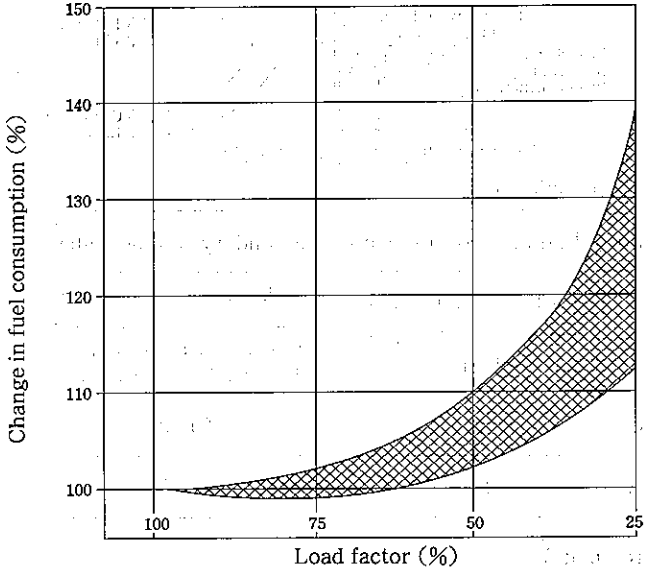
Item	Speed (rpm) / Unit	300~500 (Low speed engine)	500~1,000 (Middle speed engine)	1,000~1,800 (High speed engine)
Piston speed	m/s	4~10	4.5~10.6	5.3~10.8
Compression ratio	—	11~15	8~16.5	12~23
Maximum pressure	MPa	4.9~14.7	4.9~14.4	5.9~14.4
Net mean effective pressure	MPa	0.8~2.5	0.50~2.5	0.51~2.14
Fuel consumption	g/kWh	169~232	179~287	205~296
Thermal efficiency	%	37~51	30~48	29~42
Machine efficiency	%	75~95	75~95	75~92
Fuel oil type	—	Heavy oil A, B or C	Light oil, or heavy oil A, B or C	Light oil or heavy oil A
Startup time of normal facilities	min	Approx. 10	Approx. 7	Approx. 5
Output range	kW	600~21,000	100~11,000	100~4,600
Major application		Normal use	Normal use	Normal use

Note: Fuel consumption is converted on assumption that the lower heating value of fuel oil is 41,860kJ/kg.

20-3 Required Space for Diesel Power Generating Facilities



20-4 Fuel Consumption vs. Load Factor for 4 Cycle Diesel Engines for Power Generation



Note: This chart is applicable to diesel engine generators ranging from 350 to 21,000 kw.

Fuel consumption differs with the engine speeds, cylinder diameters, average effective pressures, supercharging methods used for the generators.

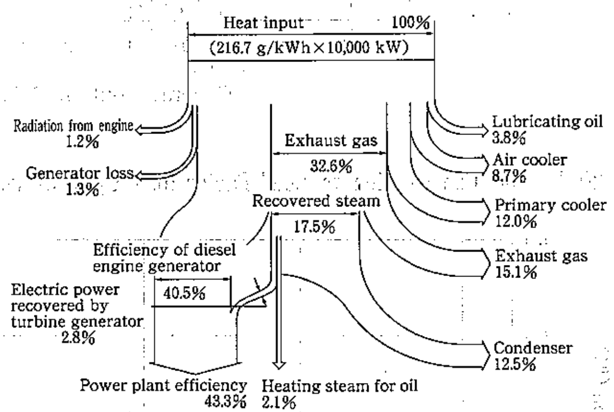
The approximate fuel consumption at full load conforms to the values shown in 20−2 and JIS F4301.

20-5 Example of Heat Balance of 4 Cycle Diesel Engines and Related Data

(1) Heat balance (example)

No.	Item	High speed small engine		Low speed large engine[1]	
		Heat load kJ/kWh	Heat input ratio (%)	Heat load kJ/kWh	Heat input ratio (%)
1	Cooling water loss	1,590	16.7	2,010	12.0
2	Lubricant loss	340	3.6	637	3.8
3	Exhaust gas loss	3,190	33.5	2,530	15.1
4	Radiant heat loss	340	3.6	200	1.2
5	Air cooler loss	455	4.8	1,460	8.7
6	Condenser loss	–	–	2,090	12.5
	Remarks	Example of 1,200 rpm engine		Example of 400 rpm engine	

Note: 1) Diesel engine generator with heat recovery steam turbine generator; Exhaust gas loss 32.6% is converted and recovered in steam energy.



(2) Cooling water conditions (Approximate)

No.	Item	Unit	Primary cooling water	Secondary cooling water
1	Description	–	Cooling water which flows into the engine and cools it.	Cooling water to cool the primary cooling water, lubricating oil, supercharged air, etc. through a heat exchanger.
2	Temperature	℃	50～90	30～35
3	Flow	ℓ/kWh	27～54	41～54

(3) Intake air quantity (Approximate)

Intake air quantity per output: Approx. 0.08 to 0.14 $m^3{}_N/(kW\cdot min)$

20-6 Relationship between Generator Capacity and Approximate Engine Power of Diesel Power Plants

$$\frac{\text{〔Generator capacity〕}}{\text{〔Generator efficiency〕}} = C \times \text{〔Generator capacity〕} = \text{〔Engine power〕}$$

Generator capacity (kW)	50	100	200	300	500	800～1,500	2,000	3,000
Approx. value of C	1.13	1.12	1.10	1.08	1.07	1.05	1.04	1.04
Engine power (kW)	57	112	219	324	533	838～1,580	2,090	3,110

Note: C=1.04 for 3,000 kW or larger.

20-7 Foundation of Diesel Power Plants and Vibration Prevention

In general, a reciprocal internal engine has a vibromotive force, which causes vibrations. The vibromotive force is roughly divided into two elements: A reactive force originating from uneven turning force, and unbalanced couple of forces of an unbalanced engine. The foundation and vibration prevention should be designed properly according to the vibrations of a diesel engine to be used.

The three methods shown below are used to prevent vibrations of an engine from propagation.

(1) Installation on concrete block foundation

This method is adopted for large capacity engines over 3,000 kW, in particular. The important design points are minimizing the moment of inertia in vibrations and maximizing the foundation area in order to make vibrations diffuse into the ground.

Attenuation of vibrations may be estimated relatively accurately from the semi-definite elastic theory of the ground.

(2) Spring snubber

The engine and generator are installed on a base plate, which is supported by a number of springs to prevent vibrations from being transmitted. Oil clamper is used in parallel. This method is applicable to middle speed engines.

(3) Rubber snubber

Rubber is used to prevent vibrations instead of the springs shown in (2) above. This method is applicable to high speed engines.

21-1 Major Items for Typical Gas Turbines

Type	501F	701F	MS7001FA	MS9001FA	GT24	GT26	V84.3A	V94.3A
Output Base load rating (MW)	185.4	270.3	168	250	183	265	180	255
Thermal efficiency Base load rating (%)	37.0	38.2	36.2	36.5	38.3	38.5	38.5	38.5
Number of compressor stages	16	17	18	18	22	22	15	15
Number of turbine stages	4	4	3	3	1 high pressure/ 4 low pressure	1 high pressure/ 4 low pressure	4	4
Number of combustors	16	20	14	18	2 annular stages	2 annular stages	annular (1 stage)	annular (1 stage)
Speed (rpm)	3,600	3,000	3,600	3,000	3,600	3,000	3,600	3,000
Exhaust gas flow (t/h)	1,670	2,401	1,591	2,430	1,408	2,023	1,602	2,308
Exhaust gas temperature (℃)	607	586	589	609	640	640	577	577

Note: The values shown above are on the assumption that the atmospheric temperature is 15℃, atmospheric pressure is 101.3kPa (abs), relative humidity is 60%, fuel is vaporized LNG, efficiency is based on the lower heating value and the exhaust gas flow and temperature are at base load.

21-2 Cycles and Types of Gas Turbines

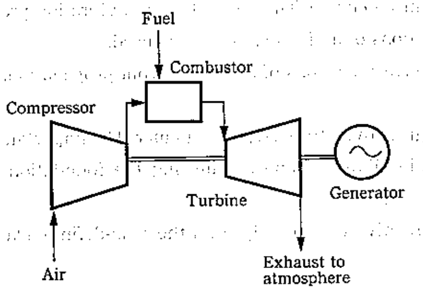


Fig. 1 Open simple cycle

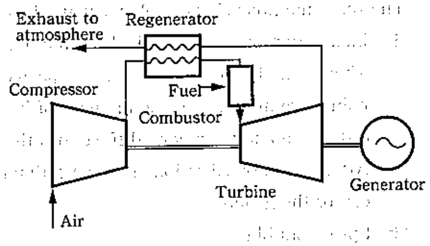
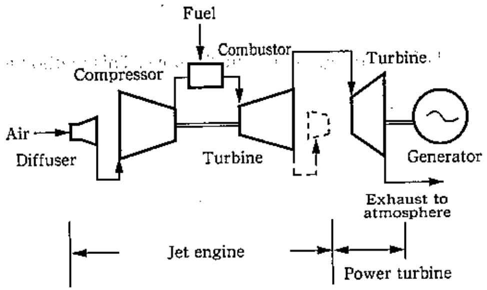


Fig. 2 Open regenerating cycle



(Dotted line shows the airplane jet nozzle.)

Fig. 3 Jet engine cycle

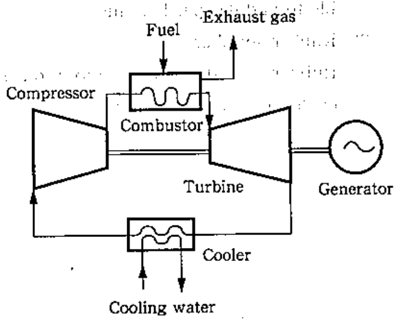


Fig. 4 Closed cycle

21-3 Outputs of Gas Turbine Power Generating Facilities

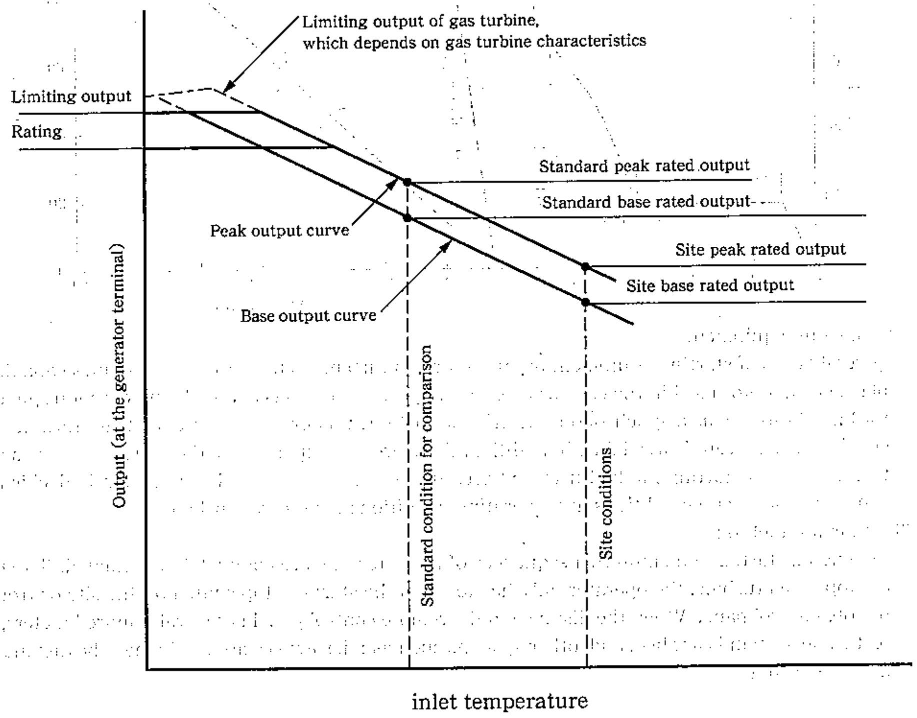
The gas turbine inlet gas temperature changes with the fuel flow, and the output and thermal efficiency change accordingly. In addition, the output of the gas turbine changes with the inlet air temperature and the atmospheric pressure, even if the turbine inlet gas temperature is maintained constant. Therefore, these conditions shall be specified for determining the output of a gas turbine. The turbine inlet gas temperature has direct influence upon the service life of the materials of turbine blades, combustors and components exposed to high temperature. Therefore, the turbine inlet gas temperature shall be properly specified for long term operation and short term operation. The turbine inlet gas temperature is different depending upon materials, cooling system structures, etc. of the turbine types supplied by manufacturers.

JIS B-0128 "Terms of Thermal Power Plants (Gas turbines and auxiliary facilities)" specifies the output of the gas turbines as shown below.

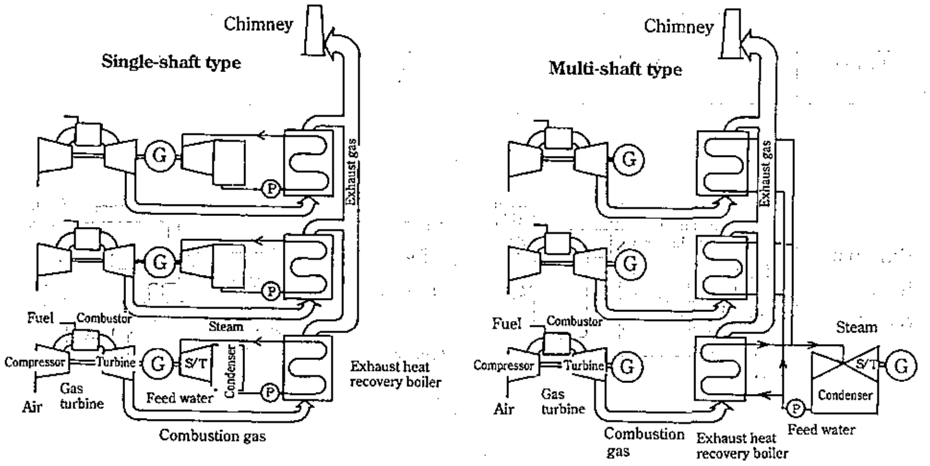
Rated output:	The guaranteed or planned output at the generator terminals in operations of a gas turbine on the predetermined conditions
Standard rated output:	The rated output when a turbine is operated on the relative standard conditions [i.e., At the compressor inlet flange, the total temperature of air is 15℃, total pressure is 101.3 kPa (abs), relative humidity is 60%. And static exhaust pressure at the turbine exhaust flange is 101.3 kPa (abs)]
Site rated output:	The rated output of a gas turbine operated under the site installed conditions (such as the atmospheric pressure, the atmospheric temperature, the pressure loss, and so forth)

The rated outputs are classified into the base rating output and peak rating output according to applications of gas turbines. The figure below shows the relationship between the inlet temperature and gas turbine output.

Relationship between inlet temperature and gas turbine output

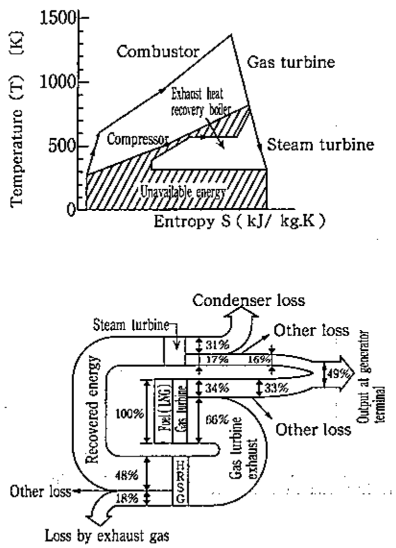


22-2 Conception of Exhaust Heat Recovery Combined Cycle Power Generating Plants

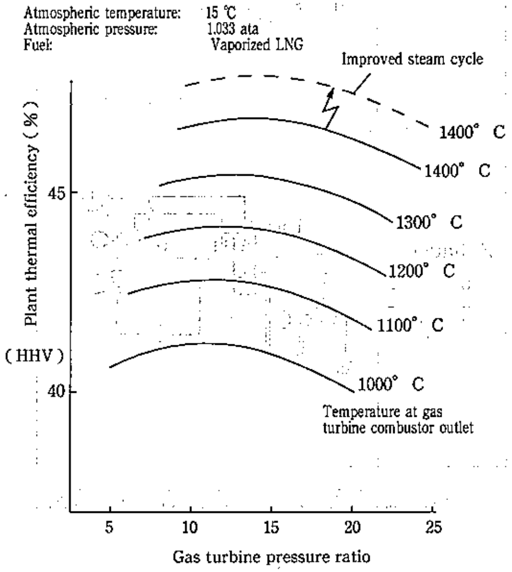


22-3 Characteristics of Exhaust Heat Recovery Combined Cycle Power Generating Plants

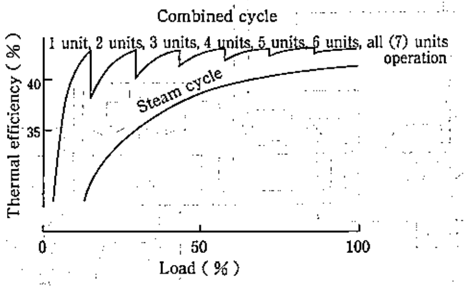
(1) T-S chart and heat balance diagram (Example of 1300℃ class)



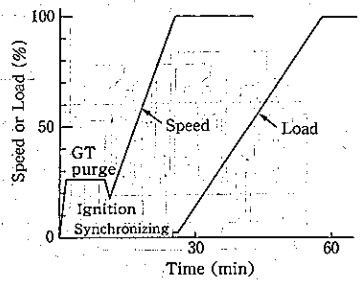
(2) Example of calculated plant thermal efficiency



(3) Thermal efficiency change of combined cycle power generation and steam power generation (Example of 1100℃ class)



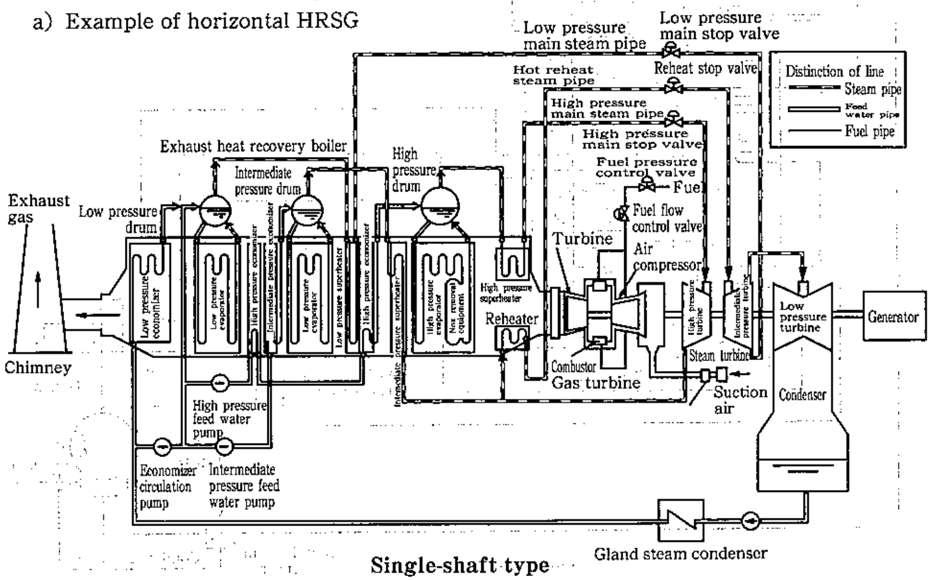
(4) Start-up curve of single-shaft type exhaust heat recovery cycle power generating plant (Example)



22-4 System Diagrams of Combined Power Generating Plants

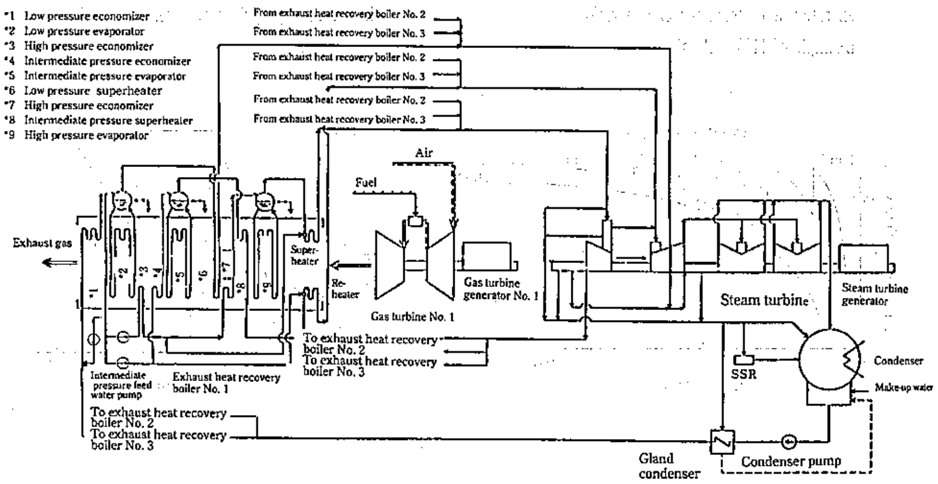
(1) Exhaust heat recovery type combined power generating plants

a) Example of horizontal HRSG



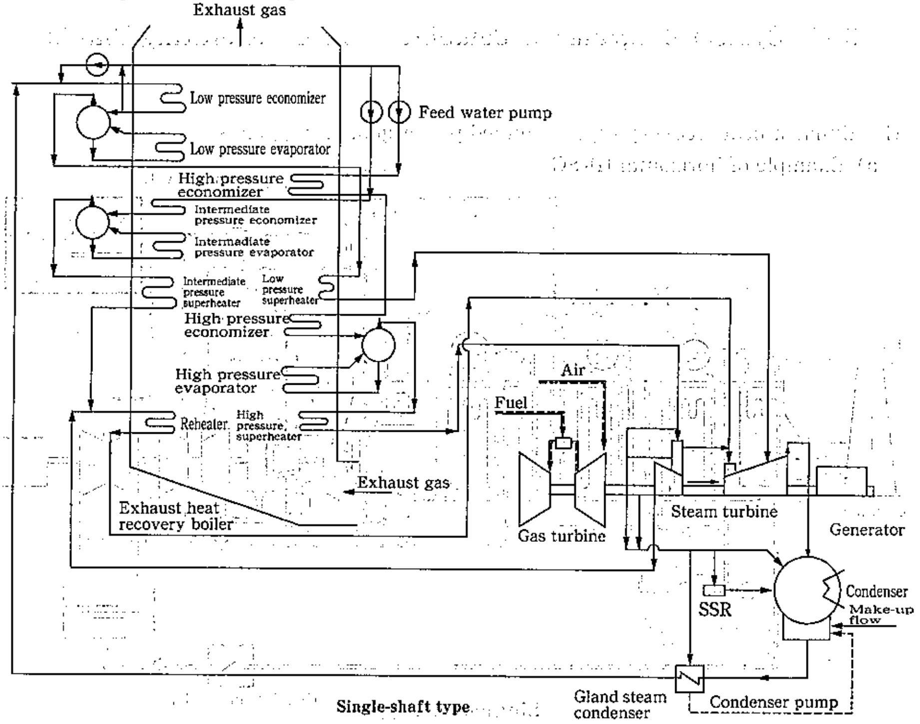
Single-shaft type

〔Source: Introduction Lecture, Combined Power Generetion, The Thermal and Nuclear Power Vol. 48/No. 8 〕

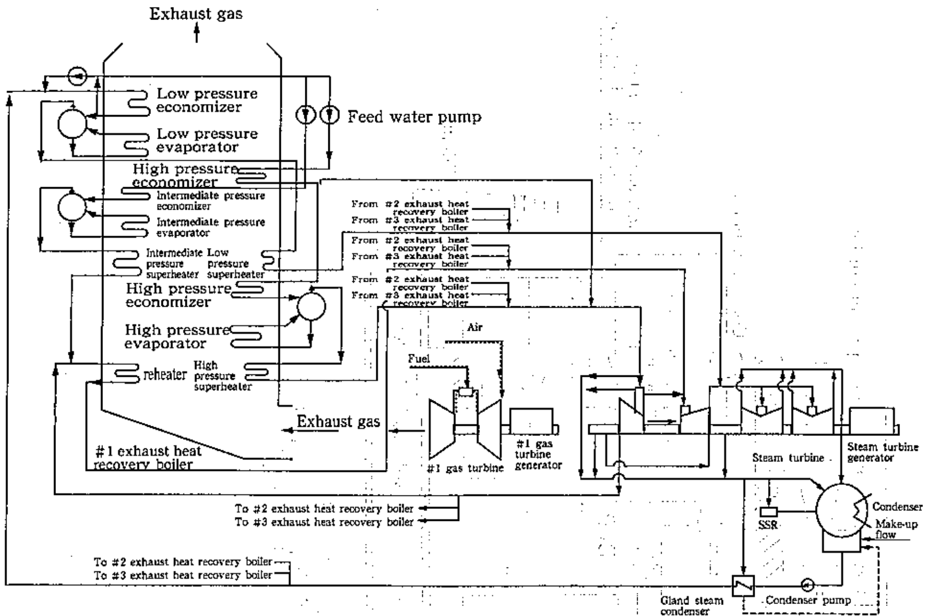


Multi-shaft type

b) Example of vertical type HRSG

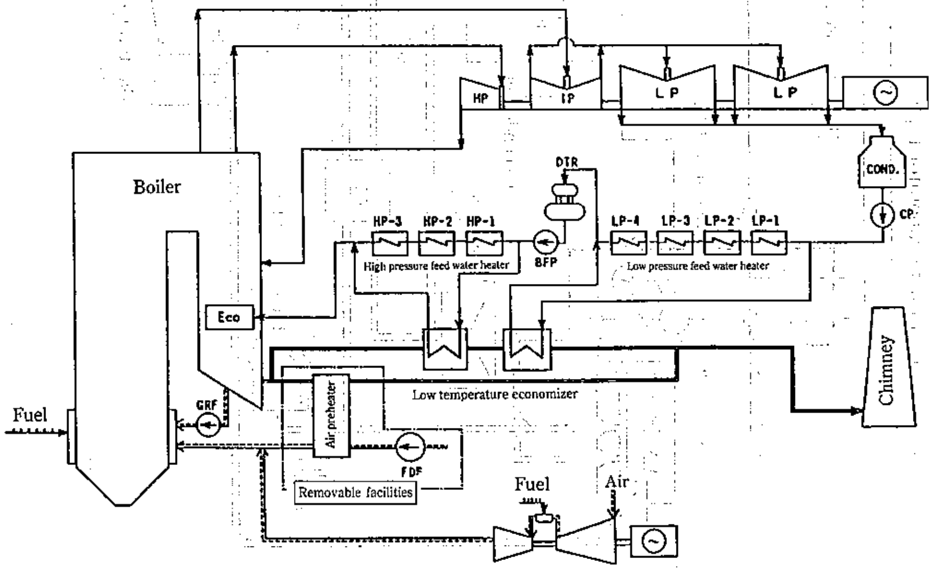


Single-shaft type



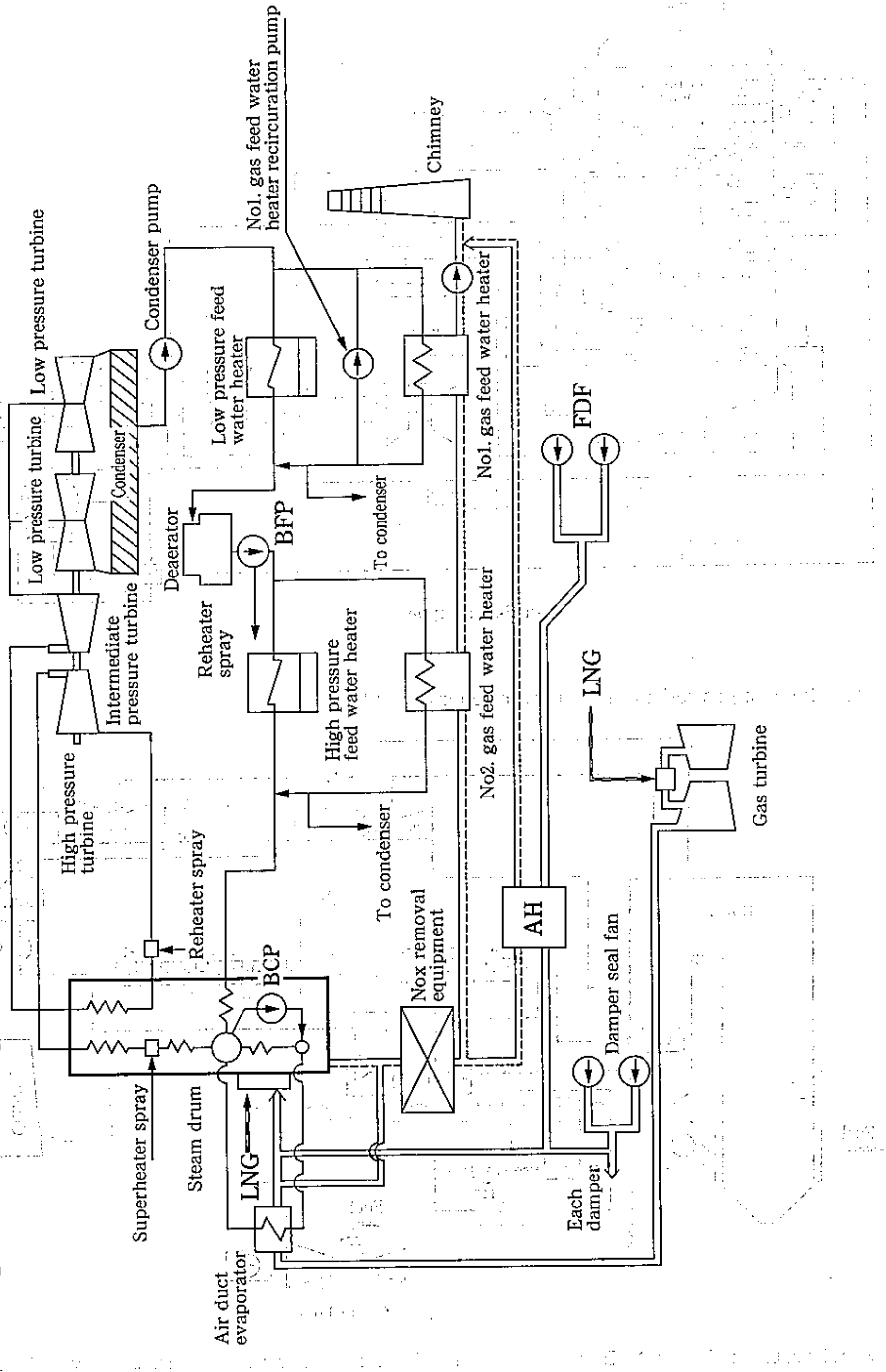
Multi-shaft type

(2) Exhaust gas refiring type power generating plant



Gas turbine

〔Source: Lecture Course for Improvement of Energy Efficiency in Use, Thermal and Nuclear Power Engineering Society Branch of Kyushyu. (1991/2·7)〕



Exhaust gas refiring type (Air duct evaporator type)

22-5 Pressurized Fluidized Bed Combustion (PFBC) Combined Power Generating Plants

(1) PFBC plants

1) Feature

The pressurized fluidized bed combustion (PFBC) boiler can improve the heat transfer coefficient by setting a fuel (coal) combustion zone to be pressurized fluidized bed. Furthermore, improvement of plant efficiency can be obtained compared with the conventional coal fired thermal power generation, as the combined cycle of a gas turbine and a steam turbine is realized. The configuration of this system is shown in Fig. 1

2) Better environmental performance

Furnace desulfurization which desulfurizes simultaneously with combustion can be performed by supplying the lime stone in furnace as SOx removal materials. Since high pressure air is used, high draft resistance of fluidized bed can be taken. Therefore, the bed height can be about 3-5m higher, and better SOx removal efficiency is obtained, as stay time can be about 4 seconds longer. Since furnace combustion temperature is low (860℃~870℃), production of NO_x gas is suppressed. Also the production of CO_2 gas can be reduced compared with the conventional coal fired thermal power generation because of improvement in thermal efficiency.

3) Compact

Since the volume of air for combustion and the exhaust gas decreases by pressurization, large down sizing of the main part of a boiler can be attained. Moreover, since exhaust gas desulfurization equipment also becomes unnecessary, large decrease of plant site area can be possible.

4) Dust removal system of boiler exhaust gas

The dust of about 20~40g / m^3_N dispersed from the fluidized bed (scattering limestone+coal ashes) is contained in furnace outlet exhaust gas of the pressurized fluidized bed boiler. In oder to protect gas turbine blades from wear by this dust, dust removal equipment is installed into the high pressure and the high temperature gas system between the boiler furnace outlet and gas turbine inlet. There is combination of the primary cyclone for removal coarse dust and the secondary cyclone for removing fine dust as the removal equipment. (Refer an example of actual result 1). There is another combination of a primary cyclone (for large diameter) and a ceramic filter (for small diameter) for the same purpose (Refer an example of actual result 2).

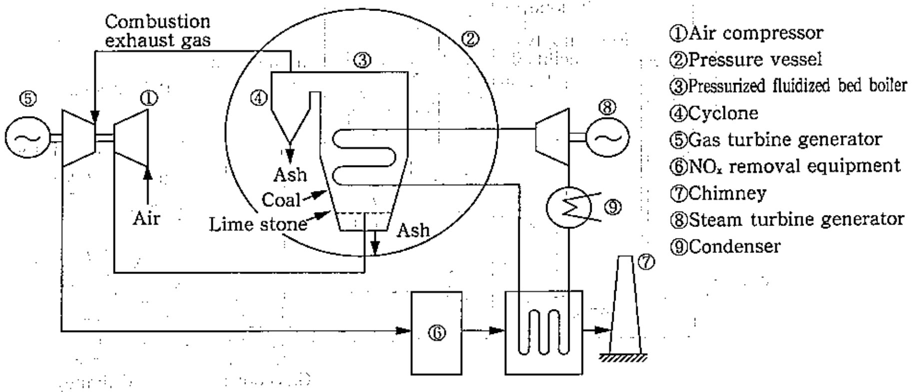
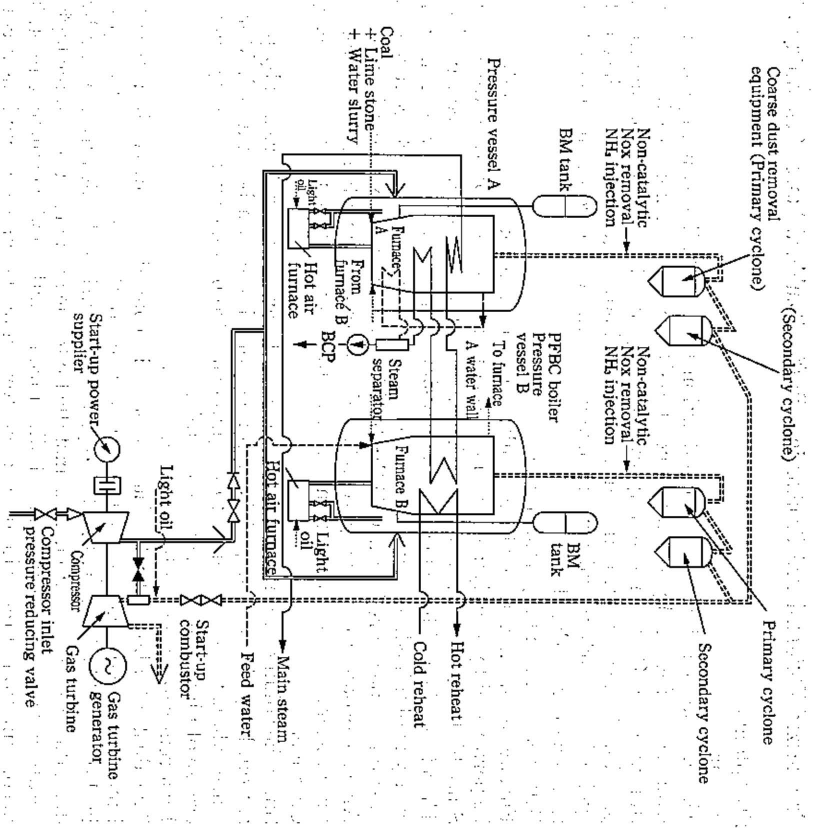
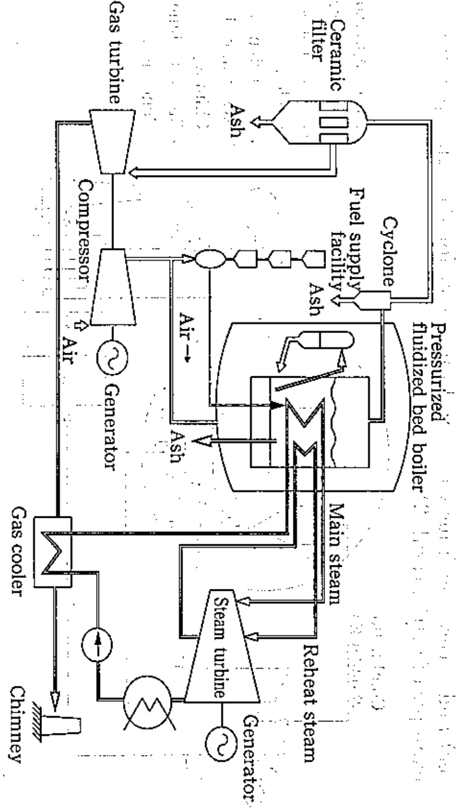


Fig 1. PFBC System

(Source: Sakae Ando, Turbo Machine, Vol.20, No.1, 1992)



Actual example 1: Primary cyclone+secondary cyclone system



Actual example 2: Primary cyclone+Ceramic filter system

〔Source: Thermal and Nuclear Power Vol.49/№10, Pressurized fluidized bed boiler combined power generation〕

(2) Features of actual pressurized fluidized bed power plants

Name of power plant	Hokkaido Electric Power Co., Inc. Tomato Azuma P/S No. 3 Unit	The Chugoku Electric Power Co., Inc. Osaki P/S No.1 System	Kyushu Electric Power Co., Inc. Karita P/S 360MW New No.1	Electric Power Development Co., Ltd., Wakamatsu Coal Exploitation Technology Research Center 71MW Demonstration Unit
Plant output Gas turbine output Steam turbine output	85.0MW 11.1MW 73.9MW	250 MW×2 36.5MW×2 213.5MW×2	360MW 75MW 290MW	71 MW 14.8MW 56.2MW
Boiler Type	Pressurized fluidized bed reheat forced circulation type	Pressurized fluidized bed reheat one-through type(Bubbling type)	Pressurized fluidized bed bubbling type	Pressurized fluidized bed bubbling type
Steam flow	195t/h	522t/h	760t/h	146.6t/h
Coal supply system	—	Wet coal supply system by slurry	Wet coal supply system by slurry	Wet coal supply system by slurry
Combustion temperature	870℃	—	—	—
Steam turbine Type	Single casing single flow exhaust reheat regenerative condensing type	Tandem-compound reheat regenerative condensing type	Tandem-compound reheat regenerative condensing type	Tandem-compound reheat regenerative condensing type
Steam condition	16.6MPa×566/538℃	16.6MPa×566/593℃	24.1MPa×566/593℃	10MPa×593/593℃
Gas turbine Type	Open simple cycle single shaft type	Open simple cycle single shaft type	Open simple cycle multi shaft type	Open simple cycle multi shaft type
Inlet gas temperature	831℃	Approx.840℃	Approx.850℃	Approx.830℃
Pressure	0.95MPa	—	—	—
Dust collection system	Cenrifugal type cyclone Ceramic filter type	2 stage×24 units cyclone + Bag filter	2 stage cyclone + Electrostatic precipitator	1 stage cyclone +ceramic filter
SOx removal system	In furnace SOx removal system by lime stone	In furnace SOx removal system by lime stone	In furnace SOx removal system by lime stone	In furnace SOx removal system by lime stone
NOx removal system	Dry type ammonia catalytic reduction	Non-catalytic NO$_x$ removal + catalytic NO$_x$ removal (Dry type ammonia catalytic reduction)	Dry type ammonia selective catalytic reduction	Dry type ammonia catalytic reduction

〔Source: Thermal and Nuclear Power Vol. 49/№10 (1998), Thermal and Nuclear Power Engineering Society〕

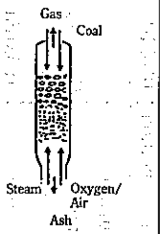
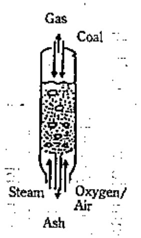
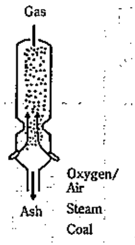
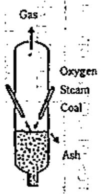
22-6 Types and Features of Coal Gasifiers

(1) Fixed bed gasifiers are put to practical use.
Since they gasify coal at relatively low temperature, they produce relatively much tar and other byproducts and cannot use coking coal since it is easily solidified. Thus, they need proper byproduct processing, coal type selection, coal size adjustment, etc.

(2) Some types of fluidized bed gasifiers were put into practice, and some types of gasifiers are under development now. Since the fluidized bed gasifier gasifies coal at 850℃ to 1100 ℃ and gas and solid fuel are brought into good contact in the furnace, the gasification efficiency is high, the unit capacity is large, and the calorific value of gas is relatively high. It can handle a variety of coals, except for coal which cokes easily.

(3) Entrained flow gasifiers pulverize coal into fine particles, gasify them at high temperature (approx. 1200℃ to 1600℃) and produce molten ash. They gasify coal efficiently and have large capacities.

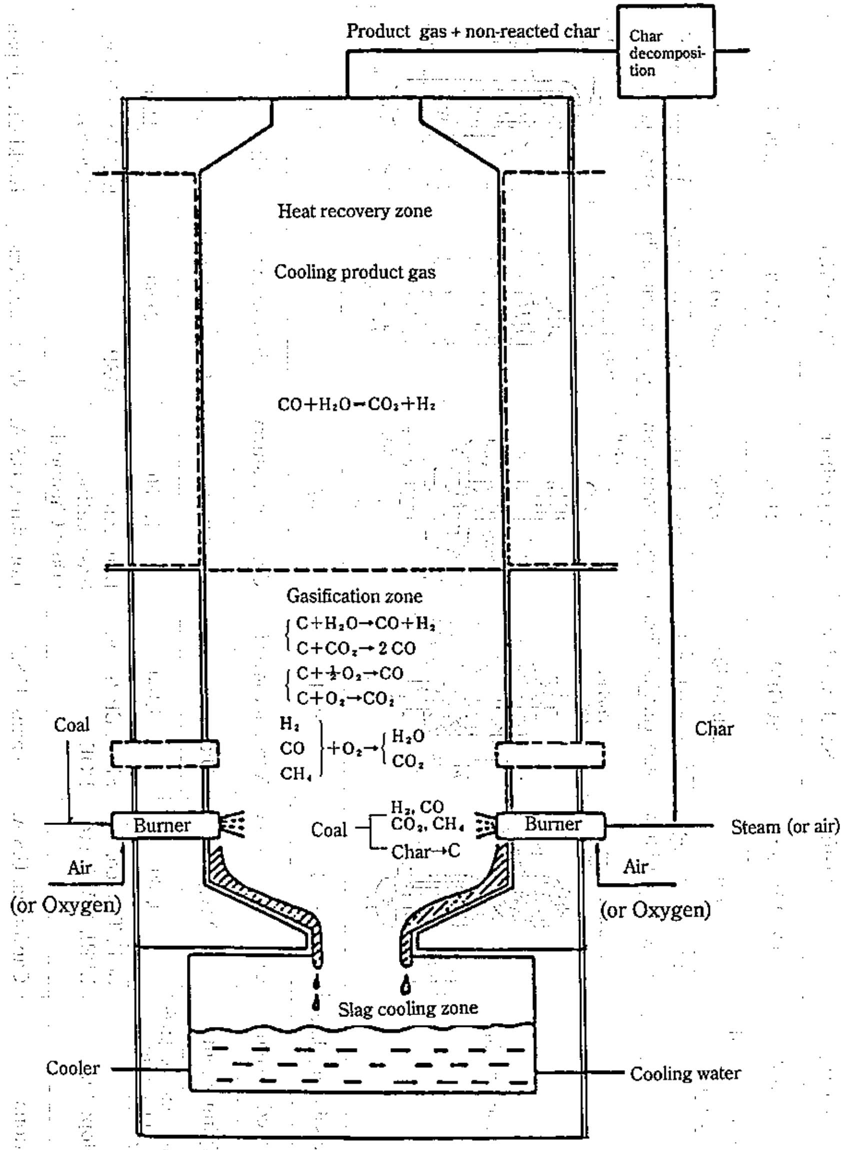
(4) Molten iron bath gasifiers are modified from entrained flow gasifiers. Coal is blown into a molten metal bath. It is difficult to make large size and high pressure type furnace.

Types Item	Fixed bed gasifier		Fluidized bed gasifier		Entrained flow gasifier		Molten iron bath gasifier
Capacity	Small	Large	Medium		Large		
Ash removal method	Dry ash	Slag	Dry ash	Dry ash & fine particles	Slag		
Gasification temperature (℃)	450 to 1,100	450 to 1,600	850 to 1,100		1,200 to 1,600		>1,500
Applicable coal	Non-coking coal		Non-coking coal		No restriction		
Coal feed system	Dry coal		Dry fine particles		Dry fine particles	Wet slurry	Dry
Coal size (mm)	Min. 5		0.1 to 3		Max. 0.1		No restriction
Production of tar and byproducts	Produced.		May be produced.		Not produced.		
Unburnt carbon in ash	Little	Quite	Little	Quite	Quite little		None
	Lurgi gasifier	BGC-Lurgi gasifier	1. Winkler gasifier 2. KRW gasifier 3. CMRCJ* gasifier	U-gas gasifier	1. Shell gasifier 2. CRIEPI* gasifier	1. Texaco gasifier 2. Dow gasifier	1. Otto gasifier 2. Furnace by Sumitomo Metal
Typical gasifier							

〔Source: N. Takanari, The Thermal and Nuclear Power Vol.42/№10-Oct.1991〕

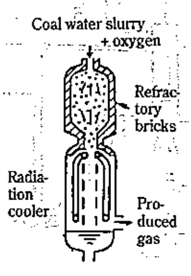
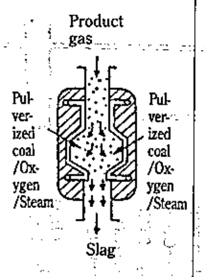
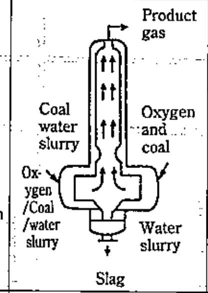
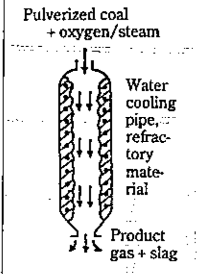
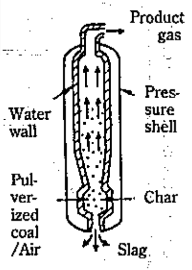
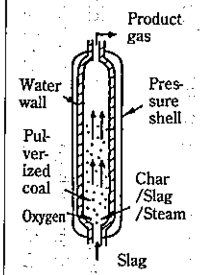
22-7 Principle and Types of Entrained Flow Gasifiers

(1) Principle of entrained flow gasifiers
In an entrained flow gasifier, coal burns partially to make a high temperature zone over 1200℃, where H_2 and CO are produced and ash content in the coal is melted into slag. The following figure shows the reactions taken place in a entrained flow gasifier.



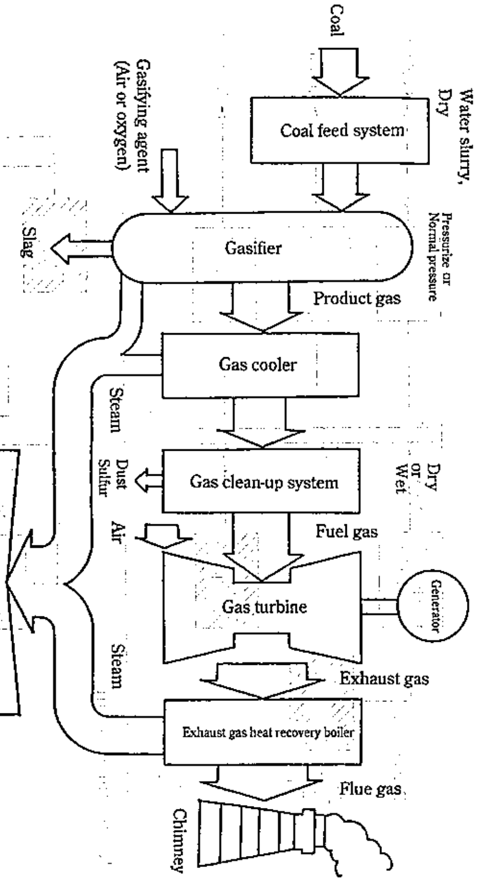
〔Source: S. Akatsuka, Research Association for Hydrogen-from-Coal Process Development (HYCOL) Feb. 1987〕

(2) Types and features of entrained flow gasifiers

Gasifier types	Texaco gasifier	Shell gasifier	Dow gasifier	VV gasifier	CRIEPI-Mitsubishi gasifier	Hycol gasifier
Plant examples	Cool Water	SCGP-1	Dow	VV30	200t/day P/P	Hydrogen production P/P
Quantity of coal used (t/day)	910	250 to 400	2,000	360 to 720	200	20 to 50
Types	Pressurized single-stage entrained flow	Pressurized single-stage entrained flow	Pressurized double-stage entrained flow	Pressurized single-stage entrained flow	Pressurized double-stage entrained flow	Pressurized single-stage entrained flow
Schematic drawings						
Commissioning date	'84/6	'86/11	'87	—	'97/3	'91/6
Coal feed system	Coal water slurry	Nitrogen conveying	Coal water slurry	Air conveying	Air conveying	Nitrogen conveying
Gasifying agent	Oxygen	Oxygen/steam	Oxygen	Oxygen/steam	Air	Oxygen/steam
Calorific value of product gas (kJ/m³NHHV)	10,430	11,180	10,050	10,050	4,270	10,890
Developed by	SCE, Texaco, EPRI, JCWP, etc.	Shell, EPRI and DOE	Louisiana Gasification (Dow Chemical)	GSP	IGC Association (NEDO)	Hycol (NEDO)
Locations	California, U.S.A.	Texas, U.S.A.	Louisiana, U.S.A.	Shwartz Punp, Germany	Iwaki City, Japan	Sodegaura, Japan

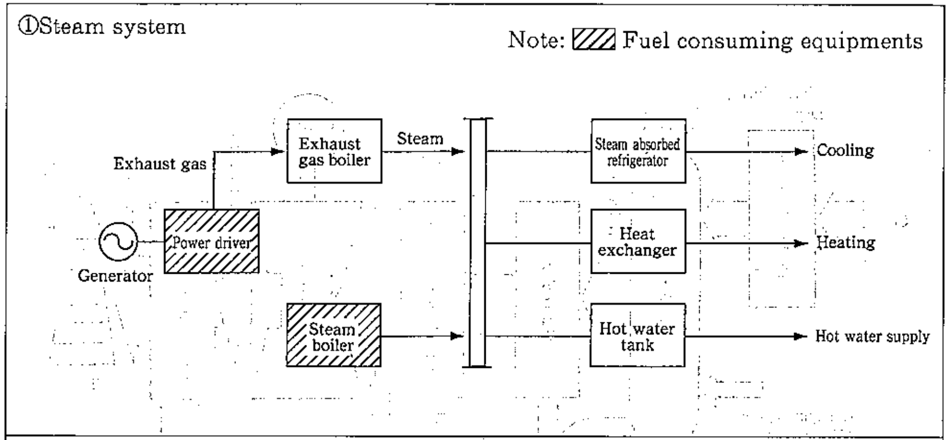
〔Source: T. Hamamatsu, The Thermal and Nuclear Power, Vol.41/No.12 (Dec. 1990)〕

22-8 Conceptual System of Coal Gasification Combined Cycle Power Plants

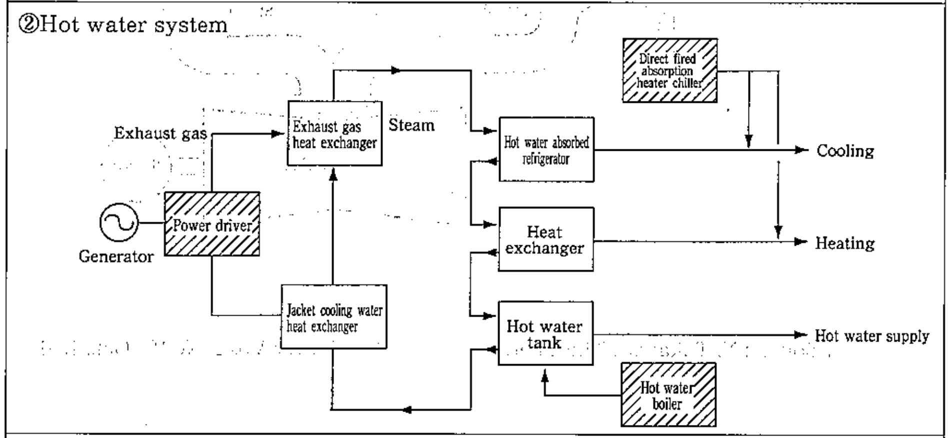


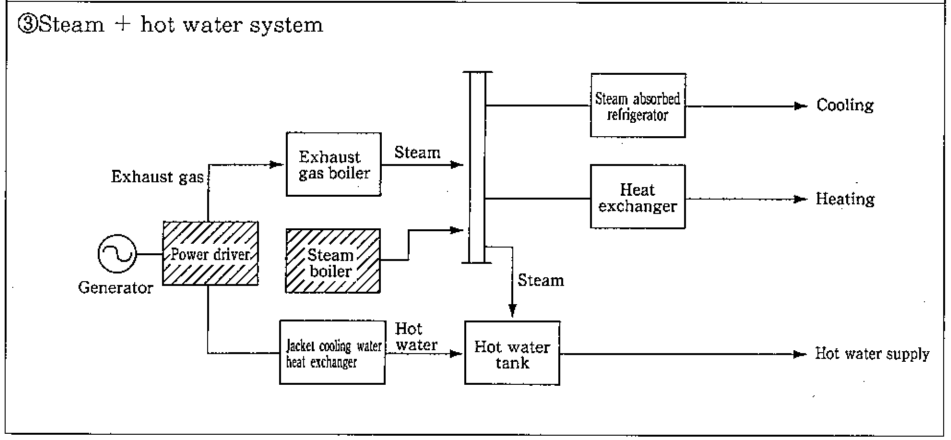
〔Source: N. Takanari, The Thermal and Nuclear Power Vo.42/No.10 (Oct., 1991)〕

23-1 Basic Systems of Cogeneration


①Steam system

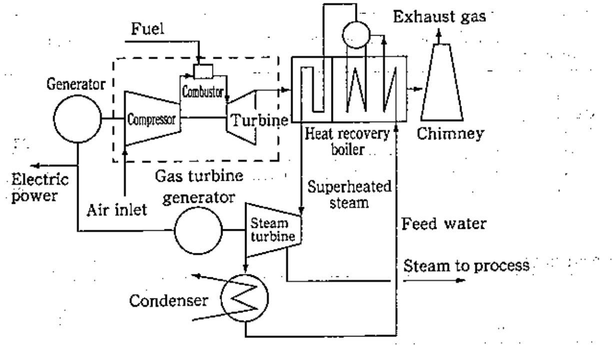
Note: ▨ Fuel consuming equipments


②Hot water system

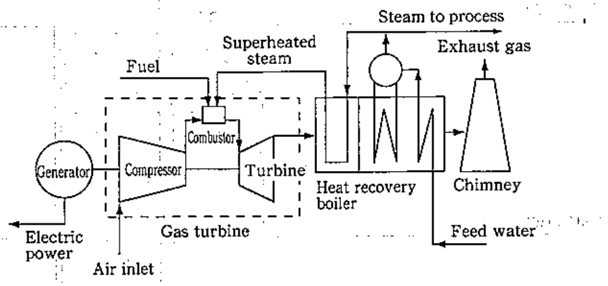

③Steam + hot water system

〔Source: Cogeneration, Vol. 14, No.1, 1999〕

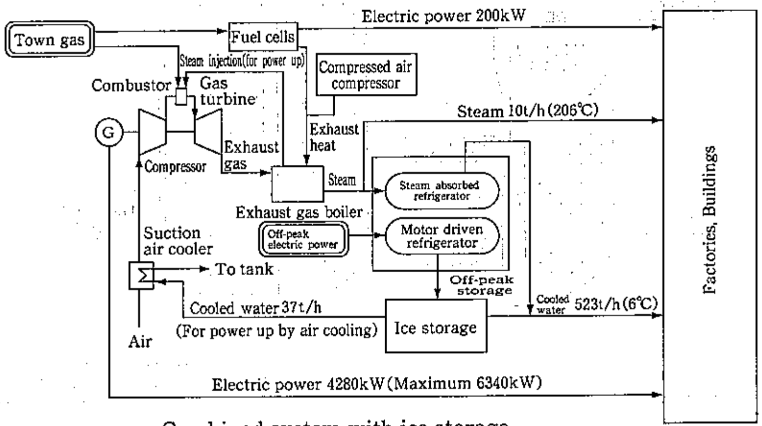
23-2 Examples of Cogeneration Systems



Heat and power variable type combined cycle

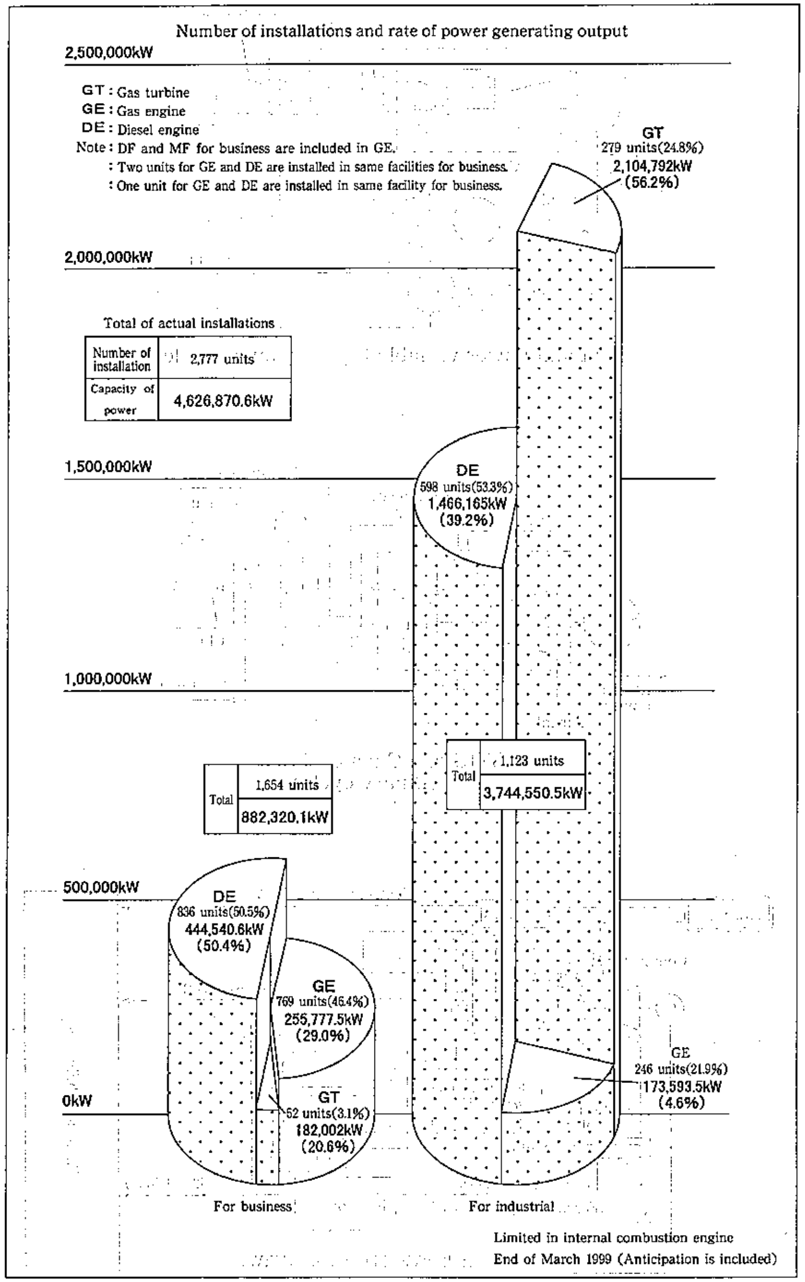


STIG and Chen cycle
(Binary cycle)



Combined system with ice storage

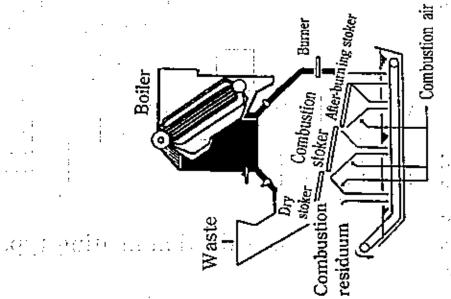
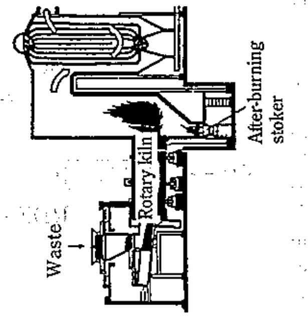
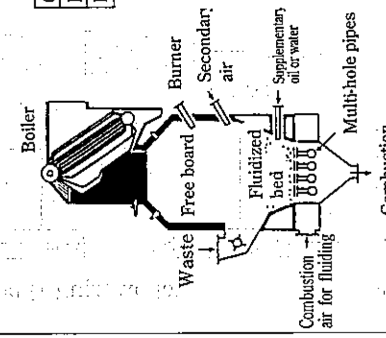
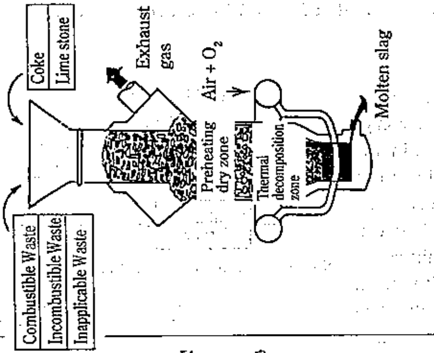
23-3 Experience List of Cogeneration Systems in Japan (Thermal Engines)



Limited in internal combustion engine
End of March 1999 (Anticipation is included)

[Source: Cogeneration, Vol. 14, №1, 1999]

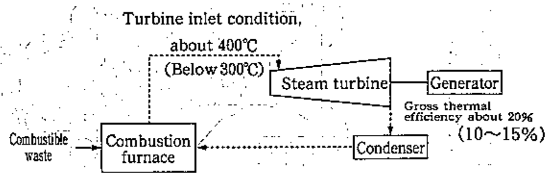
23-4 Types of Waste Incinerators

	Stoker type	Kiln + stoker type	Fluidized bed furnace type	Molten iron bath furnace type
Schematic drawings				
Features	● Slow combustion in drying, combustion and after-burning. ● Suitable for wet garbage in cities, with long experiences. ● Not suitable for garbage with high calorific values (such as plastic, and so forth) since the fire grate may be damaged in combustion.	● Decomposes and gasifies hard-to-burn objects (such as sludge) and garbage with high calorific values (such as plastic) in rotary kiln for long time to burn them gradually. ● Then, burns them in after-burning stoker. ● Complicated facility construction. Requires much house power.	● Stirs and dries garbage with air and sand intensely for burning in a short time. ● Garbage should be crushed into pieces of sizes suitable to fluidized bed combustion. ● Handles various types of garbages with low to high calorific values. ● Capable of desulfurization and denitrification in the furnace.	● Blast furnace can burn all types of garbages including metals in batch without sorting. ● Requires supplementary burning material (such as coke or the like).

23-5 Outline of Waste Power Generation Systems

(1) Conventional type

Widely spread power generation system using waste as fuel. To avoid corrosion of superheater by chlorine contained in the exhaust gas, steam temperature has to be held below 300℃, and thus, in most cases, thermal efficiency of this type is between 10-15% at most. However, facilities of about 20% thermal efficiency with steam temperature of 400℃ are now realized at the Eastern Saitama Cleaning Association, Obihiro city, etc.

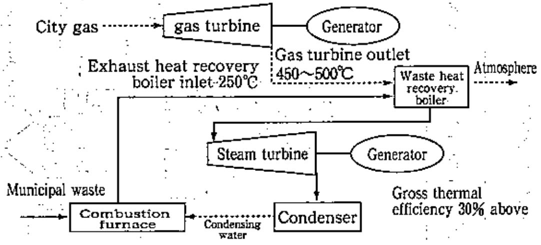


Note: ( ) are conventional data in general

Conventional type

(2) Super-waste power generation system (Repowering type)

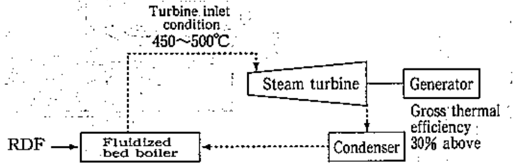
Waste power generation system combined with a steam turbine and a gas turbine so as to improve thermal efficiency. Thermal efficiency is improved by reheating the low-temperature-low-pressure steam producted in the refuse incinerator with the exhaust heat from gas turbine. This system is under operation at the Takahama Clean Center in Gunma Pref., etc.



Repowering type

(3) RDF (Refuse Derived Fuel) power generation system

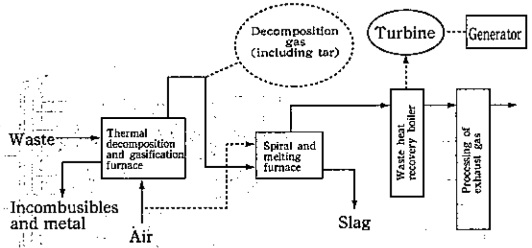
RDF is a refused solid fuel and is used as fuel at power generation system. By solid-fuelizing the kitchen garbage, performance in transportation and storage is improved, and thus makes large-scale intensive waste-power generation facilities possible. The variation in calorific value of RDF is small compared with the kitchen garbage and RDF has a desulfurization effect by the calcium added at the refining process.



RDF type

(4) Gasified-waste power generation system (The next generation type)

The waste is thermally decomposed, and the decomposition gas is burned and used for melting ashes while recovering exhaust heat. Using this generation system, utilizable slag can be produced from the waste. It is also possible to control generation of dioxin because of its high combustion temperature.



Gasification melting type

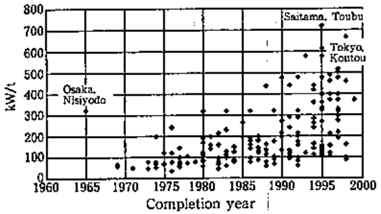
〔Reference: Electrical Review, Nov., 1997〕

23-6 Output and Thermal Efficiency of Waste Power Generation

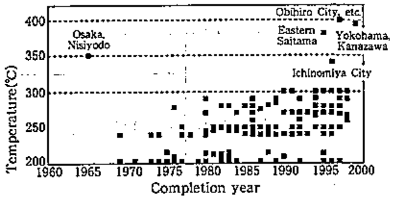
(1) The output by waste power generation in overseas and Japan

Japan	Approx. 750MW(173 Facilities: End of 1997)
USA	Approx. 2,600MW
Germany	Approx. 1,000MW
Britain	Approx. 70MW(400MW Anticipation in 2000)

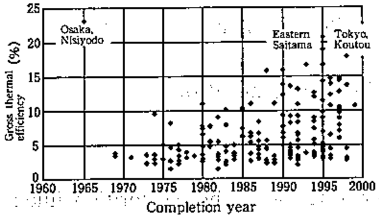
(2) Transition of the characteristics of waste power generation



Transition of the output of power generation per one (1) ton of refuse



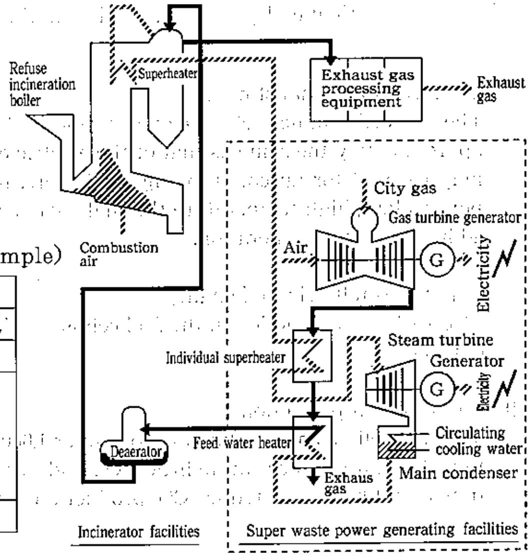
Transition of the steam temperature of waste power generating boiler



Transition of gross thermal efficiency

(3) Thermal efficiency of combined type waste power generation (Example)

Management object	Kita kyushu city environmental office
Name of incineration plant	Sinkougousaki plant
Refuse incineration capability	810t/day
Maximum amount of power generation Steam turbine output Gas turbine output ST inlet steam condition	 36,300kW 28,300kW 8,000kW 2.2MPa×380℃
Completion year	June, 1998



Kita Kyushu City:
Flow sheet of gas turbine combined type power generation

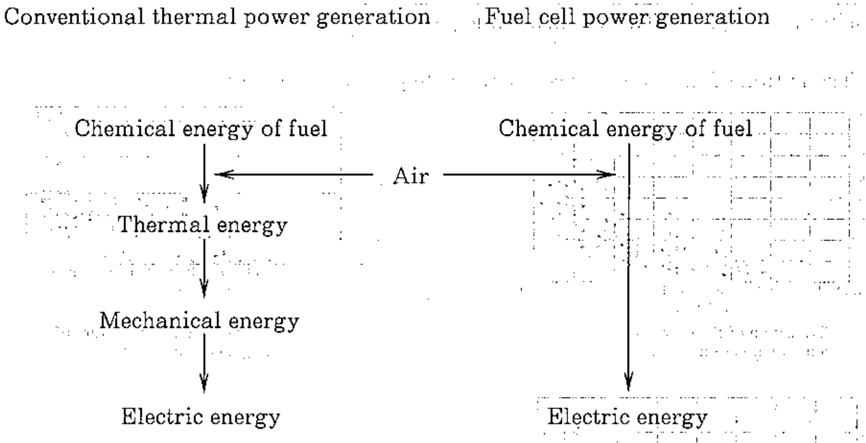
Total efficiency of power generation

	GT-operation	GT-stop
810t/day・12,600kJ/kg	25.4	17.3
711t/day・10,900kJ/kg	26.5	16.5
540t/day・10,900kJ/kg	26.2	14.1

23-7 Features of Fuel Cell Power Generation

(1) High generating efficiency

Fuel cells can convert the chemical energy (i.e. heating value) of a fuel into electric energy directly. Accordingly, it has high generating efficiency.



Fuel cell power generation vs thermal power generation

(2) Available exhaust heat

The fuel cell produces electric energy, and it also generates heat whose calorific value is approximately the same as that of the electric energy. Thus, it may feed hot water and may be used for air-conditioning. Still more, in the case of high temperature fuel cell power plant, high temperature thermal energy can be recovered and it may be used for additional power generation.

(3) Rapid load following capability

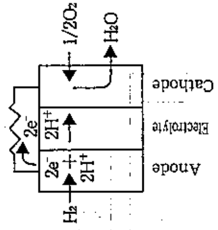
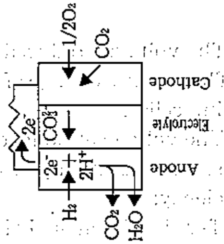
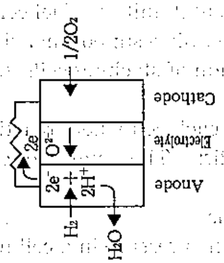
Electrochemical reaction in the fuel cell is rapid. Thus, the fuel cell can follow quick load demand.

(4) Environment protection

The fuel cell has no combustion zone over 1,000℃ and uses clean fuel for power generation. Thus, it produces quite little NOx and SOx causing atmospheric pollution. In addition, it will be able to reduce CO_2 production with high power generating efficiency.

23-8 Types of Fuel Cells

The fuel cells are classified according to the type of electrolyte used in cells: phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), solid electrolyte fuel cell (SOFC) and so on. Features of these types are shown in the following table, operating temperature and applicable fuels depend on types of fuel cells. MCFC and SOFC are called high temperature fuel cells.

Generations	First	Second	Third
Types	Phosphoric acid	Molten carbonate	Solid oxide
Electrolyte	Phosphoric acid solution (Liquid)	Molten carbonate (Liquid)	Stabilized zirconia (Ceramics) (Solid)
Operating temperature	190 to 220℃	600 to 700℃	800 to 1,000℃
Abbreviations	PAFC	MCFC	SOFC
Fuel flexibility	Natural gas, LPG & methanol	Natural gas, LPG, methanol & coal gasified gas	Natural gas, LPG, methanol & coal gasified gas
Operation principle			
Fuel electrode reaction Air electrode reaction	$H_2 \rightarrow 2H^+ + 2e^-$ $1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$	$H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$ $1/2O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$	$H_2 + O^{2-} \rightarrow H_2O + 2e^-$ $1/2O_2 + 2e^- \rightarrow O^{2-}$
Major cell materials	Carbon	Nickel & stainless steel	Ceramics
Features	• Low temperature: Wide flexibility of materials for stack • Available exhaust heat for co-generation. • Technical field test stage.	• Capability using fuel gases containing CO. • Without any expensive platinum catalyst in electrodes • Applicable exhaust heat to additional steam power generation.	• Capability using fuel gases containing CO. • High temperature: Without any catalyst in electrodes • Applicable exhaust heat to additional steam power generation.
Power generating efficiency	35−45%	45−60%	50−60%

23-9 Basic Terms on Fuel Cell Power Generation

Terms on cell specifications

(1)	Cell:	The fundamental unit of a fuel cell. The basic cell structure consists of an electrolyte within a support matrix sandwiched between anode and cathode.
(2)	Stack:	An aggregation of stacking cells, to which gas is fed through a common gas header.
(3)	Cell area:	The area of each cell where reaction is made.
(4)	Number of stacking cells:	The number of cells of a stack.

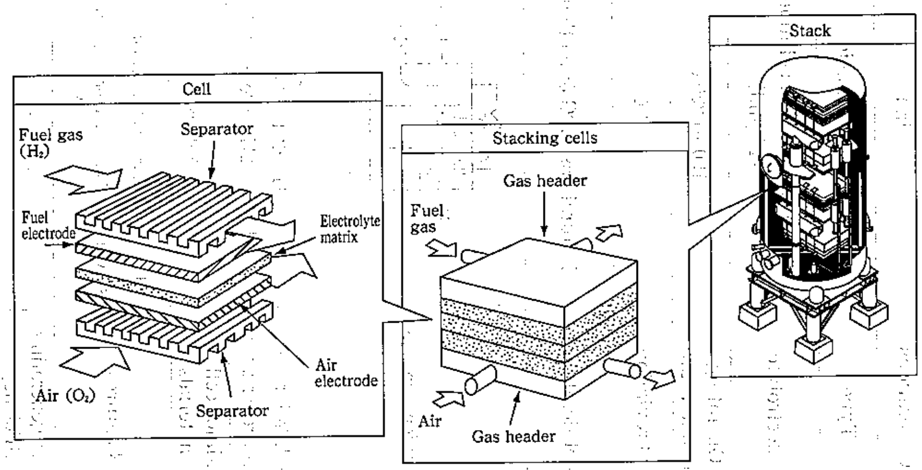
Terms on operation conditions

(1)	Operation pressure:	The pressure in a cell housing.
(2)	Fuel utilization :	The ratio of fuel gas contributed for power generation to supplied fuel gas.
(3)	Current density:	The flowing current per unit area of a cell.

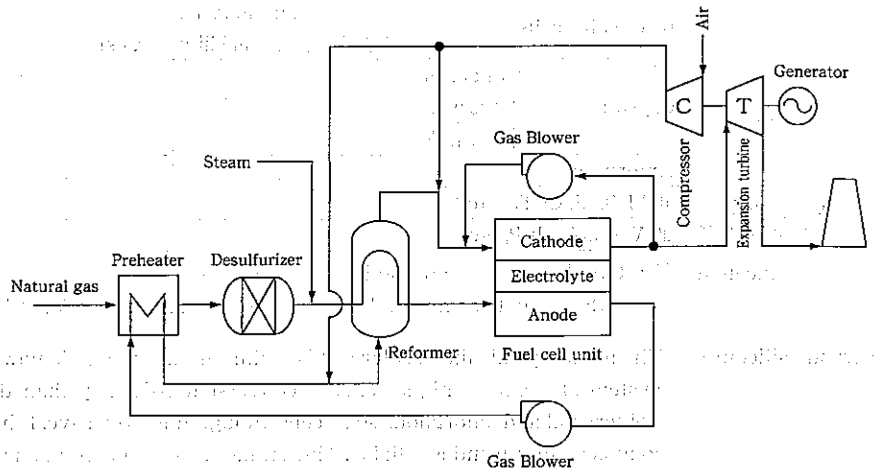
Terms on cell performances

(1)	Stack voltage:	The voltage produced by a stack.
(2)	(Mean) cell voltage:	The (mean) voltage of each cell (Stack voltage/number of stacking cells).
(3)	Open circuit voltage:	The voltage at no load (May be calculated from the gas composition, operation pressure and operation temperature).
(4)	Energy conversion efficiency:	The electric output divided by the chemical energy of supplied fuel.

23-10 Example of Fuel Cell Structures

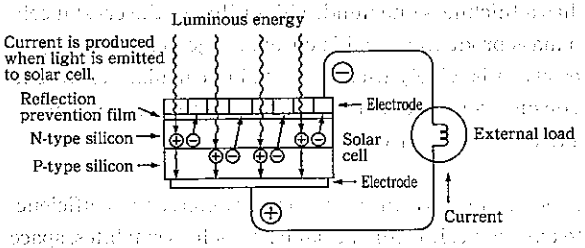


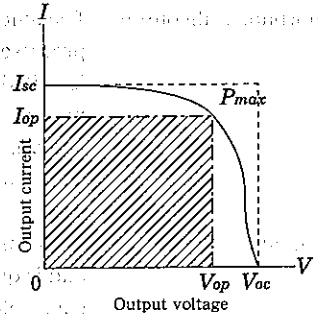
23-11 Example of Fuel Cell Power Generation Systems



23-12 Principle of Solar Cells

The solar cell consists of laminated P-type and N-type semiconductors.
When light is irradiated onto a solar cell, electrons having negative charges and electron holes having positive charges are produced. The electrons move to the negative electrode and the electron holes move to the positive electrode. Such movement of electrons and electron holes cause potential difference between the positive and negative electrodes, and accordingly direct current is produced.





Voc : Open circuit voltage
Isc : Short circuit current
$P_{\max}$: Maximum electric power

Output characteristics of solar cell

[Source: Takahiko Ohno, Kazuhiro Sahara, Termal and Nuclear Power, 42-421 (October, 1991) P.1249, and Thermal Power Handbook P.435, (1992), Denryoku-Sinpo-sha]

23-13 Types of Solar Cells

Type of solar cells			Characteristics		
			Conversion efficiency	Reliability	Cost
Silicon	Crystal	Monocrystal	○	○	○
		Polycrystal			
		Polycrystal thin film			
	Amorphous		△	△	◎
Compound semiconductor	Ⅱ-Ⅵ (CIS, CdTe, etc.)		△	○	○
	Ⅲ-Ⅴ (GaAs, InP, etc.)		◎	◎	×

◎ : Excelent ○ : Good △ : Not so good × : Not good

〔Source: Thermal and Nuclear Power, August, 1998, P.14〕

Monocrystal silicon······ The monocrystal silicon solar cell is mainly used for electric power systems. It features higher energy conversion efficiency than the polycrystal and amorphous solar cells, though it is expensive. It has long been in use and is reliable. Thus, it has also been used in an artificial satellite.

Polycrystal silicon······ The polycrystal silicon solar cell is mainly used for electric power systems. It is produced at lower cost, while featuring high efficiency and high reliability like the monocrystal silicon solar cell. Recently, the energy conversion efficiency of the polycrystal silicon solar cell has come closer to that of the monocrystal silicon solar cell.

Amorphous silicon······ The amorphous silicon solar cell is produced in simpler production processes, has a thickness one hundredth of that of the crystal cells, is suited to mass production, and is cheap. Large-area cells may be produced easily. It is widely used for portable calculators, watches and other consumer-use products. It has low energy conversion efficiency and deteriorates easily.

Compound solar cells······The compound solar cell features high energy conversion efficiency and is quite expensive. It is for special uses such as satellites, spaceships, etc. Gallium arsenide solar cells and indium phosphorous solar cells are also available.

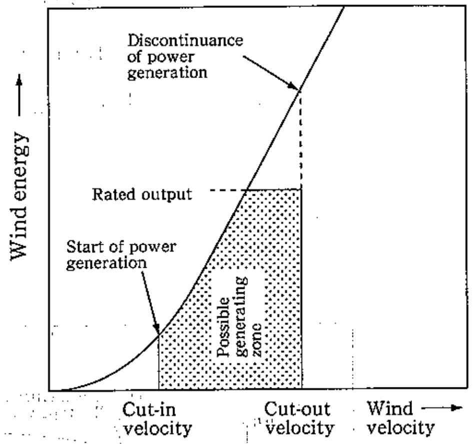
〔Source: Thermal Power Handbook P.435, (1992), Denryoku-Sinpo-sha〕

23-14 Wind Power Generation

Wind power generation is the system of changing the kinetic energy of the wind into rotation energy with a windmill, and generate the electric energy. This system does not discharge contaminant and infinitive energy can be obtained, but, stability of power generation cannot be obtained and the demerit is high power generation costs, compared with thermal power generation or nuclear power generation, etc. The kinetic energy of the wind is proportional to the cube wind velocity, as shown in the following formula.

$$E = \frac{1}{2}mv^2 = \frac{1}{2}\rho Av^3$$

Where, E: Kinetic energy of wind (W)
m: Mass of wind (kg/s)
v: Velocity of wind (m/s)
ρ: Density of air (kg/m³)
A: Area of windmill vanes receiving wind (m²)



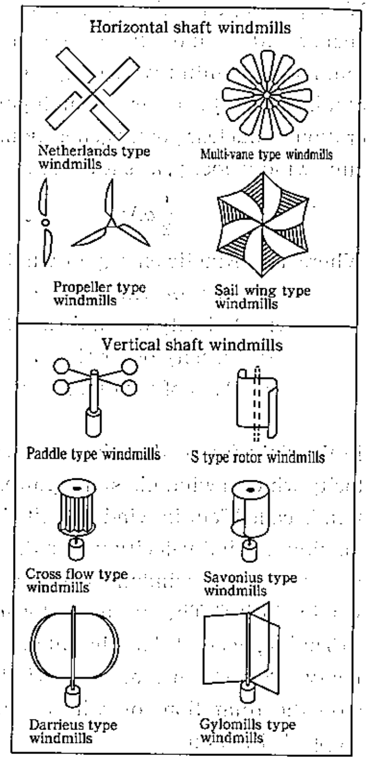
In the right figure, the minimum wind velocity which a windmill starts power generation is called "cut in wind velocity" and the maximum wind velocity under the generating output of a windmill is called "cut out wind velocity". The cut in wind velocity is 3 to 5 m/s in general. And the cut out wind velocity is 20 to 25 m/s, and the windmill will stop the rotatation, or will be in almost stopped situation.

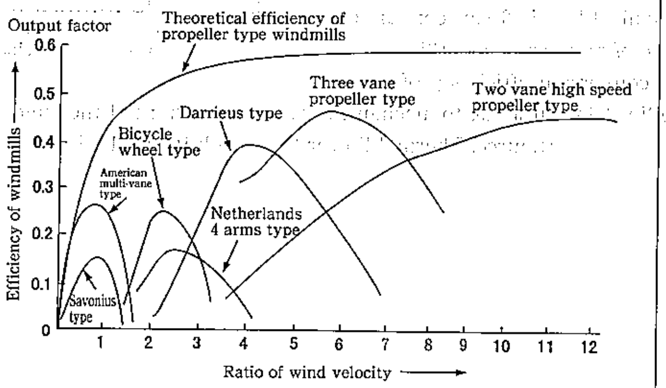
A windmill can convert energy from wind up to a certain percentage. An ideal windmill whose mechanical loss is 0 can convert energy at a rate of no more than 59.3%. The energy conversion efficiency of an actual windmill is 36 to 40% due to mechanical loss, eddy current of the wind, etc.

〔Source: Thermal Power Handbook P.439, (1992), Denryoku-Sinpo-sha〕

23-15 Types of Windmills

- Windmills
  - Horizontal shaft windmills
    - Netherlands type
    - Multi-vane type
    - Propeller type
    - Sail wing type
  - Vertical shaft windmills
    - Paddle type
    - S type rotor
    - Cross flow type
    - Savonius type
    - Darrieus type
    - Gylomills type





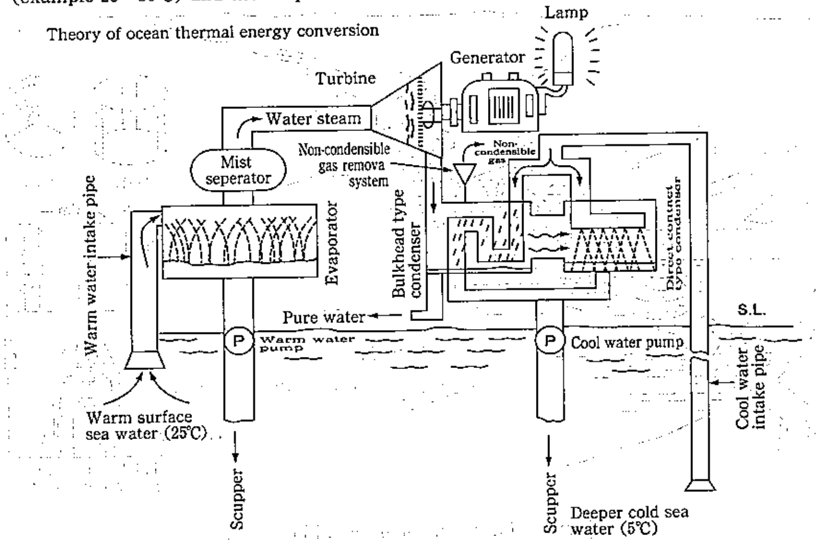
Output factor=(actual output)/(wind energy)
Ratio of wind velocity=(velocity of vane end of windmill)/(wind velocity)

[Source: Energy Manual in 1998, P.64, edited by the MITI Investigation Comittee and New Energy Current of the Earth Era, P.135, Denryoku-Shinpo-sha]

23-16 Ocean Power Generation

(1) Ocean thermal energy conversion

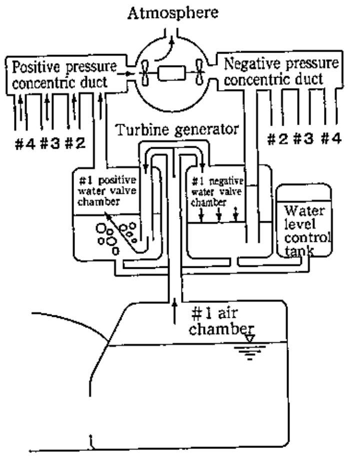
Power generation systems using the difference of temperature between the warm water of sea surface (example 25~30℃) and the deeper cold water (5~7℃) of about 500~1,000m deep in the sea.



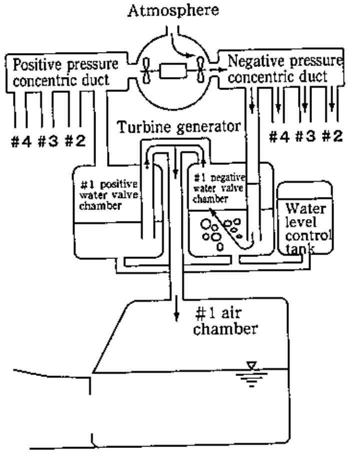
Power generation systems using the difference of temperature between the warm water of sea surface and the cold water of deep sea, and turning a turbine according to the difference of the steam pressure. (Open cycle method)

(2) Wave Power Generation

Power generation systems turning a turbine with the air pushed out by up-and-down motion of the sea surface wave. There are several kinds of systems, such as water column vibration type, movabl object type, over wave type, etc. The small scale type is already put in practical use as a power supply for lamplight of the marine buoy for beacons with the water column vibration type.



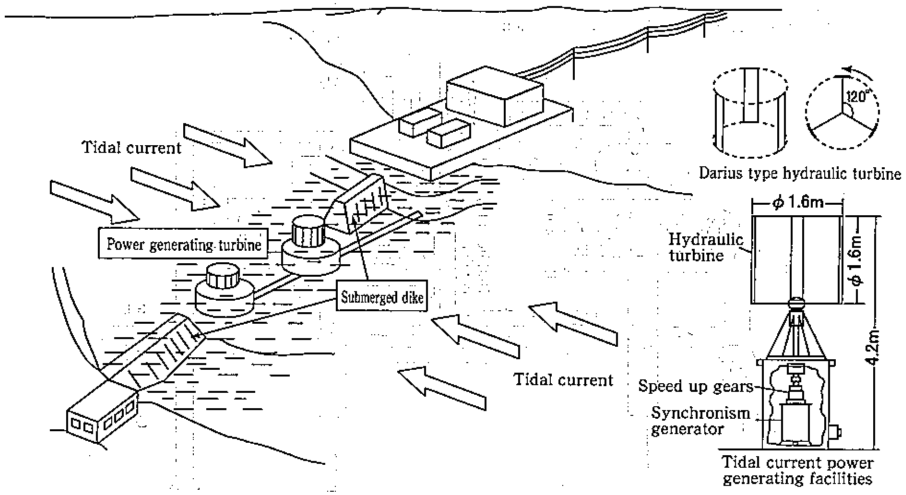
Tide wave



Ebb tide

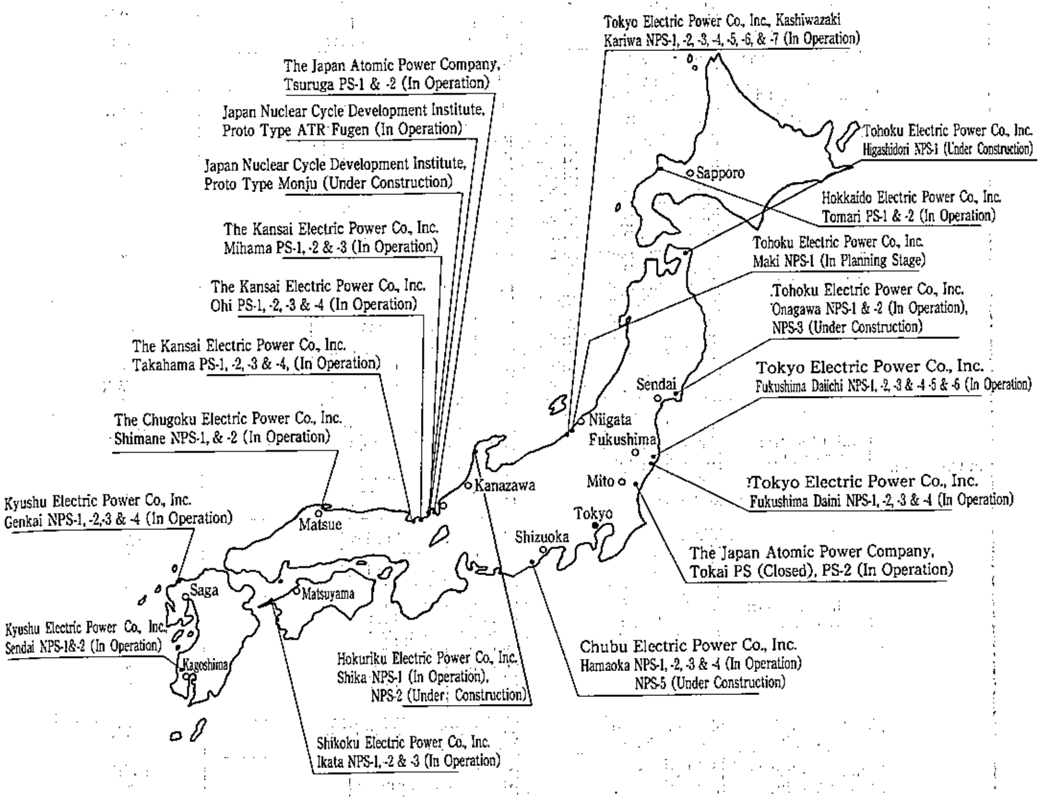
(3) Tidal power generation

The energy of the flow of the sea water by tidal phenomenon is used for power generation etc.



Source: Energy manual, 1998, P71 and 72,
Thermal Power and Nuclear Power, Oct. 1998, P.39 and 45,
New Energy Current of the Earth Era, Feb. 25, 1991,
Denryoku-Shinpo-sha, P.143

24-1 Location of Nuclear Power Plants (as of July 1st, 1999)



As of July 1st, 1999

		BWR	PWR	Total
In Operation	Units Capacity	28 2,555.1	23 1,936.6	51 4,491.7
Under Construction	Units Capacity	3 330.5	– –	3 330.5
Preparation of Construction	Units Capacity	2 218.3	– –	2 218.3
Total	Units Capacity	33 3,103.9	23 1,936.6	56 5,040.5

Unit of Capacity: 10,000kW

Note: 1. JAPC Tokai PS (Gas cooled Reactor) was stopped commercial operation at the end of 1997 FY.
2. NPS: Nuclear Power Station, PS: Power Station

[Source: Nuclear Power Generation Handbook ('99 Edition), Thermal and Nuclear Power Engineering Society]

24-2 Table of Nuclear Power Plants in Japan

as of July 1st. 1999

	Owner	Plant Name and Unit Number	Location	Reactor Type	Capacity (Unit: 10,000kW)	Schedule to be proposed	Reactor Establishment Permit	Construction Permit	Start of Commercial Operation
In Operation	The Japan Atomic Power Company	Tokai PS-2	Naka-gun, Ibaraki Pref.	BWR	110.0	1971-12	1972-12-23	1973-4	1978-11-28
		Tsuruga PS-1	Tsuruga city, Fukui Pref.	″	35.7	1965-5	1966-4-22	1967-2	1970-3-14
		Tsuruga PS-2	Tsuruga city, Fukui Pref.	PWR	116.0	1978-12	1982-1-26	1982-3	1987-2-17
	Hokkaido Electric Power Co., Inc.	Tomari PS-1	Koji-gun, Hokkaido	″	57.9	1982-3	1984-6-14	1984-8	1989-6-22
		Tomari PS-2	Koji-gun, Hokkaido	″	57.9	1982-3	1984-6-14	1984-8	1991-4-12
	Tohoku Electric Power Co., Inc.	Onagawa NPS-1	Ojika-gun, Miyagi Pref.	BWR	52.4	1970-5	1970-12-10	1971-5	1984-6-1
		Onagawa NPS-2			82.5	1987-3	1989-2-28	1989-6	1995-7-28
	Tokyo Electric Power Co., Inc.	Fukushima Daiichi NPS-1	Futaba-gun, Fukushima Pref.	″	46.0	1966-4	1966-12-1	1967-9	1971-3-26
		Fukushima Daiichi NPS-2	Futaba-gun, Fukushima Pref.	″	78.4	1967-12	1968-3-29	1969-5	1974-7-18
		Fukushima Daiichi NPS-3	Futaba-gun, Fukushima Pref.	″	78.4	1969-5	1970-1-23	1970-10	1976-3-27
		Fukushima Daiichi NPS-4	Futaba-gun, Fukushima Pref.	″	78.4	1971-6	1972-1-13	1972-5	1978-10-12
		Fukushima Daiichi NPS-5	Futaba-gun, Fukushima Pref.	″	78.4	1971-2	1971-9-23	1971-12	1978-4-18
		Fukushima Daiichi NPS-6	Futaba-gun, Fukushima Pref.	″	110.0	1971-12	1972-12-12	1973-3	1979-10-24
		Fukushima Daini NPS-1	Futaba-gun, Fukushima Pref.	″	110.0	1972-6	1974-4-30	1975-8	1982-4-20
		Fukushima Daini NPS-2	Futaba-gun, Fukushima Pref.	″	110.0	1975-3	1978-6-26	1979-1	1984-2-3
		Fukushima Daini NPS-3	Futaba-gun, Fukushima Pref.	″	110.0	1977-3	1980-8-4	1980-11	1985-6-21
		Fukushima Daini NPS-4	Futaba-gun, Fukushima Pref.	″	110.0	1978-7	1980-8-4	1980-11	1987-8-25
		Kashiwazaki Kariwa NPS-1	Kashiwazaki City, Niigata Pref.	″	110.0	1974-7	1977-9-1	1978-11	1985-9-18
		Kashiwazaki Kariwa NPS-2	Kashiwazaki City, Niigata Pref.	″	110.0	1981-3	1983-5-6	1983-8	1990-9-28
		Kashiwazaki Kariwa NPS-3	Kashiwazaki City, Niigata Pref.	″	110.0	1985-3	1987-4-9	1987-6	1993-8-11
		Kashiwazaki Kariwa NPS-4	Kashiwazaki City, Niigata Pref.	″	110.0	1985-3	1987-4-9	1987-6	1994-8-11
		Kashiwazaki Kariwa NPS-5	Kashiwazaki City, Niigata Pref.	″	110.0	1981-3	1983-5-6	1983-8	1990-4-10
		Kashiwazaki Kariwa NPS-6	Kashiwazaki City, Niigata Pref.	ABWR	135.6	1988-3	1991-5-16	1991-8	1996-11-7
		Kashiwazaki Kariwa NPS-7	Kashiwazaki City, Niigata Pref.	″	135.6	1988-3	1991-5-15	1991-8	1997-7-2
	Chubu Electric Power Co., Inc.	Hamaoka NPS-1	Ogasa-gun, Shizuoka Pref.	BWR	54.0	1969-5	1970-12-10	1971-2	1976-3-17
		Hamaoka NPS-2	Ogasa-gun, Shizuoka Pref.	″	84.0	1972-2	1973-6-9	1973-9	1978-11-29
		Hamaoka NPS-3	Ogasa-gun, Shizuoka Pref.	″	110.0	1978-10	1981-11-16	1982-6	1987-8-28
		Hamaoka NPS-4	Ogasa-gun, Shizuoka Pref.	″	113.7	1986-10	1988-8-10	1988-10	1993-9-3
	Hokuriku Electric Power Co., Inc.	Shika NPS-1	Hakui-gun, Ishikawa Pref.	″	54.0	1986-12	1988-8-22	1988-11	1993-7-30
	The Kansai Electric Power Co., Inc.	Mihama PS-1	Mikata-gun, Fukui Pref.	PWR	34.0	1966-4	1966-12-1	1967-8	1970-11-28
		Mihama PS-2	Mikata-gun, Fukui Pref.	″	50.0	1967-12	1968-5-10	1968-12	1972-7-25
		Mihama PS-3	Mikata-gun, Fukui Pref.	″	82.6	1971-6	1972-3-13	1972-7	1976-12-1
		Takahama PS-1	Ohi-gun, Fukui Pref.	″	82.6	1969-5	1969-12-12	1970-4	1974-11-14
		Takahama PS-2	Ohi-gun, Fukui Pref.	″	82.6	1970-5	1970-11-25	1971-2	1975-11-14
		Takahama PS-3	Ohi-gun, Fukui Pref.	″	87.0	1978-3	1980-8-4	1980-11	1985-1-17
		Takahama PS-4	Ohi-gun, Fukui Pref.	″	87.0	1978-3	1980-8-4	1980-11	1985-6-5
		Ohi PS-1	Ohi-gun, Fukui Pref.	″	117.5	1970-10	1972-7-4	1972-10	1979-3-27
		Ohi PS-2	Ohi-gun, Fukui Pref.	″	117.5	1970-10	1972-7-4	1972-11	1979-12-5
		Ohi PS-3	Ohi-gun, Fukui Pref.	″	118.0	1985-1	1987-2-10	1987-3	1991-12-18
		Ohi Ps-4	Ohi-gun, Fukui Pref.	″	118.0	1985-1	1987-2-10	1987-3	1993-2-2
	The Chugoku Electric Power Co., Inc.	Shimane NPS-1	Yatou-gun, Shimane Pref.	BWR	46.0	1969-5	1969-11-13	1970-2	1974-3-29
		Shimane NPS-2	Yatou-gun, Shimane Pref.	″	82.0	1981-3	1983-9-22	1984-2	1989-2-10
	Shikoku Electric Power Co., Inc.	Ikata NPS-1	Nishiuwa-gun, Ehime Pref.	PWR	56.6	1972-2	1972-11-29	1973-6	1977-9-30
		Ikata NPS-2	Nishiuwa-gun, Ehime Pref.	″	56.6	1975-3	1977-3-30	1978-2	1982-3-19
		Ikata NPS-3	Nishiuwa-gun, Ehime Pref.	″	89.0	1983-3	1986-5-26	1986-11	1994-12-15
	Kyushu Electric Power Co., Inc.	Genkai NPS-1	Higashimatuura-gun, Saga Pref.	″	55.9	1970-5	1970-12-10	1971-3	1975-10-15
		Genkai NPS-2	Higashimatuura-gun, Saga Pref.	″	55.9	1974-7	1976-1-23	1976-5	1981-3-30
		Genkai NPS-3	Higashimatuura-gun, Saga Pref.	″	118.0	1982-9	1984-10-12	1985-3	1994-3-18
		Genkai NPS-4	Higashimatuura-gun, Saga Pref.	″	118.0	1982-9	1984-10-12	1985-3	1997-7-25
		Sendai NPS-1	Sendai city, Kagoshima Pref.	″	89.0	1976-3	1977-12-17	1978-11	1984-7-4
		Sendai NPS-2	Sendai city, Kagoshima Pref.	″	89.0	1978-7	1980-12-22	1981-3	1985-11-28
		Sum		(51 units)	4,491.7				
Under Construction	Tohoku Electric Power Co., Inc.	Onagawa NPS-3	Ojika-gun, Miyagi Pref.	BWR	82.5	1994-3	1996-4-12	1996-9	2002. 1. (Scheduled)
		Higashidori NPS-1	Shimokita-gun, Aomori Pref.	BWR	110.0	1996-7	1998-8-31	1998-12	2005. 7. (Scheduled)
	Chubu Electric Power Co., Inc.	Hamaoka NPS-5	Ogasa-gun, Shizuoka Pref.	ABWR	138.0	1997-3	1998-12-25	1999-3	2005. 1. (Scheduled)
		Sum		(3 units)	330.5				
In Planning Stage	Tohoku Electric Power Co., Inc.	Maki NPS-1	Nishiurahara-gun, Niigata Pref.	BWR	82.5	1981-11			2008. FY. (Scheduled)
	Hokuriku Electric Power Co., Inc.	Shika NPS-2	Hakui-gun, Ishikawa Pref.	ABWR	135.8	1997-3	1999-4-14		2006. 3. (Scheduled)
		Sum		(2 units)	218.3				
		Total		(56 units)	5,040.5				

Note: JAPC Tokai PS was stopped commercial operation at the end of 1997 FY.

(Reference)

In Operation	Japan Nuclear Cycle Development Institute	Fugen	Tsuruga City, Fukui Pref.	Proto Type ATR	16.5	–	1970-11-30	1971-8	1979-3-20
Under Construction		Monju	Tsuruga City, Fukui Pref.	Proto Type FBR	28.0	–	1983-5-27	1985-9	1994. 4. 5 (Critical)

Note: 1. The date of construction start is defined as the date of the approval of the 1st. construction permit.

3. In planning stage means that the plan was decided at the Electric Power Development Management Council (Denchoushin),but the 1st. Construction permit was not accepted.

2. The date for start of commercial operation, in principle, is in accordance with Power Supply Planning of 1999 FY.

[Source: Nuclear Power Generation Handbook ('99 Edition), Thermal and Nuclear Power Engineering Society]

24-3 Capacity of Nuclear Power Plants in the World (as of December 31, 1999)

(Unit: 10,000kW, Gross Electrical Output)

Ranking	Country or Region	In Operation		Under Construction		In Planning Stage		Total	
		Output	Units	Output	Units	Output	Units	Output	Units
1	U.S.A.	10,064.0	103					10,064.0	103
2	France	5,988.8	55	606.4	4			6,595.2	59
3	Japan	4,508.2	52	494.3	5	220.8	2	5,233.2	59
4	Germany	2,220.9	19					2,220.9	19
5	Russia	2,155.6	29	380.0	4	616.0	8	3,151.6	41
6	United Kingdom	1,417.3	35					1,417.3	35
7	Republic of Korea	1,371.6	16	400.0	4			1,771.6	20
8	Ukraine	1,281.8	14	500.0	5			1,781.8	19
9	Canada	1,061.5	14					1,061.5	14
10	Sweden	982.2	11					982.2	11
11	Spain	774.9	9					774.9	9
12	Belgium	599.5	7					599.5	7
13	Taiwan	514.4	6	270.0	2			784.4	8
14	Bulgaria	376.0	6					376.0	6
15	Switzerland	331.4	5					331.4	5
16	Lithuania	300.0	2					300.0	2
17	Finland	276.0	4					276.0	4
18	China	226.8	3	560.0	7	300.0	3	1,086.8	13
19	Slovak Republic	218.0	5	44.0	1	88.0	2	350.0	8
20	South Africa	193.0	2					193.0	2
21	India	184.0	10	88.0	4	588.0	12	860.0	26
22	Hungary	184.0	4					184.0	4
23	Czech Republic	176.0	4	194.4	2			370.4	6
24	Mexico	130.8	2					130.8	2
25	Argentina	100.5	2	74.5	1			175.0	3
26	Romania	70.6	1	264.0	4			334.6	5
27	Slovenia	66.4	1					66.4	1
28	Brazil	65.7	1	130.9	1	130.9	1	327.5	3
29	Netherlands	48.1	1					48.1	1
30	Armenia	40.8	1					40.8	1
31	Pakistan	13.7	1	32.5	1			46.2	2
32	Iran			229.3	2	152.0	4	381.3	6
33	Cuba			88.0	2			88.0	2
34	DPRK					200.0	2	200.0	2
35	Kazakhstan					192.0	3	192.0	3
36	Egypt					187.2	2	187.2	2
37	Israel					66.4	1	66.4	1
Total (data of the previous year)		35,942.5 (35,849.0)	425 (422)	4,356.3 (3,806.8)	49 (46)	2,741.3 (3,488.8)	40 (46)	43,040.1 (43,104.6)	514 (514)

Note: In principle, the countries are put in order of capacities of the nuclear power plants under operation.

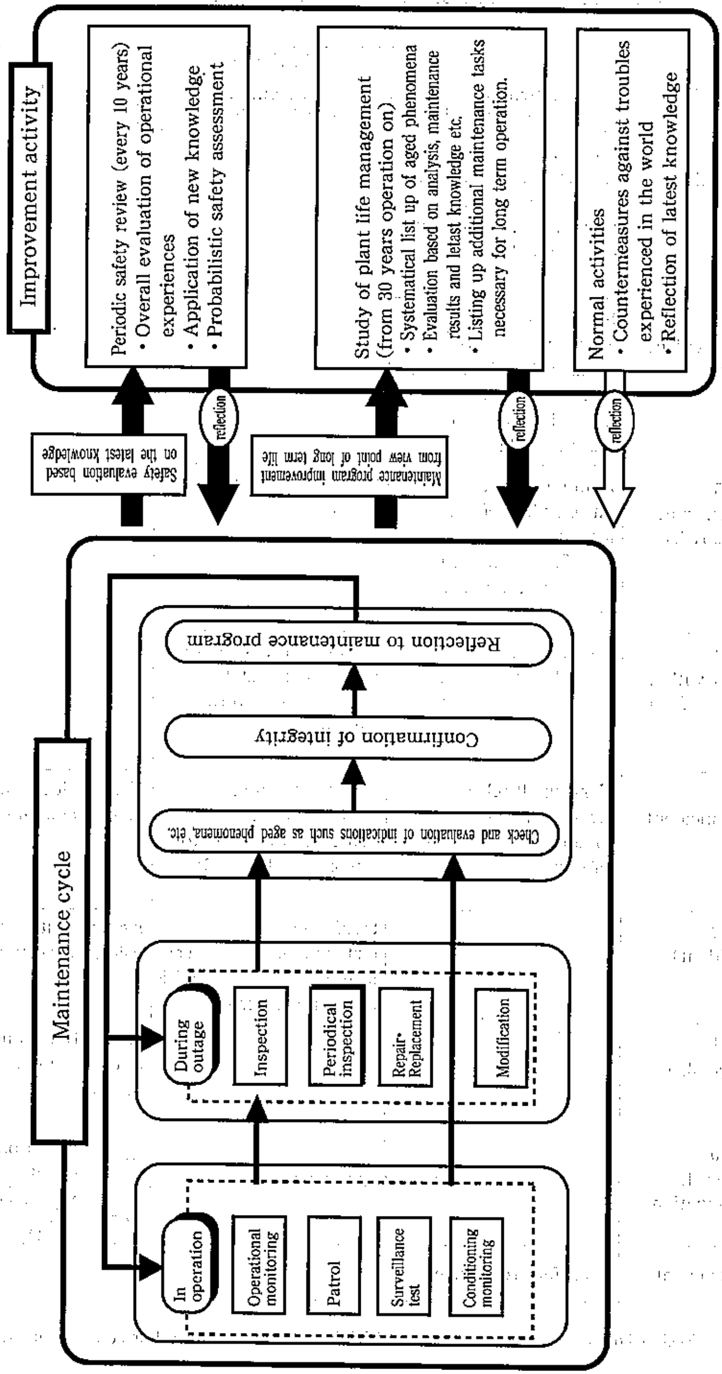
[Source: Trend of development for Nuclear Power Plants in the World, Japan Atomic Industrial Forum, Inc.]

24-4 The International Nuclear Event Scale

	Significance	Attribute		
		Attribute 1 Off-site impact	Attribute 2 On-site impact	Attribute 3 Defense in depth degradation
Accident	7 (Major accident)	Major release: external release of radioactive fission products about several ten thousand tera becquerel equivalent to I-131		
	6 (Serious accident)	Significant release: external release of radioactive fission products from several thousand to several ten thousand tera becquerel equivalent to I-131		
	5 (Accident with off-site risk)	Limited release: external release of radioactive fission products from several hundred to several thousand tera becquerel equivalent to I-131	Severe damage to reactor core	
	4 (Accident without significant off-site risk)	Minor release: personal exposure of public about several millisievert	Significant damage to reactor core/fatal exposure of a worker (about 5Gy)	
Incident	3 (Serious incident)	Very small release: personal exposure of public about one tenth of several millisievert	Severe spread of contamination/acute health effects to a worker (about 1Gy)	Near accident-no safety layers remaining
	2 (Incident)		Significant spread of contamination/over exposure beyond the legal limited value in a year on a worker	Incidents with significant failures in safety provisions
	1 (Anomaly)			Anomaly beyond the authorized operating regime
Below scale event deviation	0 (Below scale event deviation)	No safety significance		0＋ Effect on safety event 0－ No effect on safety event
Out of scale event		No safety relevance		

[Source: Nuclear Power Generation Handbook ('99 Edition), Thermal and Nuclear Power Engineering Society]

24-5 Outline of Maintenance Activity for Nuclear Power Plants



24-6 Regulatory Guide for Aseismic Design of Nuclear Power Reactor Facilities

(by Japan Nuclear Safety Commission, July 20, 1981)

(1) Basic philosophy
Each nuclear power reactor facility shall maintain its structural integrity against any conceivable seismic force likely to occur at the site so that no earthquake leads to a major accident. Moreover buildings and structures shall be, in principle, of rigid construction and the important buildings and structures shall be supported on bedrock.

(2) Classification of facilities based on classes of aseismic design
The nuclear power reactor facilities shall be classified into the following categories;

Classification	Explanation	Example	
		BWR	PWR
Class A Facility	Facilities containing radioactive material or related directly to equipment containing radioactive material and whose loss of function might lead to the release of radioactive material to the atmosphere, facilities required to prevent the occurrence of such accidents, and facilities required to mitigate the consequences resulting from the spread of radioactive material in the event of an accident and whose effectiveness in mitigating such consequence is significant. Among Class A facilities, the facilities belonging to special important facilities are designated Class As.	(i) Buildings and structures ∘ Reactor containment vessel ∘ Reactor building ∘ Spent fuel storage pool ∘ Reactor building gas treatment system outlet (ii) Equipment/piping system ∘ Vessel, piping and other equipments constituting the reactor coolant pressure boundaries ∘ Control rods/control rod drive mechanism and hydraulic system ∘ Residual heat removal system ∘ Emergency core cooling system	(i) Buildings and structures ∘ Same as left ∘ Spent fuel pit ∘ Containment exhaust stack (ii) Equipment/piping system ∘ Same as left ∘ Control rod culster and control rod cluster drive machine ∘ Residual heat removal system ∘ Safety injection system
Class B Facility	Same as above, but its influence and effect are small.	(i) Buildings and structures ∘ Radwaste building (ii) Equipment/piping system ∘ Main steam and feedwater system ∘ Radwaste treatment facilities ∘ Main turbine	(i) Buildings and structures ∘ Same as left (ii) Equipment/piping system ∘ Chemical and volume control system (letdown and excess letdown systems) ∘ Same as left
Class C Facility	Facilities except for class A and B ones. This facility is only required to have the same safety properties as those of general industrial facilities.	(i) Buildings and structures ∘ General buildings and structures (ii) Equipment/piping system ∘ New fuel storage facilities ∘ Turbine facilities	(i) Buildings and structures ∘ Same as left (ii) Equipment/piping system ∘ Same as left

(3) Earthquake motion to be considered for aseismic design

(a) Basic design earthquake ground motions S1: According to the historical evidence, the earthquakes to be taken into account, which would affect the site and the surrounding region in the past are likely to occur again in the near future and can be expected to have the same effect on the site and the surrounding region, and which would have the greatest effect on the site and the surrounding region among those earthquakes that might be induced by highly active faults in the near future.

(b) Basic design earthquake ground motions S2: Assumed to occur the earthquake whose intensity is higher than that of the basic design earthquake ground motions S1 from a seismological standpoint, and should be reviewed from an engineering standpoint. In addition, a shallow-focus shall be considered.

(4) Design earthquake forces

In determining the seismic force for each facilities, values shall be applied as shown in the Table below.

The value in parentheses ( ) is for equipment and piping.

Direction / Classification based on the aseismic design	Horizontal	Vertical
As	S_2	$1/2\,S_2$
A	S_1, $3C_I$ $(3.6C_I)$	$1/2\,S_1$, Cv (1.2Cv)
B	$1.5C_I$ $(1.8C_I)$	——
C	C_I $(1.2C_I)$	——

Note : (1) For Class A facilities, both horizontal and vertical seismic forces from the dynamic analysis should be combined concurrently and in the most adverse fashion, and both horizontal and vertical seismic coefficients based on the static method should be combined concurrently and in the most adverse fashion.

(2) For buildings and structures, horizontal seismic forces shall be determined from horizontal seismic coefficients, and vertical seismic forces shall be determined from vertical seismic coefficients.

(3) For equipment and piping, horizontal seismic forces shall be determined from horizontal seismic coefficients at the location where these are installed.

(4) S_2: Basic earthquake ground motion S_2, S_1: Basic earthquake ground motion S_1.

(5) C_1: Horizontal seismic coefficients based on the seismic coefficients given in the Building Standard Law.

(6) Cv: Vertical seismic coefficient obtained by the static method.

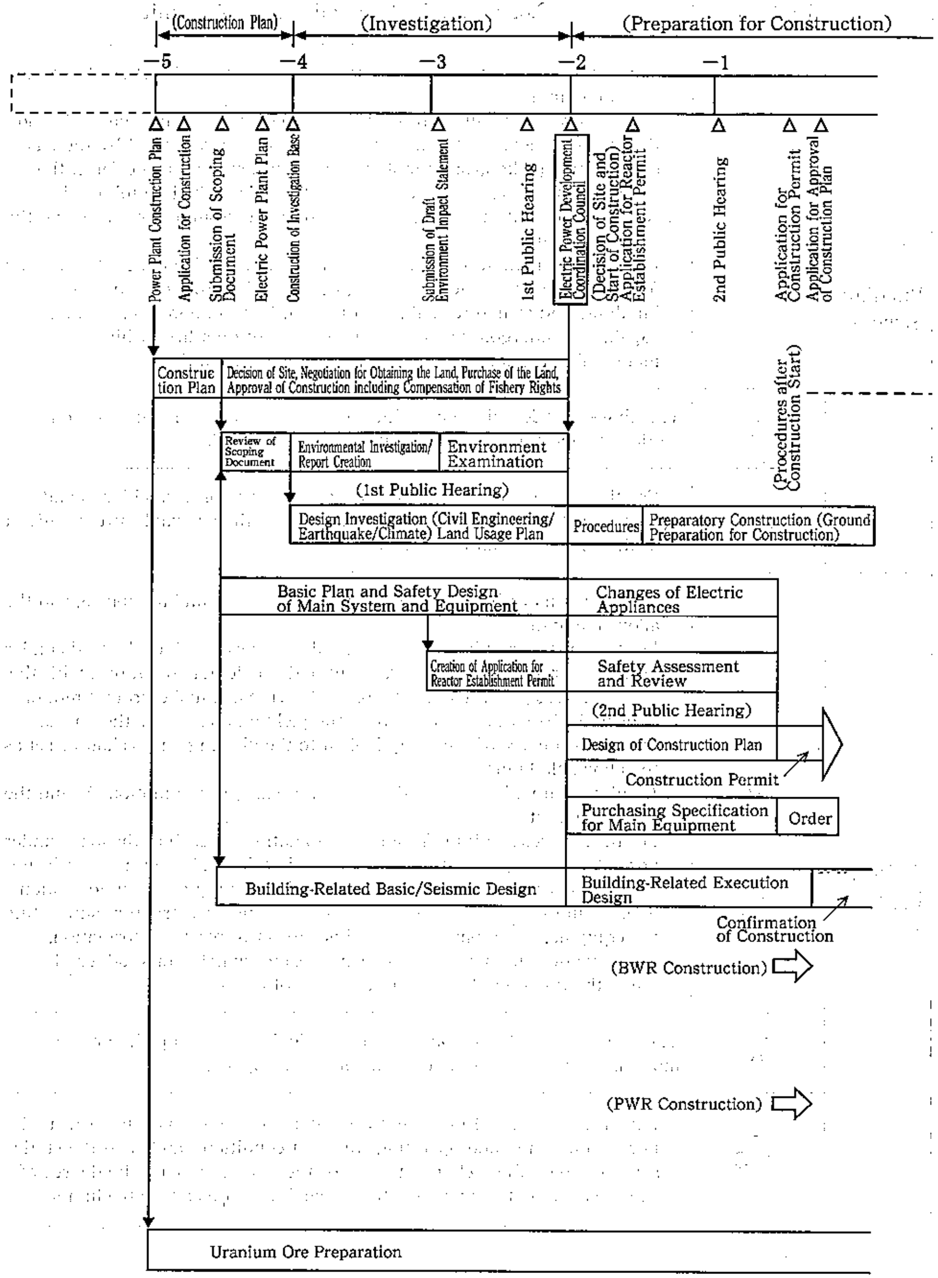
(7) $1/2S_2$: Vertical seismic coefficient shall be obtained by multiplying the maximum acceleration amplitude of the basic earthquake ground motion S_2 by a half(1/2).

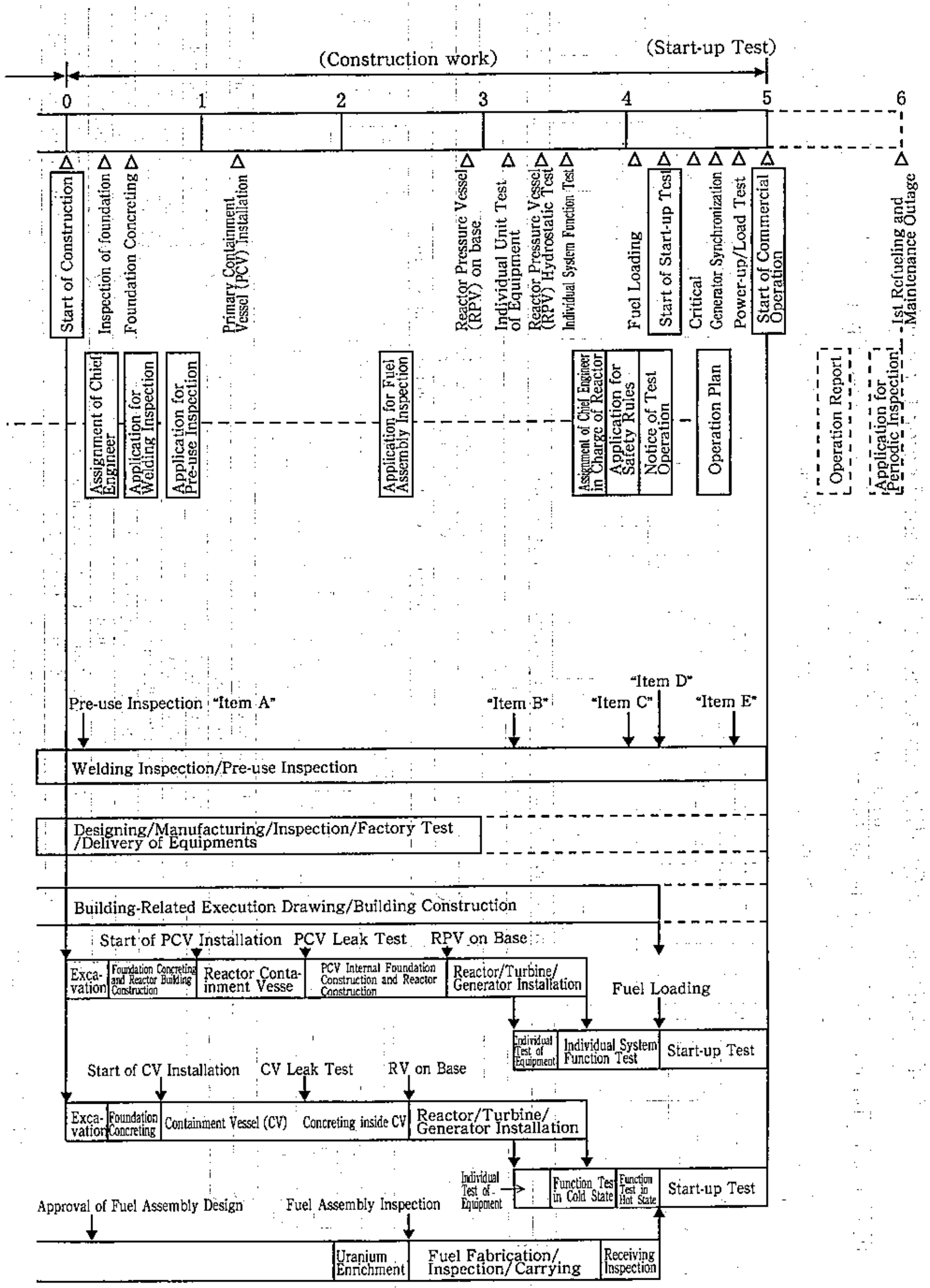
(8) $1/2S_1$: Vertical seismic coefficient shall be obtained by multiplying the maximum acceleration amplitude of the basic earthquake ground motion S_1 by a half(1/2).

(5) Load combination and allowable limit

	Classification based on the aseismic design	Load Combination and Allowable Limit
Building/ Structure	As	(i) Combinations with the basic design earthquake ground motions S_1 and the allowable limits For the stresses resulting from the combination of the normal loads and the operating loads with either the seismic forces generated by the basic design earthquake ground motions S1 or with static seismic force, the allowable stresses given in the code and standard shall be followed. (ii) Combination with the basic design earthquake ground motions S_2 and the allowable limits For the combinations of normal loads and operating loads with the seismic forces generated by the basic design earthquake ground motion S_2, buildings and structures subjected to such load combinations shall be capable of undergoing deformation (margin of ductility) while maintaining a safety margin to their ultimate strength.
	A	The above (i) "Combinations with the basic design earthquake ground motions S_1 and the allowable limits" shall be applied.
	B. C	For the stresses resulting from the combinations of normal loads and operating loads with the static seismic forces, the allowable stresses given in the above (i) shall be applied.
Equipment/ Piping system	As	(i) Combinations with the basic design earthquake ground motions S_1 and the allowable limits For the stresses resulting from the combinations of each of the loads under normal operating, operating transient and accidental conditions, with the seismic forces generated by the basic design earthquake ground motions S_1 or with the static seismic forces, the yielding stresses or the stresses having the degree of safety equivalent to the yielding stress shall be set as the allowable limits. (ii) Combination with the basic design earthquake ground motions S_2 and the allowable limits For the stresses resulting from the combinations of each of the loads under normal operating, operating transient and accidental conditions with the seismic forces generated by the basic design earthquake ground motion S_2, even in the case where a portion of a building or a structure supporting the equipment or piping yields and is subject to plastic deformation, excessive deformation, cracking, rupture, etc., which would adversely affect the function of the facilities shall not occur.
	A	The above (i) "Combinations with the basic design earthquake ground motions S_1 and the allowable limits" shall be applied.
	B. C	For the stresses resulting from the combinations of each of the loads under normal operating and operating transient conditions, and with the static seismic forces, the yielding stresses or the stresses having the degree of safety equivalent to yielding stresses shall be set as allowable limits.

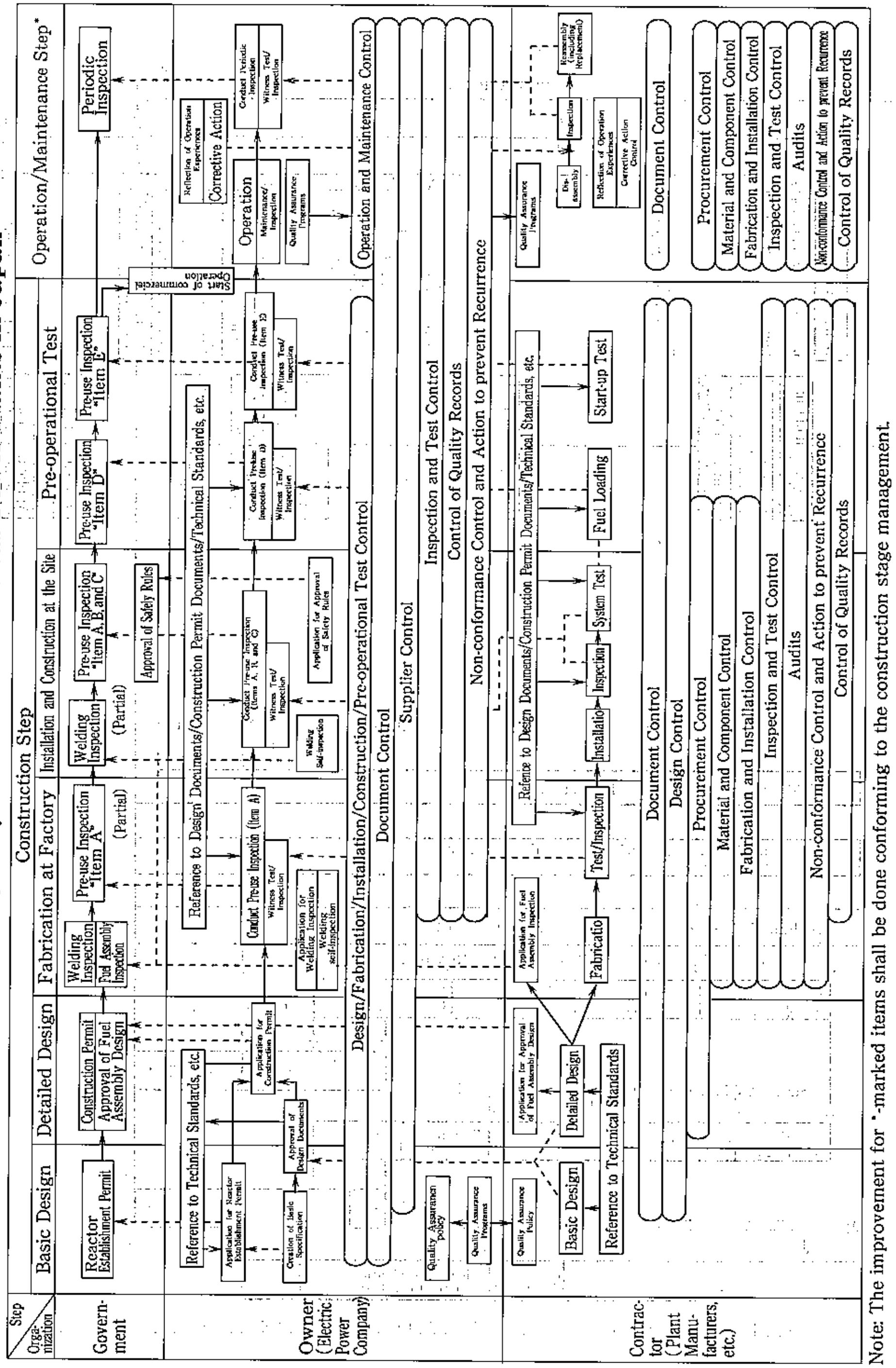
24-7 Constructing Schedule of a Nuclear Power Plant





[Source: Planning/Designing and Constructing a Nuclear Power Plant by Iwao Tokumitsu (1979), Denki Shoin, Revised it partially]

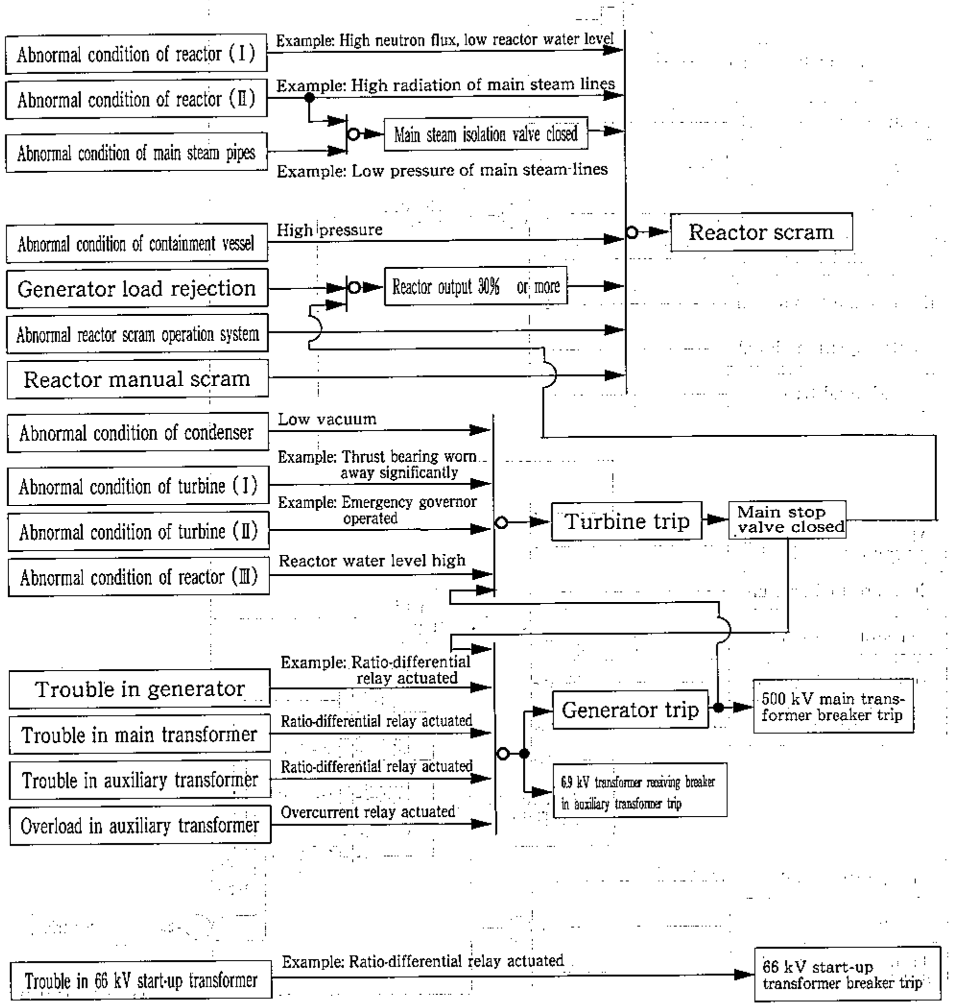
24-8 Outline for Quality Assurance of Nuclear Power Plants in Japan



Note: The improvement for *-marked items shall be done conforming to the construction stage management.

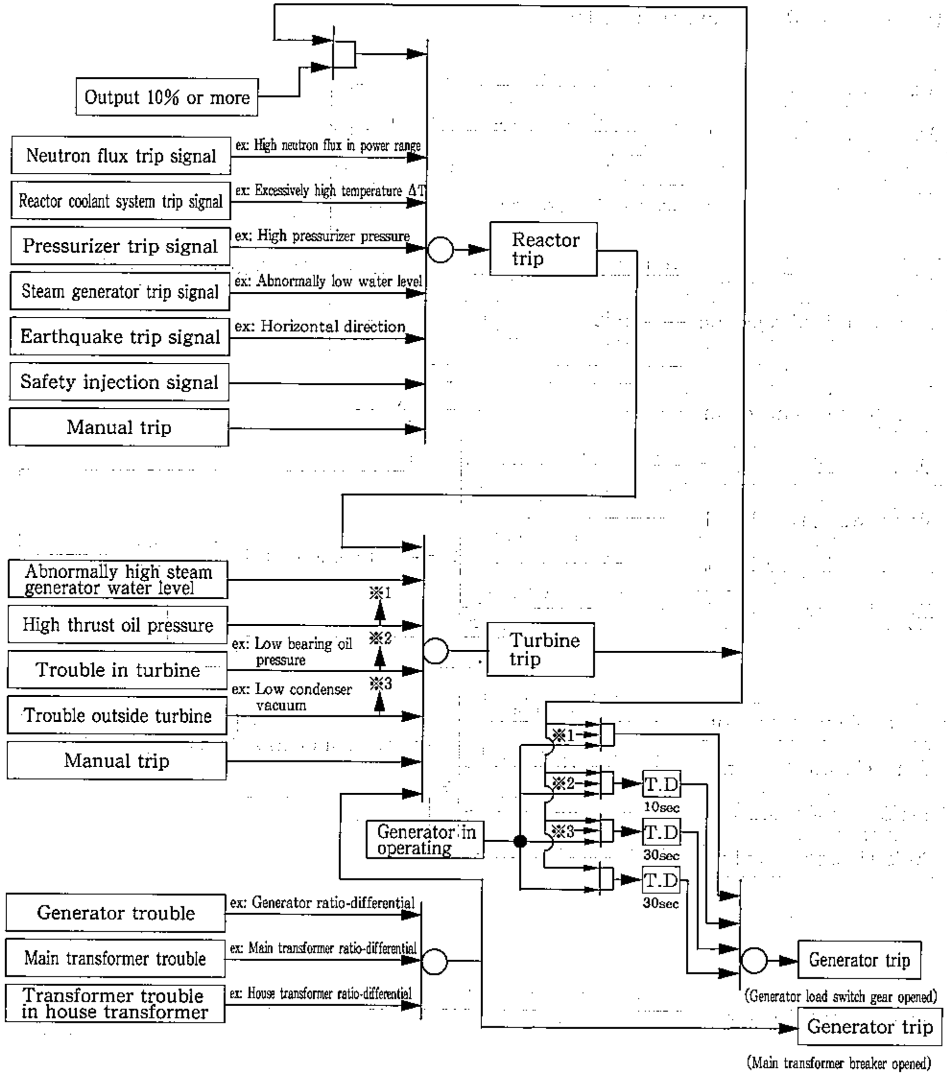
24-9 Overall Interlock Diagram for Light Water Reactors

(1) Typical BWR plant overall interlock



[Source: Nuclear Power Generation Handbook ('99 Edition) edited by the Nuclear Power Generation Section in the Public-Service Undertaking Dept., Agency of Natural Resource and Energy, Ministry of International Trade and Industry, Denryoku Shinpo-Sha]

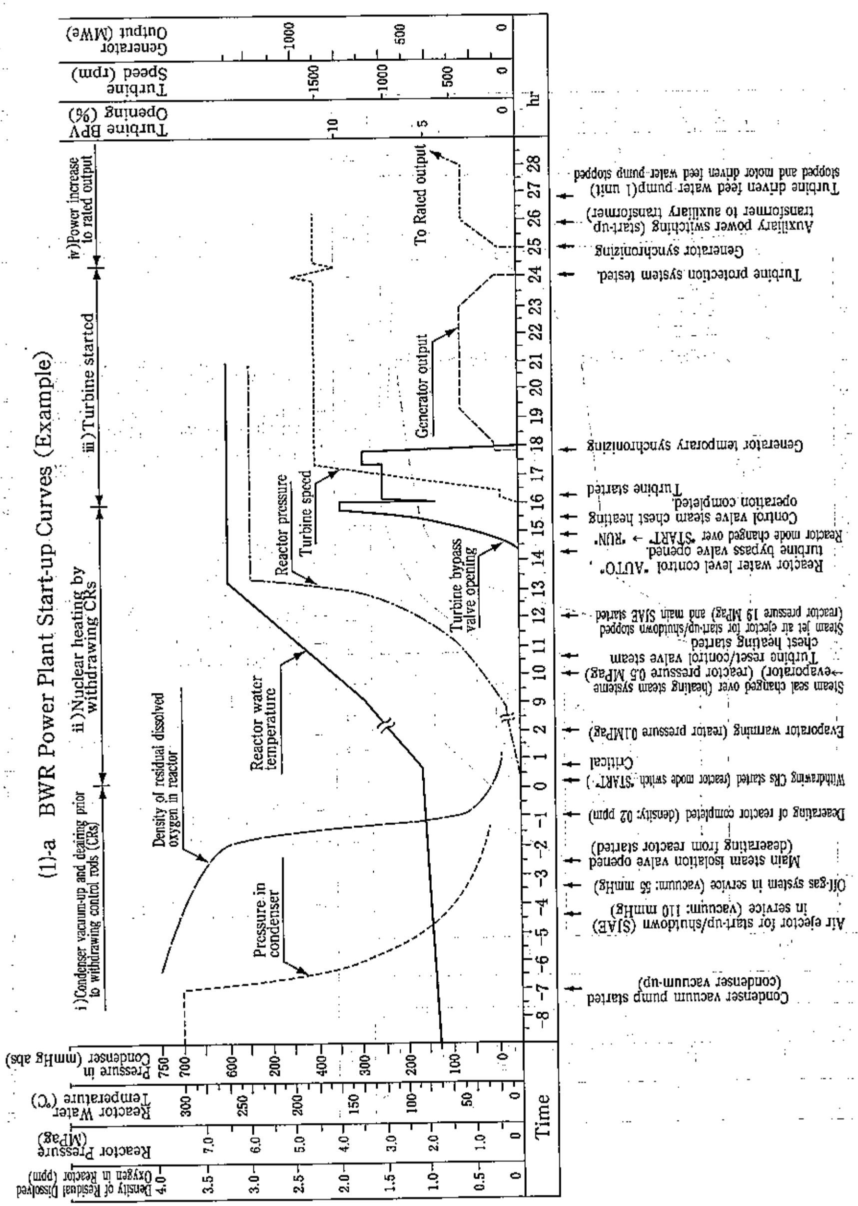
(2) PWR plant colligated interlock (example)



[Source: Nuclear Power Generation Handbook ('99 Edition) edited by the Nuclear Power Generation Section in the Public-Service Undertaking Dept., Agency of Natural Resource and Energy, Ministry of International Trade and Industry, Denryoku Shinpo-Sha]

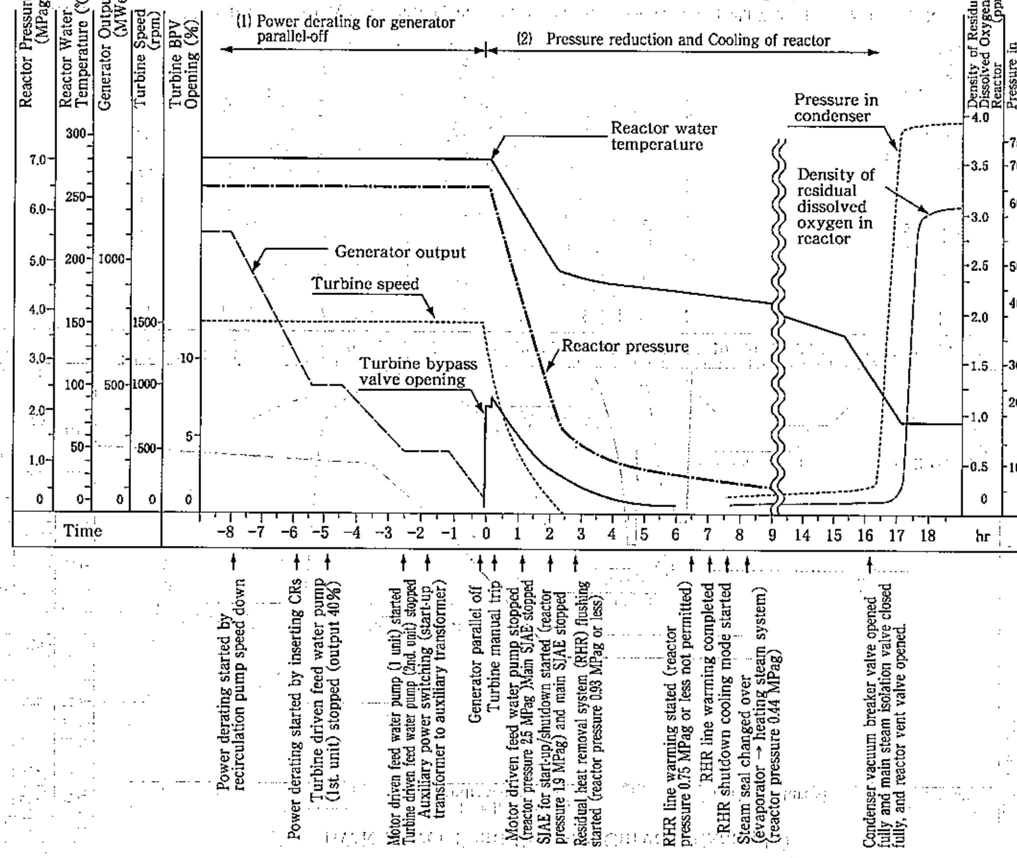
24-10 Light Water Reactor Start-up/Shutdown Curves

(1)-a BWR Power Plant Start-up Curves (Example)



[Source: "Practical Work Text" (Plant System) edited by the Editing Committee, "Overview of Light Water Reactor (1992)," Nuclear Safety Research Association.]

(1)-b BWR Power Plant Shutdown Curves (Example)



[Source: "Practical Work Text" (Plant System) edited by the Editing Committee, "Overview of Light Water Reactor (1992)," Nuclear Power Safety Research Association.]

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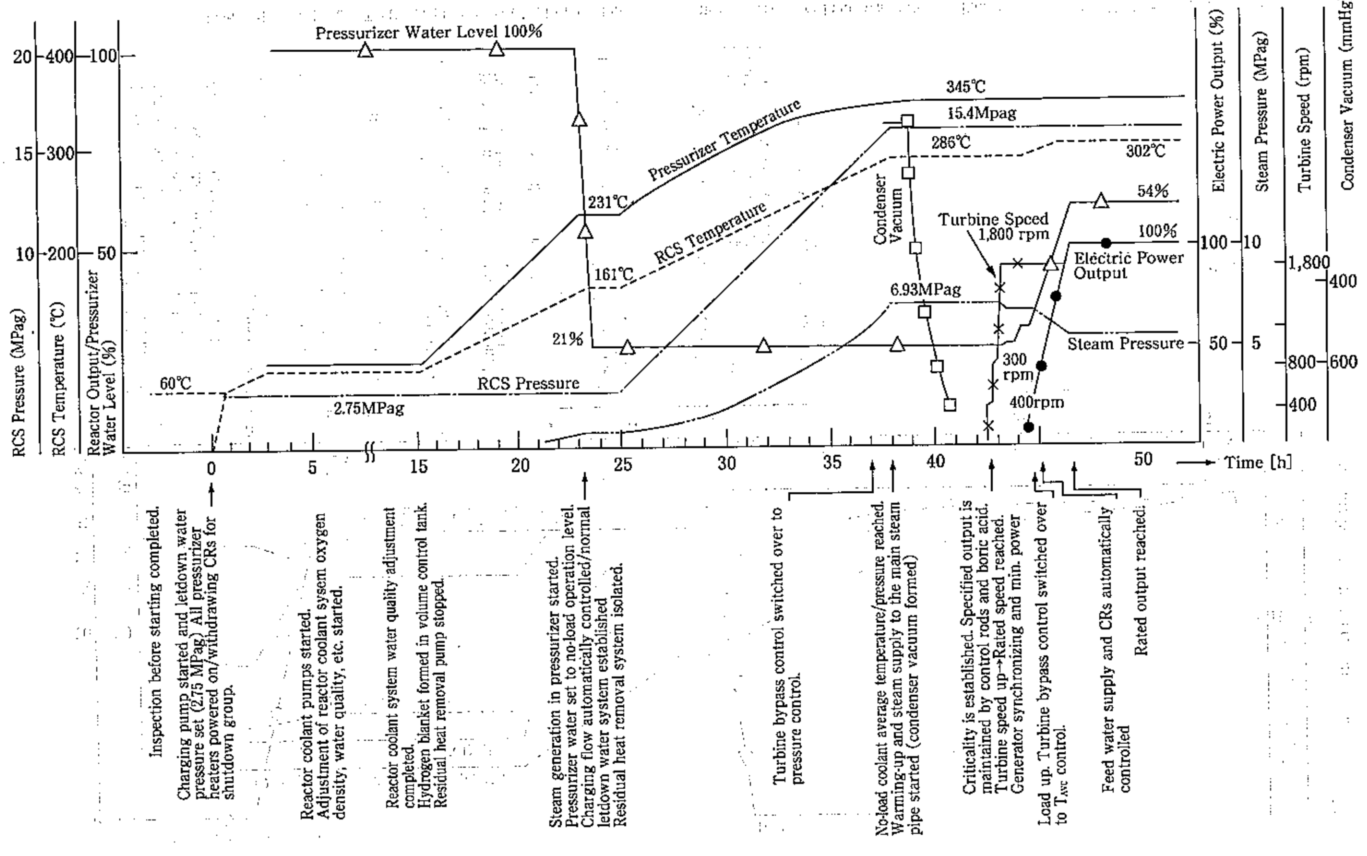
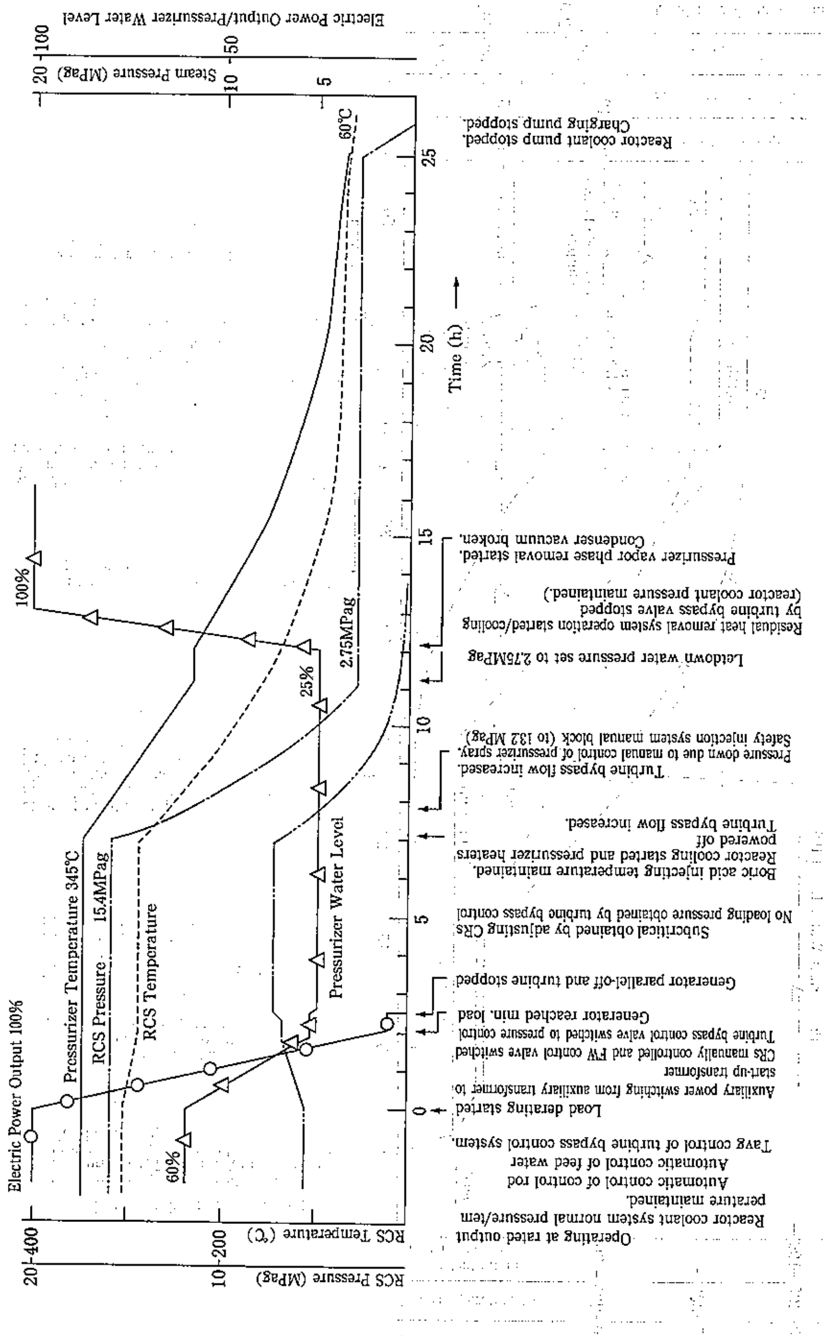
(2)-a PWR Power Plant Start-up Curves (Example)



[Source: "Practical Work Text" (Plant System) edited by the Editing Committee, "Overview of Light Water Reactor Power Plants (1992)," Nuclear Safety Research Association.]

(2)-b PWR Power Plant Shutdown Curve (Example)



[Source: "Practical Work Text" (Plant System) edited by the Editing Committee, "Overview of Light Water Reactor Power Plants (1992)," Nuclear Safety Research Association.]

24-11 Light Water Reactor Surveillance Test

Surveillance test is executed to confirm periodically that important systems and equipments, such as engineered safety systems are capable of performing their required functions.

(1) Periodical inspection during power operation for typical BWR plants

Test Item	Cycle	Test Contents
Diesel generator manual start-up	Once/month	The diesel generator is started up manually from the main control room to confirm the performance.
Standby gas treatment system manual start-up	Once/month	The system is started up manually from the main control room to confirm the motion of each related auto actuated valve and the system performance.
Core spray system		
(1) Pump manual start-up	Once/month	The pump is started up manually from the main control room to confirm the performance.
(2) Motor operated valve operation	Once/month	The motor operated valve is opened and closed manually from the main control room to confirm the motion.
Residual heat removal system		
(1) Pump manual start-up	Once/month	The pump is started up manually from the main control room to confirm the performance.
(2) Motor operated valve operation	Once/month	The motor operated valve is opened and closed manually from the main control room to confirm the motion.
High pressure coolant injection system		
(1) Pump manual start-up	Once/month	The pump is started up manually from the main control room to confirm the performance.
(2) Motor operated valve operation	Once/month	The motor operated valve is opened and closed manually from the main control room to confirm the motion.

(2) Periodical inspection during power operation for typical PWR plants

Test Item	Cycle	Test Contents
Diesel generator manual start-up	Once/month	The diesel generator is started up manually from the main control room to confirm the performance.
Safety injection system		
(1) High pressure injection pump manual start-up	Once/month	The pump is started up manually from the main control room to confirm the performance.
(2) Motor operated valve operation		The motor operated valve is opened and closed manually from the main control room to confirm the motion.
Residual heat removal pump manual start-up	Once/month	The pump is started up manually from the main control room to confirm the performance.
Containment spray system		
(1) Pump manual start-up	Once/month	The pump is started up manually from the main control room to confirm the performance.
(2) Motor operated valve operation		The motor operated valve is opened and closed manually from the main control room to confirm the motion.
Annulus air recirculation fan manual start-up	Once/month	The fan is started up manually from the main control room to confirm the performance.

[Source: Nuclear Power Generation Handbook ('99 Edition) edited by the Nuclear Power Generation Section in the Public-Service Undertaking Dept., Agency of Natural Resource and Energy, the Ministry of International Trade and Industry, Denryoku Shinpo-Sha]

24-12 Transition of Average Periodical Inspection Term (except GCR plant)

Fiscal year	1981	82	83	84	85	86	87	88	89	90
Average number of days (number of months)	175 (5.8)	150 (5.0)	146 (4.9)	143 (4.8)	139 (4.6)	134 (4.5)	118 (3.9)	135 (4.5)	155 (5.5)	177 (5.9)

Fiscal year	1991	92	93	94	95	96	97	98
Average number of days (number of months)	143 (4.8)	138 (4.6)	145 (4.8)	137 (4.6)	116 (3.9)	131 (4.4)	108 (3.6)	103 (3.4)

Note: 1. Average number of days: Averaging of periodical inspection term (by the end of Integrated Performance Test) of each plants which completed the inspection within the fiscal year.
2. Mihama-1 is not subject to count in the data before 1993 FY.
3. Mihama-2 is not subject to count in the data of 1994 FY.
4. (number of months) = (days/30 days)

[Source: Nuclear Power Generation Handbook ('98 Edition), Thermal and Nuclear Power Engineering Society]

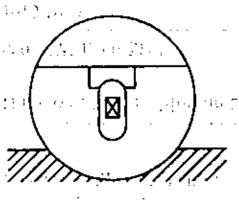
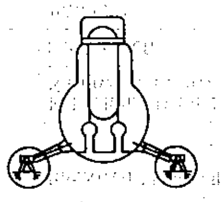
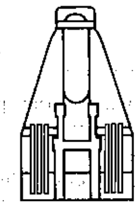
24-13 Improvement and Standardization of Light Water Reactors

		1st Phase	2nd Phase	3rd Phase
Execution Period		1975-1977	1978-1980	1981-1985
Major Achievement (Main Contents for the 3rd Plan)	Reliability and Availability Improvement	Capacity factor: About 70% [Adoption of SCC-resistant materials, improvement of steam generator, etc.]	Capacity factor: About 75% [Improvements of control rod drive mechanism and fuel, etc.]	(1) Advanced light water reactor development/standardization A-BWA: Adoption of internal pump, advanced control rod drive mechanism, high performance fuel, etc. A-PWR: Adoption of large core, high performance fuel, etc. (2) Improvement of conventional light water reactors Improvement of periodical inspection methods (mainly for the turbine system), radwaste treatment system, construction technology, etc. (3) Standardization program Standardization of seismic design, items relating to licensing radwaste treatment methods, and establishment of standard plant basic specifications
	Shortening of Periodical Inspection Period	Number of days for periodical inspection: About 85 days [Conventional plant: 90 to 100 days] [Scale up of containment vessel, improvement of refueling machine, etc.]	Number of days for periodical inspection: About 70 days [Adoption of control rod drive mechanism automatic exchanger, improvement of fuel inspection system, etc.]	
	Reduction of Radiation Exposure on Workers	About 75% of conventional plants [Prevention of crud generation and removal of crud, automation of steam generator tubes inspection]	About 50% of conventional plants [Extension of automated ISI (in-service inspection) range, automation of water quality analyzer, etc.]	
Typical Plant (Example)	BWR	Fukushima Daini 2 (in operation), Hamaoka 3 (in operation)	Kashiwazaki Kariwa 2 (in operation), Kashiwazaki Kariwa 5 (in operation)	ABWR: Kashiwazaki Kariwa 6, 7 (in operation) APWR: Not determined
	PWR	Sendai 1 (in operation), Tsuruga 2 (in operation)	Genkai 3 (in operation) Genkai 4 (in operation)	

[Source : "Atomic Energy Pocket Book" 1998/1999 Edition, Japan Atomic Industrial Forum, Inc.]

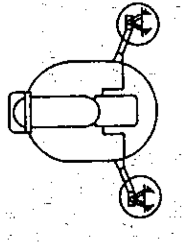
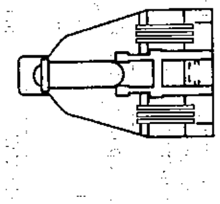
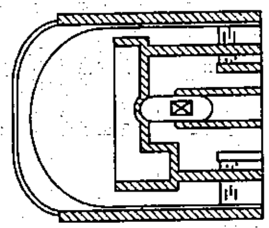
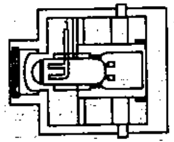
24-14 History of Light Water Reactor Plants

(1) History of BWR (Part 1)

Type	BWR 1	BWR 2	BWR 3 (65PL)	BWR 4 (67PL)	BWR 5
	Prototype BWR	Old Type BWR	Old Type BWR	BWR	
Characteristics	Double cycle, Natural recirculation or forced recirculation Dry type spherical PCV	Direct single cycle, Forced recirculation Pressure suppression type PCV	Jet pump adopted	Core power density and fuel burn-up improved Design standardized	Recirculation system and emergency core cooling system improved. MARK-II PCV
Typical Plant	Dresden power plant 1 (USA), Senn power plant (Italy), KRB power plant (Germany)	Oyster Greek power plant (USA), Tsuruga 1	Dresden power plant 2 (USA), Fukushima Daiichi 1, Shimane 1	Browns Ferry power plant (USA), Fukushima Daiichi 2-5, Hamaoka 1 and 2, Onagawa	Zimmer power plant (USA), Fukushima Daiichi 6, Tokai 2, Fukushima Daini 1
Electric Output	160 MW-250 MW	350 MW-640 MW	460 MW-810 MW	540 MV-1,100 MW	660 MW-1,100 MW
Date of Design	1955	1963	1965	1966-1967	1969
Features	• Completed as a large demonstration reactor. • Demonstrated double cycle. • Operation experience accumulated • Fuel irradiation experience accumulated • Operation of various equipments improved. • In-vessel steam-water separator.	• Forced recirculation and direct single cycle adopted • Drywell: torus type PCV adopted • Large capacity realized. • Economy improved.	• In-vessel jet pump adopted • Emergency core cooling system improved.	• Core power density increased. • Fuel burn-up improved • System design standardized. 500 MW class, 800 MW class, and 1,100 MW class	• Recirculation flow control valve adopted (*). • Emergency core cooling system improved. • MARK-II (over-under type) PCV adopted. • Safety relief valve adopted.
PCV model	Spherical dry type	MARK-I pressure suppression type (torus type)	Same as left	Same as left	MARK-II
			Same as left	Same as left	

(*) : The recirculation flow control valve is not adopted for the reactors in Fukushima Daiichi 6 and Fukushima Daini 1.
[Source: "Atomic Energy Pocket Book" supervised by the Nuclear Power Bureau of the Science and Technology Agency (1992) , Japan Atomic Industrial Forum Inc.]

(Continued) (Part 2)

Type	BWR 5 (Improvement and Standardization)	BWR 5 (Improvement and Standardization)	BWR 6 BWR	A－BWR (Improvement and Standardization)
Characteristics	Improved MARK-Ⅰ PCV	Improved MARK-Ⅱ PCV	8×8 fuel adopted and core power density improved. MARK-Ⅲ PCV	Internal pump and RCCV adopted.
Typical Plant	Hamaoka 3 and Shimane 2	Fukushima Daini 2-4 and Kashiwazaki Kariwa 2 and 5	Grand Gulf power plant (USA)	Kashiwazaki Kariwa 6 and 7
Electric Output	820 MW-1,100 MW	Same as left	990 MW-1,300 MW	1,300 MW class
Date of Design	1975-1980	1975-1980	1972	1987
Features	• Improved PCV adopted • Reduction of radiation exposure on workers	• Improved PCV adopted. • Various improvements including reduction of radiation exposure on workers.	• 8×8 small size fuel rod adopted. • Thin type control rod adopted. • Core power density increased. • Jet pump improved. • MARK-Ⅲ PCV adopted. • Turbine building design improved. • Reactor service building built. • Fuel storage pool building constructed individually.	• Internal pump adopted. • Advanced control rod drive mechanism adopted. • Reinforced concrete containment vessel adopted • Other various improvement including reduction of radiation exposure to workers.
	Improved MARK-Ⅰ	Improved MARK-Ⅱ	MARK-Ⅲ	Reinforced concrete containment vessel (RCCV)
PCV model				

[Source: "Atomic Energy Pocket Book" Supervised by the Nuclear Power Bureau of Science and Technology Agency (1992), Japan Atomic Industrial Forum, Inc.]

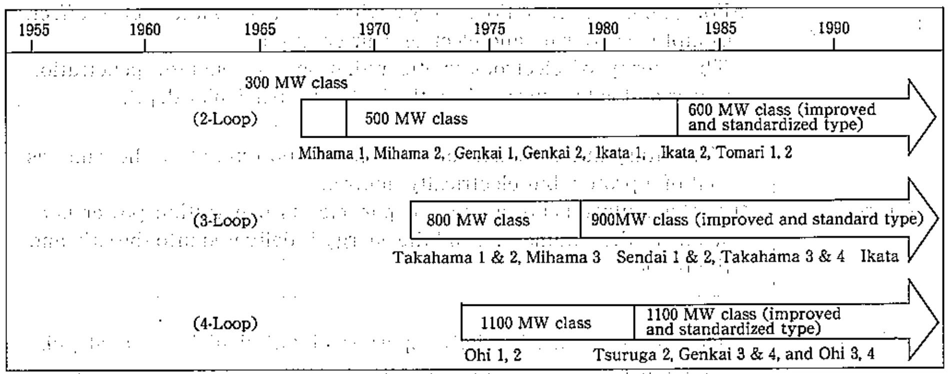
(2) History of PWR

(a) Basic specifications

Number of loops		2		3		4	
Electric power (MWe)		340	500～579	826	870～890	1,175	1,160 ～1,180	1,538
Reactor thermal power (MWt)		1,031	1,456 ～1,650	2,440	2,660	3,423	3,423	4,466
Fuel assembly	Type	14×14	14×14	15×15	17×17	17×17	17×17	17×17 improved type
	Loaded quantity	121	121	157	157	193	193	257
Average linear heat rate (kW/m)		15.4	18.7～20.4	20.2	17.1	17.9	17.9	17.6
Power density (kW/l)		71	83～95	92	100	105	105	103
Steam generator		35F type	46F type, 51M type, 51F type, 52F type, 54F type	52F type, 54F type	51M type, 51F type	52FA type, 54FA type	52F type	70F-1 type
Reactor coolant pump		63 type	93A type, 100D type	93A type	93A type, 93A-1 type	93A type	93A-1 type	100A type
Containment vessel		Steel structure semi-double type	Steel structure semi-double type Steel structure double type	Steel structure semi-double type Steel structure double type	Steel structure semi-double type	Ice condenser Ⅱ type	PCCV	PCCV
Turbine generator		TC2F44	TC4F40 TC4F44	TC6F40	TC6F40 TC4F52	TC6F44	TC6F44	TC6F54
Application plant name		Mihama 1	Mihama 2 Genkai 1 Genkai 2 Ikata 1 Ikata 2 Tomari 1 Tomari 2	Takahama 1 Takahama 2 Mihama 3	Sendai 1 Sendai 2 Takahama 3 Takahama 4 Ikata 3	Ohi 1 Ohi 2	Tsuruga 2 Ohi 3 Ohi 4 Genkai 3 Genkai 4	Improved type PWR

Note: PCCV (prestressed concrete containment vessel)

(b) History of plant construction



[Reference: Atomic Energy Pocket Book supervised by the Nuclear Power Bureau of the Science and Technology Agency (1992)]

24-15 Types of Radiation

Type	Properties
Alpha particle	● A positively charged particle identical to the nucleus of a helium atom and composed of two protons and two neutrons. ● It hardly penetrates the material, and will be absorbed completely within a few layers of paper or at the skin surface, producing ions. ● It will not become so great problem in the case of external exposure because of low penetration, but internal exposure can cause as a significant damage.
Beta particle or electron	● A negative electron emitted from a nucleus during beta decay. The penetration power is more than 100 times of alpha ray, and the range reaches some millimeters depth beneath the tissue. ● Capability of ionization of beta ray is weaker than that of alpha ray. Generally, beta ray loses energy by ionizing and exciting the substances directly. ● As the penetration power is greater than alpha ray, the skin dose should be noted.
Positron	● An electron with positive charge. ● The average life of positron is 10^{-9}sec. The annihilation of a positron-electron pair results in the production of two photons, each of 0.5 MeV energy. These photons have properties identical with those of gamma rays, and it is necessary to consider the annihilation from the radiation protection point of view.
Gamma ray	● Extremely short-wavelength electromagnetic wave emitted from the nucleus, equivalent to high energy X-rays. ● For gamma ray radiation, energy will be lost by photoelectric effect, Compton scattering and electron-pair creation. ● The energy of electromagnetic radiation has enough penetration power and is transferred into the body at a particular depth.
Neutron	● Elementary nuclear particle with a mass approximately the same as that of a proton, but electrically neutral. ● As the neutron is not a charged particle, its penetration power is as strong as the gamma ray, and the energy is delivered into the skin and the tissue.

References: New Nuclear Handbook, editorially supervised by Chuichi Asada, et al, published, by Ohmsha, Ltd. Isotope Handbook (1984), edited by the Japan Radioisotope Association, published by Maruzen, Co., Ltd.

24-16 Unit of Radioactivity

	International System of Unit (SI)			Conventional System of Unit		
Radioactivity (disintegration rate)	Becquerel	Bq	This means radioactivity with which one nucleus is disintegrated per second 1 Bq ≈ 2.703×10^{-11}Ci 1 Ci = 3.7×10^{10}Bq	Curie	Ci	This means radioactivity with which 3.7×10^{10} nucleuses are disintegrated per second
Exposure dose	Coulomb per kilogram	C/kg	This means the dose exposure that the charge of either electron or ion that is to be ionized in the air becomes 1 coulomb (C). 1 C/kg ≈ 3.876×10^{3}R 1 R = 2.58×10^{-4}C/kg	Roentgen	(1) (3) R	This means the dose exposure that allows to form either positive or negative charge of 1 esu in the dry air per 1 cc (0.001293g) at 0℃ and one barometric pressure
Absorbed dose	Gray	Gy	This means the absorbed dose that allows the avarage energy to be provided for a 1 kg mass substance through ionizing radiation becomes 1 joule. 1 Gy = 1 J/kg = 100rad 1 rad = 10^{-2}Gy	Rad	(1) (3) rad	This means the absorbed dose when 100 erg radiation energy is absorbed per gram of absorbing material.
Dose equivalent	Sievert	Sv	(Sv) = (Gy) × (Radiation quality coefficient Q) × (Correction coefficient N) 1 Sv = 1J/kg = 100rem (for gamma rays) 1 rem = 10^{-2}Sv	Rem	(2) (3) rem	This is obtained by multiplying absorbed dose by coefficients for which the biological effect is taken into consideration.

Reference: Nuclear Power Handbook (New Edition) supervised by Chuichi Asada and others, Ohm Corporation, and Radioactivity Measurement Handbook (1982) translated by Itsuro Kimura and Hidefumi Sakai, Nikkan Kogyo Shinbun-sha.

Notes: (1) 1R X-ray or γ-ray that passes through one gram of soft tissue of a human body provides about 98 erg due to an ionizing action. Therefore 1Ris is equal to about 1rad.

(2) The relationship between rad and rem differs among radioactivity types and energies, but 1 rad absorbed dose is almost equal to the following.

X-rays, γ-ray, and β-ray	1 rem
α-ray	20 rem
Thermal neutron rays	2.3 rem

(3) Those dose rates are represented as rad/h, R/h, rem/h, etc.

24-17 Permissible Dose of Radioactivity and Permissible Density of Radioactive Materials

["The Laws on Prevention of Radiation Injury by Radio-Isotope, etc." Revised in No.21 Notice issued by the Science and Technology Agency on May 18, 1988]

The dose limits shall not exceeded the following limits.

After Revision	Before Revision	Remarks
(1) Radiation worker ① whole-body: Effective dose equivalent limit: 50 mSv/year	(1) Radiation worker ① whole-body: Max permissible dose exposure: 3 rem/3 months Max. permissible integrated dose exposure: D=5 (N−18)	● One year beginning on April 1 ● The integrated dose exposure regulations have been abolished.
② The equivalent dose limit to an organ or tissue: The crystalline lens of the eye 150mSv/year An equivalent dose to the extremities or the skin other than the lens 500 mSv/year Abdomen of fecundity women (except for pregnancy period) 13 mSv/3 months Abdomen of pregnant women (between diagnosis of pregnancy and delivery) 10 mSv	② Each part of body: Only skin: 8 rem/3 months Hands, Arms, legs, and leg joints only: 20 rem/3 months Abdomen of women with possibility of pregnancy: 1.3 rem/3 months Abdomen of women during pregnancy (between diagnosis of pregnancy and delivery) 1 rem	● 3 months" means the 3 months beginning on April 1, July 1, October 1, or January 1.
③ The equivalent dose limit in an emergency: The effective dose accumulated by any worker (other than women capable of pregnancy) 100mSv	③ Allowable dose exposure in an emergency Radioactive rays related male operators: 12 rem	● Double of the normal time one
(2) An equivalent dose limit to the site relevant members involved in transportation or carrying work inside and outside the factory and plant, other than the radiation workers: 15mSv/year	(2) Persons who enter the subject area as needed Overall: 1.5 rem/year Skin only: 3 rem/year	● The sections that allow persons to be entered as needed have been excluded

[Source: Brief Explanation for Laws on Prevention of Troubles by Radioactive Rays (1988), Nuclear Power Industrial Council.]

24-18 Radioisotope Half-Life

Nuclide	Half-Life	Disintegration Type and Energy (MeV)	Nuclide	Half-Life	Disintegration Type and Energy (MeV)
^{3}H	12.3 y	β^-0.0186	^{90}Y	64.0 h*	β^-2.29;(γ)
^{14}C	5.730 y	β^-0.155	^{91}Y	58.5 d*	β^-1.54;(γ)
^{13}N	9.97 m	β^+1.19	^{95}Zr	64.1 d*	(β^-); γ 0.757,0.724
^{16}N	7.14 s	α 1.7; β^-4.27,10.4 γ 6.13	^{95}Nb	35.1 d*	β^-0.160; γ 0.776
^{19}O	29.1 s	β^-3.25,4.60 γ 0.197,1.36	^{99}Mo	66.0 h*	β^-1.21,0.45 γ 0.141,0.739,0.181,0.778,0.366
^{24}Na	15.0 h	β^-1.39; γ 1.37,2.75	^{106}Ru	368 d*	β^-0.039
^{32}P	14.3 d	β^-1.71	^{131}I	8.04 d*	β^-0.607,0.336; γ 0.364
^{35}S	87.5 d	β^-1.67	^{132}I	2.30 h*	β^-2.12 γ 0.652,0.654,0.668,0.765,0.773
^{36}Cl	3.01×10^5y	β^-0.709;EC; β^+0.115	^{133}I	20.8 h*	β^-1.28,0.94,0.7 γ 0.530,0.876,1.30,0.511,1.24
^{41}Ar	1.83 h	β^-1.12; γ 1.29	^{134}I	52.6 m*	β^-2.42,2.22,1.69,1.50,1.26 γ 0.847,0.884,1.07,0.595,0.622
^{42}K	12.36 h	β^-3.52; γ 1.52	^{135}I	6.61 h*	β^-1.33,0.877 γ 1.26,1.13,0.527,1.68,1.46
^{45}Ca	164 d	β^-0.258	^{133}Xe	5.25 d*	β^-0.346; γ 0.081
^{51}Cr	27.7 d	EC; (γ 0.320)	^{137}Cs	30.2 y*	β^-0.512
^{56}Mn	2.58 h	β^-2.54,1.53,0.718 γ 0.847,1.81,2.11	^{137}Ce	9.0 h	EC; γ 0.447;0.436
^{55}Fe	2.73 y	EC	^{141}Ce	32.5 d*	β^-0.444,0.582; γ 0.145
^{59}Fe	44.5 d	β^-0.475,0.274 γ 1.10,1.24	^{144}Ce	284 d	β^-3.16,0.185; γ 0.134
^{60}Co	5.27y	β^-0.318; γ 1.17,1.33	^{198}Au	2.69 d*	(β); γ 0.412,0.676
^{64}Cu	12.7 h	EC; β^-0.571; β^+0.657	^{239}Pu	2.41×10^4y*	α 5.16;5.14,5.10:(γ)
^{65}Zn	244 d	EC; β^+0.325; γ 1.12	^{242}Cm	163d*	α 6.11,6.07 γ 0.0441,0.102,0.158
^{85}Kr	10.7 y*	β^-0.672;(γ)		7.2×10^6y	SF
^{89}Sr	50.5 d*	β^-1.49;(γ)	^{244}Cm	18.1 y*	α 5.80,5.76;(γ)
^{90}Sr	29.1 y*	β^-0.546		1.31×10^7y	SF

Note: Half-life: No-marked items are from the "Nuclear Power Handbook" and *-marked items are from ENDF/B-V. y: year, d: day, h:hour, m: minute, s: second, α: α discharge, β^-: negative electron discharge, β^+: positive electron discharge, γ:γ discharge, EC: orbital electron capture, SF: spontanous fission···Atomic fission fragments, neutrons, gamma rays, etc. are emitted at this time. In case of a nucleus that disintegrates more than two types or when there are more than two types of radioactive ray energies, they will be described in order of higher rate ones. Disintegration type of 10% or less rate will be described in ( ).

(Reference: Nuclear Power Handbook (New Edition) supervised by Chuichi Asada and others, Ohm Corporation. Evaluated Nuclear Date File/B-V, (1982), Brook haven National Laboratory)

24-19 Monitoring of Ambient Radioactive Rays

Ambient Radioactive Rays Monitoring Items[1)]

Category	Check Item	Measuring Frequency	Measuring Method[2)]	Remarks
Ambient radioactive rays	Dose rate Integrated dose	Continuous Every quarter	NaI (Tl), ionization chamber, and TLD	
Land samples	Floating dust in the air	As needed	Nuclide analysis	
	Land water (drinking)	Every quarter	Nuclide analysis	
	Milk	As needed	Iodine 131 analysis	
	Soil	Every 6 months	Nuclide analysis	Surface soil
	Agricultural products: leaf vegetables, root vegetables, and rice	Harvest time	Nuclide analysis	
	Index organisms	Every quarter	Nuclide analysis	Mugwort, pine needles, etc.
	Drops-rainwater, dust	Every month	Nuclide analysis	Basin method
Ocean samples	Sea water Sea bed soil Sea food	Every 6 months Every 6 months Fishing season	Nuclide analysis	Surface water Surface soil
	Index organism	Every quarter	Nuclide analysis	Gulfweed, etc.
Climatic elements	Temperature Wind direction Wind speed Precipitation, etc.	Continuous in principle		

Note: 1. For one or two years after the operation starts, the monitoring should be done more in detail and more frequently than those mentioned in this plan.

2. In principle, nuclide analysis should be done as device analysis.

[Source: Nuclear Power Generation Handbook (1989), Guidance to Monitoring of Ambient Radioactive Rays]

24-20 Monitoring Radioactive Materials

Ralease Form		Target Nuclide	Lower Limit Density Bq/cm³	Minimum Measurement Frequency
Gas	Gas-like material	Radioactive gas	2×10^{-2}	Continuously
	Volatile material	Iodine 131	7×10^{-9}	Once/week
		Iodine 133	7×10^{-8}	Once/week
		Tritium	4×10^{-5}	Once/month
	Grain-like material	Gamma-rays radiating nuclides such as chromium 51, manganum 54, iron 59, cobalt 58, cobalt 60, iodine131 cesium 134, cesium 137, etc.	4×10^{-9} 1)	Once/week
		Strontium 89, strontium 90	4×10^{-10} 2)	Once/quarter
		Total beta radioactivity	4×10^{-9}	Once/month
		Total alpha radioactivity	4×10^{-10}	Once/month
Liquid		Gamma-rays radiating nuclides such as chromium 51, manganum 54, iron 59, cobalt 58, cobalt 60, iodine 131, cesium 134, cesium 137, etc.	2×10^{-2} 1)	Each discharging time or once/week
		Strontium 89, strontium 90	7×10^{-4} 2)	Once/quarter
		Tritium	2×10^{-1}	Once/month
		Total beta radioactivity	4×10^{-2}	Once/month
		Total alpha radioactivity	4×10^{-3}	Once/month

Note: 1. The value for cobalt 60 is shown as a representative one.
2. The value for strontium 90 is shown as a representative one.

[Source: Guidance to Measuring of Radioactive Materials in Power Generation Light Water Reactors, issued by the Nuclear Power Committee (1978).]

24-21 Radiation Monitors

1. X and Gamma Rays Survey Meters

	Sensitivity Measuring Range	Radiation Quality Characteristic Using Energy Range	Purpose and Other
Ionizing chamber type	Low 1 μSv/h～1Sv/h	Good 25keV～3MeV	Since the response speed is not fast, it may not be suitable for quick measurement, but suitable for accurate measurement.
GM radiation counter tube type	Middle 0.2 μSv/h～100mSv/h	Possible 100keV～1.5MeV	Used to check the presence/absence of radioactive rays or estimate the dose rate roughly. Since the time resolution is poor, this cannot be used to measure higher dose rates and pulse-like radioactive rays.
Scintillation type	High 0.1 μSv/h～50 μSv/h	Possible 50keV～2MeV	Used to check the presence/absence of high energy gamma rays. The background inspection sensitivity differs between sizes of NaI (Tl).
Semiconductor type	Low 10 μSv/h～20mSv/h	Good 50keV～6MeV	Response time is relatively fast.

[Source: Nuclear Power Handbook (1997)]

2. Neutron Survey Meters

Most of the survey meters used to measure the neutron dose rate in a wide range of energy adopt the BF_3 proportional counter tube. Usually, cps and mrem/h are used for the scale divisions.

[Source: Nuclear Power Handbook (1997)]

3. Survey Meters for Surface Contamination

Target Radioactive Rays	Classification by Detector	Characteristics
Alpha rays	Gas flow proportional counter tube type	More stable than the air proportional counter tube, although a gas cylinder is needed for measurement.
	Air proportional counter tube type	Easy to be affected by humidity.
	Scintilltion type	ZnS (Ag) scintillator used.
	Ionizing chamber type	Used to measure gamma rays as well. The incidence window is 0.5 to 0.8 mg/cm² in thickness.
Beta rays	Scintillation type	The scintillator is plastic or anthracene.
	Gas flow proportional tube type	The incidence window is 0.5 to 0.8 mg/cm² in thickness so the meter can obtain a large effective area.
	GM counter tube type	End window type GM tube: 1 to 2 mg/cm² in window thickness. Side window type GM tube: About 30 mg/cm² in window thickness.

[Source: Nuclear Power Handbook (1997)]

4. Personal Radioactive Rays Monitor

There are various types of radioactive rays measuring instruments the workers can bring with them. Some of them are as shown below.

Application of Personal Exposed Dose Meters and Their Features

		Film Badge	Glass Dose Meter	Thermal Luminance Dose Meter	Direct Reading Pocket Dose Meter	Alarm Dose Meter[6]
Use purpose	To measure integrated dose.	Yes	Yes	Yes	Yes	Yes
	To monitor works[1]	No	Yes	Yes	Yes	Yes
	To estimate global exposed dose.	Yes	Yes	Yes	No	No
	To estimate local exposed dose.	Yes	Yes	Yes	No	No
Radioactive ray type and measuring range	Gamma ray 〔mSv〕	0.1 to 10^4[2]	0.1 to 10^4	0.05 to 10^4	0.05 to 2	0.05 to 100
	Beta ray 〔mSv〕	0.1 to 10^4	0.1 to 10^4	0.05 to 10^4	–	–
	Thermal neutron ray 〔mSv〕	0.1 to 5×10^3	0.3 to 5×10^3[3,4]	0.3 to 10^3[3,4]	0.05 to 2[5]	–
	Fast neutron ray 〔mSv〕	0.2 to 50[3]	–	–	–	–
Gamma ray energy dependency		Much	Medium	Medium	Less	Medium
Gamma ray energy identification		Possible when a filter is used.	Possible when a filter and more than 2 elements are used	Same as left	Impossible	Impossible

Note:
1. The meter should be read soon after the subject person is exposed to radioactive rays.
2. When this is used together with a low sensitivity film.
3. Nuclear emulsion is used.
4. This must be combined with a special element or a filter and more than 2 elements.
5. ^{10}B is coated on the inside wall of this ionizing chamber.
6. A GM tube, semiconductor detector, or ionizing chamber is used as a detector.

[Source: Nuclear Power Handbook (New Edition) supervised by Chuichi Asada, Ohm Corporation.]

24-22 Contamination Protection Clothes and Tools

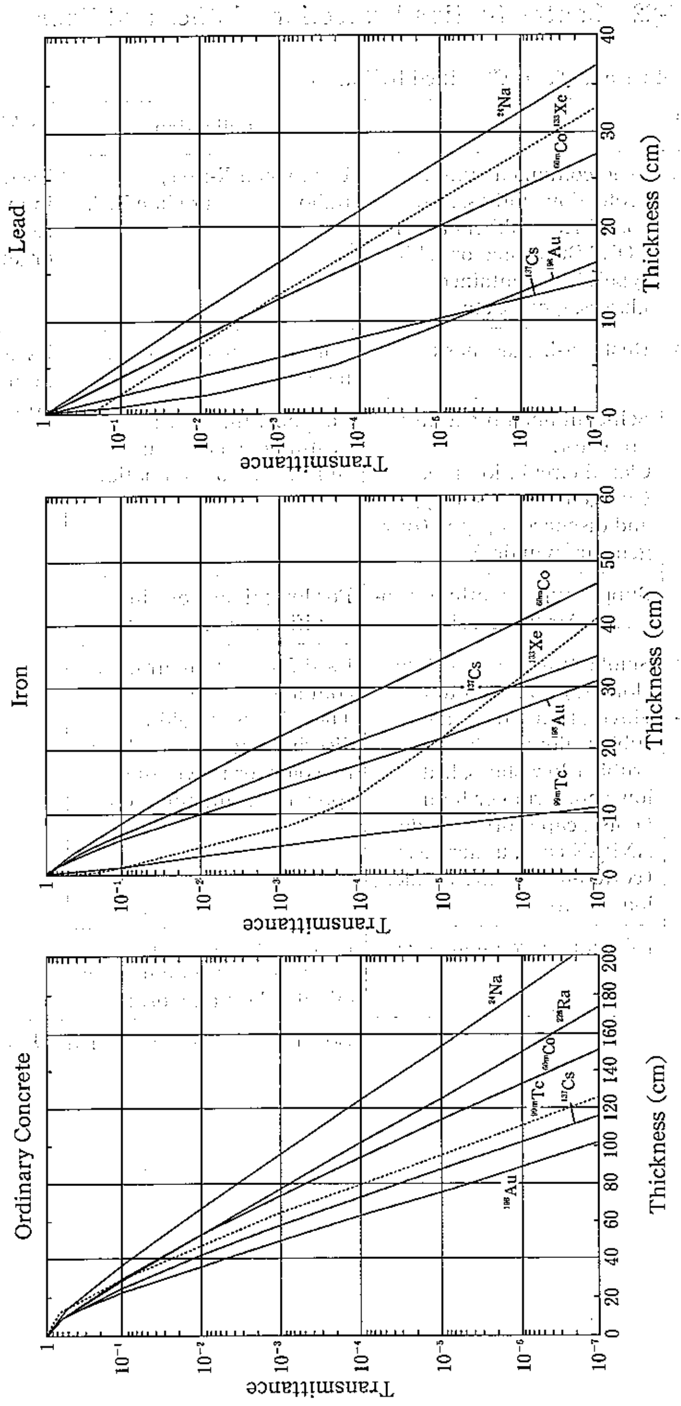
1. Protection Clothes and Tools Classified by Purpose

Item / Purpose	Type	Application	Application Place
Used to shield radioactive rays.	Lead contained (vinyl) protection clothes, lead contained (rubber) apron, GONADO protector (skirt type), lead contained glasses, gloves, etc.	Used when X-rays, radioisotopes are handled.	Used mainly in medical/research organizations.
Used to avoid absorbing radioactive substances in the air.	Dust mask (gas mask)	For work in low contamination	Used mainly in nuclear power plants.
	Self-contained breathing protector: Closed circulation type (oxygen circulation type) and discharging type (oxygen/air/cylinder)	For short time work (within one hour) in significant contamination	
	Supply type breathing protector: Air line mask	For long time work in significant contamination	
Used to protect body surfaces from contamination	Smoke tube type working clothes, gloves (cotton gloves, thin gloves, and rubber gloves), shoes (rubber low shoes, leather low shoes, rubber high boots), cap (cotton-made ANPAN cap), underwear (cotton-made shirts, under long pants)	Used for work in afraid of contamination area. These items should be discriminated from others by color for preventing spread of contamination.	
	PVC suits (frogman suit)	Used for work in area where contamination water might splash on workers.	

[Source: Nuclear Power Handbook (1997)]

24-23 Shield of Gamma Rays for Different Materials

(1 cm Gamma Rays Dose Fquivalent Transmission Rate)



[Source: Isotope Notebook (1991), edited by Japan Radioisotope Association, Maruzen Co., Ltd.]

24-24 Main Formulas for Radiation

Logarithm $\log N = 0.4343 \ln N$

$\ln N = 2.3026 \log N$

(1) Radioactive decay

(a) $A \xrightarrow[\lambda]{} B$

$$\frac{dN}{dt} = -\lambda N \qquad N = N_o e^{-\lambda t}$$

N_o : Number of atoms of the nuclide A at the initial time

N : Number of atoms of the nuclide A after t time

λ : Decay constant

t : Elapsed time

(b) $A \xrightarrow[\lambda_1]{} B \xrightarrow[\lambda_2]{} C$

$$\frac{dN_1}{dt} = -\lambda_1 \cdot N_1 \qquad \frac{dN_2}{dt} = \lambda_1 \cdot N_1 - \lambda_2 \cdot N_2$$

$$N_1 = N_{10} e^{-\lambda_1 t}$$

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{10}(e^{-\lambda_1 t} - e^{-\lambda_2 t}) + N_{20} e^{-\lambda_2 t}$$

N_{10}, N_{20} : Number of atoms of the nuclide A, B at the initial time

N_1, N_2 : Number of atoms of the nuclide A, B after t time

λ_1, λ_2 : Decay constant of the nuclide A, B

t : Elapsed time

(c) Decay constant and half-life

$$\lambda = \frac{0.693}{T}$$

(d) Radioactive equilibrium

$$\lambda_1 N_1 = \lambda_2 N_2 = \lambda_3 N_3 = \cdots\cdots = \lambda_i N_i$$

$$\frac{N_1}{T_1} = \frac{N_2}{T_2} = \frac{N_3}{T_3} = \cdots\cdots = \frac{N_i}{T_i}$$

$N_1 N_2, N_3, \cdots\cdots, N_i$: The number of atoms of each nuclide at radioactive equilibrium

$\lambda_1, \lambda_2, \lambda_3, \cdots\cdots, \lambda_i$: Decay constant of each nuclide

$T_1, T_2, T_3, \cdots\cdots, T_i$: Half-life of each nuclide

(2) Mass of 1Bq nuclide

$$m = 8.63 \times 10^{-21} T \cdot A$$

m : Mass of 1Bq (g)

T : Half-life (h)

A : The number of mass

(3) Range and energy

(a) Alpha rays

$R = 0.318 E^{3/2}$ E : Energy of alpha rays (MeV)

R : Range in the air (cm)

(b) Beta rays

When E>0.8 MeV

$R_{A\ell}=542E-133$

When 0.8MeV>E>0.15MeV

$R_{A\ell}=407E^{1.38}$

E : Energy (MeV)

$R_{A\ell}$: Range in the aluminum (mg/cm²)

(4) Absorption of beta rays

(a) Absorption coefficient

$\mu=0.017E^{-1.43}$ E : Maximum energy (MeV)

μ : Absorption coefficient (cm²/g)

(b) Compensation of self absorption

$$I = I_0\times\frac{1-exp(-\mu d)}{\mu d}$$

I : Measurements

I_0 : The value in case of assumed non-self absorption

μ : Absorption coefficient of beta rays in the specimen (cm²/g)

d : The thickness of specimen (g/cm²)

(5) Gamma radiation constant

$k\ \ (Bqh^{-1}mCi^{-1}\ \text{at 1cm}) \fallingdotseq 3.6\times10^{-11}\,\Sigma\eta_i E_i$

η_i : The fraction of gamma radiation of nuclide i

E_i : The energy of gamma radiation of nuclide i

(6) Measurement

Statistical treatment

$$(\text{Total counting}) = N\pm\sqrt{N}$$

$$(\text{Counting rate}) = \left(\frac{N}{t}-\frac{N_b}{t_b}\right)\pm\sqrt{\frac{N}{t^2}+\frac{N_b}{t_b^{\,2}}}$$

$$(A\pm\sigma_A) + (B\pm\sigma_B) = (A+B) \pm\sqrt{\sigma_A^{\,2}+\sigma_B^{\,2}}$$

$$(A\pm\sigma_A) - (B\pm\sigma_B) = (A-B) \pm\sqrt{\sigma_A^{\,2}+\sigma_B^{\,2}}$$

$$(A\pm\sigma_A) \cdot (B\pm\sigma_B) = (A\cdot B) \pm (A\cdot B)\sqrt{\left(\frac{\sigma_A}{A}\right)^2+\left(\frac{\sigma_B}{B}\right)^2}$$

$$(A\pm\sigma_A) / (B\pm\sigma_B) = (A/B) \pm (A/B)\sqrt{\left(\frac{\sigma_A}{A}\right)^2+\left(\frac{\sigma_B}{B}\right)^2}$$

N : Total counting numbers (including natural counting)

t : Measurement time of specimen

N_b : Total natural counting numbers

t_b : Measurement time of natural counting

σ_A, σ_B

: Standard deviation of quantity A, B

[Reference; Isotope Handbook (1984) edited by Japan Radioisotope Association, Maruzen Co., Ltd.]

24-25 Terms for Nuclear Power Generation

Alarm meter:
A measuring instrument used to issue an alarm when the radioactive ray reaches the preset level. For some alarm meters, an ionizing chamber type or counter tube type detector is combined with an amplifier and it issues an alarm when the radioactive ray reaches a certain level of integration.

Area radiation monitor; ARM:
A device to issue an alarm when the preset radiation level is reached while the external radiation exposure rate is measured at the main sections in the controlled area in order to know the external exposed dose in the neighboring areas of the reactor.

Aseismic design:
A design made so that the subject nuclear power facility can retain their integrity with conceivable earthquake that are expected to occur.

Breeding ratio; BR:
A process is called as breeding, in which new fissile atoms are generated through nuclear fission at a rate more than the fissile consumption by the fission in a fission chain reaction. The breeding ratio [BR] is defined as follows:

$$BR=\frac{\text{number of newly generted fissiles}}{\text{number of consumed fissiles}}$$

Burnable poison:
Neutron absorber fixed or mixed into nuclear fuel and burnt with the fuel so as to compensate the reactivity of the reactor. The deterioration of a reactor's reactivity caused by combustion of nuclear fuel can be compensated by the positive reactivity to be generated by the combustion of this burnable poison. This processing also allows the neutron flux to be smoothed at the same time. Boron, samarium, dysprosium, hafnium, and gadlinium are used as this burnable poison. They all have a large area to neutron absorption cross-section. Once they absorb neutron, they are turned into substances that never absorb neutron.

Burn up:
Rate of the fissile atom quantity consumed during operation of a reactor to the fissile atom quantity before operation or the energy generated per unit weight of fuel. As an unit %(U), MWd/tU, etc. are used.

Cask:
A container shielded with a thick wall and used to carry spent fuel or high level radioactive materials.

Chalk river unidentified deposits: CRUD:
CRUD refers to insoluble metal oxides (suspended substances) such as iron rust (iron oxide), etc. existing in coolant of 0.45 μm or more. They may be considered to be the same as corrosion product (iron oxide). CRUD generated and brought into a reactor causes the dose rate of primary cooling system devices/pipes to be increased, resulting in increasing of exposure of the maintenance/inspection workers.

Chemical and volume control system; CVCS [P] :
An equipment used to charge/supply coolant into the primary cooling system, remove corrosion products and nuclear fission products from the coolant, adjust the boric acid density, and seal the main coolant pump shaft.

Condensate demineralizer system; CD:
A device to remove fissile and corrosion products from condensate. Even when sea water leaks into the condenser, this device can keep the quality of the condensate

Containment atmosphere monitoring system; CAMS:
A device used to measure the atmosphere in the (primary) containment vessel. The main items to measure are the pressure, temperature, humidity, hydrogen density, and radioactivity level in the containment vessel.

Controlled area:
An area such as reactor room, spent fuel storage facility, radioactive waste disposal facility, etc. where the density of the external exposure, radioactive materials in the air or water, or density of radioactive materials on the surface contaminated with radioactive materials is over the value specified by the Minister of the Science and Technology

Control rod; CR:
Used to adjust the output (nuclear fission rate) of a nuclear reactor. It is made from boron, hafnium, etc. that

absorb neutron effectively. This rod is inserted/removed in/from the reactor to control the output.

Control rod cluster; CRC [P]:
This cluster is inserted in a fuel assembly and used to adjust the power of a nuclear reactor, as well as to make the neutron flux distribution uniform. The cluster is classified into a "full length control rod cluster" into which neutron absorber is inserted fully, a "part length control rod cluster" into which neutron absorber is inserted partially.

Control rod drive mechanism; CRD:
A mechanism to insert/remove the control rod in/from the reactor core. For BWR, a hydraulic drive mechanism is provided in the lower section of the nuclear reactor vessel. For PWR, a magnetic jack mechanism is provided at the top cover of the nuclear reactor vessel.

Control rod worth:
A size of reactivity change to occur when the control rod is inserted completely in the nuclear reactor that has reached the critical state in the required status.

Coolant:
Liquid used to remove heat generated in a reactor. Refer to 12-5.

Conversion ratio:
Number of fissile nucleuses transformed from the parent material of the fuel each time a fissile nucleus is consumed in the reactor.

Criticality:
A state in which fissile chain reaction is maintained on a certain level. In other words, the effective multiplication must be 1.

Decay heat:
Heat generated by the decay of radioactive materials.

Defense in depth:
A multiplex defense system to prevent radioactive substances from leaking from nuclear power facilities for safety.
This system is classified as follows:
1st defense: Highly reliable materials and devices are adopted in the design/construction stages to carry out strict quality control. In the operation stage, monitoring, inspection, and maintenance are carried out properly to prevent troubles.
2nd defense: A multiplex safety system is provided to prevent accidents from developing when a device goes down or is mishandled.
3rd defense: When an accident occurs, expansion of the accident is prevented and countermeasures are taken to protect the residents in the region from the accident. (ex: ECCS, vessel)

Dust radiation monitor; DRM:
A device to detect/measure the radioactivity contained in the dust in the air. When the density exceeds the preset value, this device issues an alarm.

Effective multiplication factor:
A factor for neutron multiplication by a fission. Neutron slow down and diffusion winthin reactor and leakage out of reactor are taken into account.

Electron volt; eV:
A unit of energy. 1 eV means the energy obtained when a given unit-charged particle (a charged electron) passes a place of 1V potential difference with no resistance. .

$1\ eV=1.602\times10^{-19}J=1.602\times10^{-12}erg=3.83\times10^{-20}cal.$

Emergency core cooling system; ECCS:
The generic term for the safety equipment used to inject coolant into the reactor core to prevent fuel break when a loss-of-primary-coolant accident occurs.

Engineered safety features:
A facility equipped with functions to control or prevent radiation materials from dispersing when the fuel in the core is damaged by an accident, trouble, etc.. This term is a generic one for emergency core cooling systems, containment vessel (including isolation valves) and CV atmosphere clean-up system.

Environment radiation monitor:
A device used to monitor or measure environment radiation.

Fail safe:
A state designed so that the functions of a unit may be protected from dangerous accidents when part of the unit goes down or an error occurs in the safety device.

Feed water sparger [B] :
Arranged in a form of donut along the inside wall of a nuclear reactor vessel and used to feed water in uniform in the pressure vessel.

Film badge:
A kind of personal exposure monitor. It is a simple method to measure the dose. A worker puts this badge on his/her clothes. After work, the special film set in this badge is developed to measure the black level to measure the radioactivity exposure.

Fissile material:
The generic term of substances such as ^{233}U, ^{235}U, and ^{239}Pu that cause nuclear fission through mutual action with thermal neutron.

Fission products; FP:
A generic term of the fission fragments which are generated directly from the fission of heavy nuclides such as ^{235}U, ^{233}U, and ^{239}Pu, and the nuclides to be generated by the beta decay of fission fragments.

Flammable gas control system; FCB [B]:
A facility to control gas density within the reaction limit in order to prevent the reaction of hydrogen and oxygen gases charged into the primary containment vessel at the time of loss-of-coolant accident. A recombiner is used for this control.

Fuel cycle or nuclear fuel cycle:
When nuclear fuel material refined from ore and burnt in a reactor as a nuclear fuel, such fissile materials as ^{235}U, etc. are consumed to generate fissile products. On the other hand, ^{239}Pu, etc. are generated at this time due to neutron capture reaction. This spent fuel can be reprocessed and used for the same reactor or another one. In general, a series of circulation processes for nuclear fuel like this is called a nuclear fuel cycle.

Fuel fabrication:
The generic term for a series of processes to mold fuel pellets and fuel plates using raw materials such as metal uranium, uranium oxide powder, etc. and then to form specified fuel rods or fuel assemblies.

Fuel pool cooling and filtering system; FPC [B] :
Same as the spent fuel pit water filtering/cooling equipment for PWR.

Fuel rod:
Fuel structure molded into rods so that it can be used for reactors. A certain number of fuel rods are bundled as a fuel assembly to be loaded into a reactor.

Half life or half valued period:
A period of time required until the radioactivity of a radioactive material is reduced to a half. The half life of the decay constant λ nucleus is represented by $T=(l_n 2)/\lambda=0.693/\lambda$.

Hand foot clothes monitor; HFCM:
A kind of surface contamination monitoring device. It is kept at the entrance/exit of workshop where radioactivity is handled so that the radioactive contamination of hands, feet and clothes can be detected.

High pressure core spray system; HPCS [B]:
One of the emergency core cooling system. It is used to spray cooling water on the reactor core at the loss-of-coolant accident while the reactor pressure is high.

Hypothetical accident:
This refers to an accident that may occur in a reactor, which is postulated and analyzed in the safety analysis of reactors. It is an accident, which exceeds the range of major accidents and are not expected to occur from the technical standpoint. For example, in estimating a major accident, it is assumed that some of the safety facilities

expected to be effective will not work, and thus radioactive substances may be dispersed. The accident influence is evaluated in the safety evaluation of reactors.

Internal exposure:

Radioactivity exposure from radioactive materials taken into a human body.

Low pressure coolant injection; LPCI [B]:

One of the emergency reactor core cooling systems, which is used to inject water into the core (using a motor driven pump) while the pressure in the reactor is low at the time of loss-of-coolant accident.

Low pressure core spray system; LPCS [B]

One of the emergency reactor core cooling systems, which is used to spray water onto the core at the time of loss-of-coolant accident while the pressure in the reactor is low. (A motor-driven pump is used for water injection.)

Low pressure coolant injection; LPCI [P]:

A facility equipped with functions to remove decay heat and sensible heat of fuel after the nuclear reactor is shutdown, and to inject low pressure water into the reactor core as the emergency reactor core cooling equipment. Just like the safety injection equipment, boron water from the refueling water storage tank is injected onto the reactor core through the low temperature leg pipe through the residual heat removal cooling system. When the water level in the refueling water storage tank becomes low, recirculation mode is set so that the water source is changed over to containment sump.

Main steam isolation valve; MSIV [B]:

An automatic gate valve provided both inside and outside the main steam pipe of containment penetrations in order to shut off coolant and radioactive materials to be discharged when the main steam pipe is broken outside of the containment vessel.

Maximum credible accident; MCA:

A serious accident that is assumed to occur in the worst case from the technical standpoint. This is considered for evaluating the safety assessment of reactor site. MCA refers to accidents of loss-of primary coolant, main steam pipe break (BWR), or steam generator heat pipe break (PWR).

Maximum permissible integral dose:

Integral dose allowable for radiation workers. The allowable value is defined by the laws on prevention of radiation injury. The allowable integral dose is calculated as $D=5(N-18)$ when D is allowable integral dose [rem] and N is numbers of age.

Moderator:

Material used to delay the speed of neutron. Light water, heavy water, graphite, beryllium, beryllium oxide are those materials.

Monitoring post:

One of the environmental monitoring devices. It is located around a power plant and used to detect the dose (rate) in the air continuously. Monitoring and recording data is observed at main control room.

Monitoring station:

An outdoor device set around a reactor facility and used to keep sampling radioactive dust in the air, as well as to record the exposed dose continuously using a dose detector.

Multiplication factor or multiplication coefficient:

Ratio of the neutron quantity in a generation to the neutron quantity in the previous generation. While this ratio is above 1, the nuclear fission chain reaction is maintained.

Natural radioactivity:

Radioactivity from natural radioactive nuclides such as uranium/radium, thorium, actinium elements, as well as kalium, samarium, rubidium, etc.

Neutron absorber:

A substance that absorbs neutron effectively. For example, it refers to boron, cadmium, xenon, hafnium, quadrium, etc.

Neutron source; NS:

A neutron source to be inserted in a reactor core to start up the reactor. Antimony, beryllium, etc. are used as this source.

Noble gas:

6 gas elements—helium, neon, argon, krypton, xenon, and radon—whose nuclear vallence are 0 and they are inactive chemically. They are rarely exist in the air, so they are thus named.

Non fuel bundle component; NFBC [P]:

A component of a reactor other than the fuel bundle. It is generic term for the plugging device inserted into the control rod guide thimble, control rod cluster, power distribution adjusting control rod cluster, burnable poison and neutron source assembly.

Nuclear fission:

A kind of nuclear reaction. It is a phenomenon of nuclear fission in which a heavy nucleus is fissioned into two (three in some cases) nucleuses, both of which have almost equal mass respectively. Nuclear fission is classified into two types; induced fission that is caused by the impact of a neutron, etc. and natural fission that occurs naturaly.

Nuclear steam supply system; NSSS:

The generic term of the main sections of a nuclear power plant, such as the primary cooling equipment, the chemical volume control equipment (PWR), the safety equipment, and the residual heat removal equipment, etc.

Pocket dosimeter; PD:

A compact portable ionizing chamber. A fountain pen type one is often used. This dosimeter is a personal one. A gamma ray dosimeter and a neutron dosimeter are available.

Pressurizer; PR [P] :

An equipment used to pressurize and maintain the pressure in the reactor. It comprises the pressurizer body, heater, surge and spray pipes, safety valve, relief valve, and pressurizer relief tank.

Primary containment vessel; PCV [B] or containment vessel; CV [P] :

An airtight and pressure-proof container used to prevent radioactive substances from dispersing from a reactor and attached systems at an accident.

Primary cooling system:

A closed circuit used to remove heat. Coolant (primary coolant) is circulated in the circuit through the reactor core.

Primary loop recirculation system; PLR [B] :

A system to adjust the recirculating flow in a reactor and control void generation to adjust the reactor output.

Process radiation monitor; PRM:

A device to measure the density of gases in the system and radioactive materials in liquid to confirm that the reactor facility is operating normally. This device issues an alarm when the radioactivity level exceeds the preset value.

Radioactive waste; RW:

The generic term for gas, liquid, and solid waste from reprocessing factories, reactors, radio chemistry laboratories, hot laboratories, nuclear fuel refining factories, etc.

Radioactivity:

The capability to discharge alpha, beta, and gamma rays when radioactive disintegration occurs. Becquerel [Bq] is used as the unit of the radioactivity level.

Reactivity:

A difference from the critical state of a reactor, which is defined as follows:

$$\rho = \frac{k_{ex}}{k_{eff}} \left(= \frac{k_{eff}-1}{k_{eff}}\right)$$

k_{ex} indicates an excess multiplication and k_{eff} indicates an effective multiplication factor. When the reactivity is positive, the reactor is in the super critical state. When it is negative, it is sub-critical.

Reactor coolant pump; RCP [P] :
A pump used to circulate primary coolant through the reactor vessel→steam generator→reactor vessel.

Reactor core isolation cooling system; RCIC [B] :
If a nuclear reactor, after it is stopped, is isolated from the condenser (heat removal source) for any reason, then the steam generated by residual heat such as decay heat, etc. flows into the suppression pool through the safety relief valve. If the condenser/feedwater system stops at this time, the water level in the reactor goes low. This system is used to restore the water level in the reactor. This system uses a turbine driven pump, which is operated by part of the steam in the reactor, to inject condensed water in the residual heat removal system steam condensation mode, or water from the condensation tank.

Reactor neutron monitoring system:
To monitor a reactor power, the neutron flux proportional to the reactor power is measured. Such a monitoring system is used for this measurement. A neutron source range monitoring system, intermediate range monitoring system, or power range monitoring system is selected according to the reactor power level.

Reactor pressure vessel; RPV [B] or reactor vessel; RV [P]:
A vessel used to accommodate the reactor core, primary coolant, etc.. For a light water reactor, thick steel is often used for this vessel.

Reactor water clean up system; CUW:
A device to filtrate reactor coolant to keep its purity.

Reprocessing:
This processing is executed to remove fission products from the spent nuclear fuel and saparate and recover remaining uranium and plutonium.

Residual heat removal system; RHR [B]:
A system used to remove decay heat and residual heat when reactor is shutdown normally or when it is isolated, and to cool the reactor core when a loss-of-coolant accident occurs.

Residual heat removal system; RHRS [P] :
Same as the low pressure water injection equipment.

Safety injection system; SIS [P]:
An equipment that injects boric acid water from a boric acid injection tank and a refueling water storage tank into the reactor core according to the actuation signal of the emergency core cooling system.

Safety protection system:
A safety equipment designed so that an action may be taken to prevent or control an abnormal condition by detecting or estimating the abnormal condition in advance. And an equipment designed to activate the engineered safety features on detecting accident condition.

Safety relief valve; SRV:
A safety valve used to prevent excessive pressure in a nuclear reactor. It is spring-driven or forcibly driven by electrical signals for high pressure.

Scram:
An unexpected shutdown of a reactor caused by the negative reactivity added suddenly to the reactor. Usually, it refers to an automatic shutdown by the safety device of the reactor, but it refers to an emergency manual shutdown in some cases.

Steam generator; SG:
A unit to transmit the heat of the primary coolant heated in the reactor to the secondary system feedwater to generate the main steam to be supplied to the turbine.

Specific power:
A value obtained by dividing the thermal power of a reactor by the mass of the fissile material (nuclear fuel) loaded into reactor. As an unit for this value, kW/kg, MW/t, etc. are used.

Spent fuel pit cooling and clean up system; SFPCS [P] :
A facility used to remove the decay heat generated from spent fuel stored in the spent fuel pit, then to clean up spent fuel pit water. For BWR, it is referred to as a fuel pool cooling/clean up system.

Stack:
A cylinder to discharge flue gas from the ventilation air conditioner and the gas waste treatment system into the air.

Standby gas treatment system; SGTS [B] :
An equipment to close the active ventilation system and process radioactivity through a charcoal filter, high performance filter, etc. to reduce the radioactive materials release when a radioactivity accident occurs in a reactor building.

Standby liquid control system; SLC [B]:
A device to inject sodium pentaborate (neutron absorber solution) from the bottom of the core to add negative reactivity and the reactor is shutdown gradually at low temperature when the reactor cannot be shutdown at low temperature, because the control rods cannot be inserted into the core.

Steam Generator; SG
An equipment to transfer the heat from secondary coolant to feed water and generate steam, which is fed to turbine.

Supervised area:
An area where the dose of external radiation exposure, the density of radioactive substances in the air or water may exceed the value defined by the laws on allowable exposed dose, etc. (Articles 2 and 10) according to the "nuclear reactor installation and operation related rules." Actually, this area is set around the site boundary considering the management convenience.

Thermal neutron:
A neutron that is at thermal equilibrium with surrounding media. The average energy in the room temperature is 0.025 eV. The average speed is 2,200 m/s.

Thermal reactor:
A reactor to maintain the fission chain reaction mainly with thermal neutrons. A neutron moderator is needed for this reactor.

Thermo luminescence dosimeter; TLD:
A dosimeter to measure dose using the phenomenon that lithium fluoride LiF, calcium fluoride CaF_2, calcium sulfate $CaFO_4$, etc. generate thermo luminescence when they are irradiated.

Yellow cake [refined uranium ore] :
An intermediate product produced in uranium ore refining processes. It is yellow or yellowish brown powder. The composition is uranyl ammonium $[(NH_3)_2U_2O_7]$ or uranyl natrium $[Na_2U_2O_7]$ or U_3O_8. It is referred to as intermediate refined uranium ore in some cases.

Reference: Nuclear Power Handbook (1989) supervised by Chuichi Asada, et al. Outline of Light Water Reactor Power Plant (1984), Nuclear Power Safety Association, Junkoh Morishima. Nuclear Power Index (1987), Nuclear Power Dictionary (1981) edited by the Nuclear Power Dictionary Editing Committee, Corona Publishing Co., Ltd.

24-26 Abbreviations on Nuclear Power Plants

AB [A/B]	Auxiliary Building
AC	Atmospheric Control System
ACC	Accumulator
ACRS	Advisory Committee on Reactor Safeguards (U.S.A)
ADS	Automatic Depressurization System
AEC	Atomic Energy Commission
AESJ	Atomic Energy Society of Japan
AGR	Advanced Gas-Cooled Reactor
AHVS	Air Conditioning and Ventilating System
AIF	Atomic Industrial Forum, Inc. (U.S.A.)
AISI	American Iron & Steel Institute (→ANSI)
ALAP	as low as practicable
ALARA	as low as reasonably achievable
ANRE	Agency of Natural Resources and Energy (JAPAN)
ANS	American Nuclear Society, Inc.
ANSI	American National Standards Institute
AO	Air Off Take System
AOP	Auxiliary Oil Pump
APRM	Average Power Range Monitor
ARM	Area Radiation Monitoring system
ASA	American Standards Association (Old: ANSI)
ASME	American Society of Mechanical Engineers
ASCRS	Auxiliary Steam Condensate Return System
ASTM	American Society of Testing Material
ASS	Auxiliary Steam System
ATR	Advanced Thermal Reactor
ATWS	Anticipated Transients Without Scram
AWS	American Welding Society
B.A Evap.	Boric Acid Evaporator Package
BCD [BSD]	Burst Cartridge (Slug) Detector
BDS	Blow Down System (Incidental System)
BIT	Boron Injection Tank
BNFL	British Nuclear Fuels Ltd.
BOP	Balance of Plant (General term of the system without NSSS in the Plant)
CAMS	Containment Atmosphere Monitoring System
CANDU	Canadian Deuterium (Type) Uranium Reactor
CBP	Condensate Booster Pump
CC	Control Center
CCWHX	Component Cooling Water Heat Exchanger
CCWP	Component Cooling Water Pump
CCWS	Component Cooling Water System
CD	Condensate Demineralizer System
CHT	Cold Hydraulic Test (→HFT)
Ci: curie	Radioactivity unit (=3.7×10^{10} dps, 3.7×10^{10} Bq)
CI [C/I]	Core Internals
COGEMA	Compagnie General des Matieres Nuclearies
CONW	Concentrated Waste System
CP	Condensate Pump
crm:	count per minute
cps:	count per second
CR	Control Rod
CRD (M) [CS]	Control Rod Drive (Mechanism), [Control System]
CRIEPI	Central Research Institute of Electric Power Industry (JAPAN)
CREST	Committee on Reactor Safety Technology (OECD)
CRW	Clean Rad. (roentgen absorbed does) Waste
CS	Core Spray System
CSNI	Committee on the Safety of Nuclear Installations (OECD/NEA)
CSS	Containment Spray System
CST	Condensate Storage Tank
CB [C/V]	Containment Vessel (→PCV)
CUW	Reactor Water Clean-up System
CVCS	Chemical and Volume Control System
CW	Closed Cooling Water System (R-, T-, RW) Circulating Water System
CWP	Circulating Water Pump
DBA	Design Basis Accident
DD	Detergent Drain System
DF	Decontamination Factor
DG [D/G]	Diesel Generator
DMWS	Demeralized Make-up Water System
DOE	Department of Energy (U.S.A)
DRM	Dust Radiation Monitoring System

ECCS	Emergency Core Cooling System
EHC	Electro Hydraulic Control System (→EHGov)
EHGov.	Electro Hydraulic Gevernor
ENEA	European Nuclear Energy Agency (currently; NEA)
ENL	Eldorado Nuclear Limited (CANADA)
EOF	Emergency Operations Facility
EOP	Emergency Gear Oil Pump
EPR	Electrical Pressure Regulator
EPRI	Electric Power Research Institute (U.S.A.)
ES	Extraction Steam System
FBR	Fast Breeder Reactor
FCS	Flammability (Flammable Gas) Control System
FDW	Feed Water System
FDWC	Feed Water Control System
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission (U.S.A.)
FHS	Fuel Handling System
FORATOM	Forum Atomique European (European Atomic Industrial Forum. Inc.)
FP	Fire Protection System
FP	Fission Products
FPC	Fuel Pool Cooling and Filtering System
FRVS	Filtration, Recirculation and Ventilation System
FSWS	Fire Service Water System
FWP	Feed Water Pump
GCFR [GCFBR]	Gas-Cooled Fast (Breeder) Reactor
GCR	Gas-Cooled Reactor
HCU	Hydraulic Control Unit
HCW	High Conductivity Waste System
HD	Heater Drain System
HFT	Hot Function Test
HPCI	High Pressure Coolant Injection System
HPCS	High Pressure Core Spray System
HS	Heating Steam System or House Boilor
HSD	Hot Shower Drain System
HT	Hold-up Tank, Hot Trap
HTGR	High Temperature Gas-Cooled Reactor
HTR	Heater

HUT	Hold-up Tank
HV	Heater Vent System
HV [H/V]	Heating and Ventilation Facilities (→AHVS)
HVAC (S)	Heating Ventilation and Air Conditioning System
HWR	Heavy Water Reactor
IA (S)	Instrument Air System
IAEA	International Atomic Energy Agency (U.N.)
IB [I/B]	Intermediate Building
ICIS	In-Core Instrumentation System
ICRP	International Coomission on Radiological Protection
IEA	International Energy Agency (OECD)
IEEE	Institute of Electrical & Electronics Engineers (U.S.A. AIEE)
INIS	International Nuclear Information System (IAEA)
INPO	Institute of Nuclear Power Operations (U.S.A.)
IPB	Isolated Phase Bus
IPR	Initial Pressure Regulator
IRM	Intermediate Range Monitor
IRPA	International Radiation Protection Association
ISI	Inservice Inspection
ISV	Intercept Valve
JAERI	Japan Atomic Energy Research Institute
JAIF	Japan Atomic Industrial Forum. Inc.
LCP	Local Control Panel
LCS	Leakage Control System (→MSLC)
LCW	Low Conductivity Waste System
LD	Laundry Drain System
LDS	Leak Detection System
LMFBR	Liquid Metal Fast Breeder Reactor
LO	Lubricating Oil System
LOCA	Loss of Coolant Accident
LPCI	Low Pressure Coolant Injection System
LPCS	Low Pressure Core Spray System
LPRM	Local Power Range Monitoring
LWR	Light Water Reactor (General term of BWR and PWR)
MCB	Main Control Board (→MCRP)
MCRP	Main Control Room Panel
MDAFP	Motor Driven Auxiliary Feed Water Pump

MG	Motor Generator Set
MOP	Main Oil Pump
MOT	Monitor Tank
MPR	Mechanical Pressure Regulator
MS	Main Steam
MS&H	Moisture Separator and Heater
MSFW	Main Steam and Feed Water System
MSIV	Main Steam Isolation Valve
MSLC	Main Steam Leakage Control System (→LCS)
MSV	Main Stop Valve
MSW	Miscellaneous Solid Waste System
MU	Make-up Water System
NEA	Nuclear Energy Agency (OECD/NEA)
NIS	Nuclear Instrumentation System
NMS	Neutron Monitoring System
NRC	Nuclear Regulatory Commission (U.S.A.)
NSC	Nuclear Safety Commission (JAPAN)
OD	Oil Drain System
OG	Off-Gas system
PC	Power Center
PCCS	Process Control Computer System
PCV	Primary Containment Vessel (→CV)
PLR	Primary Loop Recirculation System
PMWP	Primary Make-up Water Pump
PMWS	Primary Make-up Water System
PMWT	Primary Make-up Water Tank
PP	Physical Protection
PR (T)	Pressurizer (Relief Tank)
PRM	Power Range Monitor
PRRM	Process Radiation Monitoring System
rad:	roentgen absorbed dose (=0.01J/kg)
RBM	Rod Block Monitor
RCC (A)	Rod Cluster Control Assembly
RCCW	Reactor Building Closed Cooling Water System
RCDT	Reactor Coolant Drain Tank
RCIC	Reactor Core Isolation Cooling System
RCP	Reactor Coolant Pump

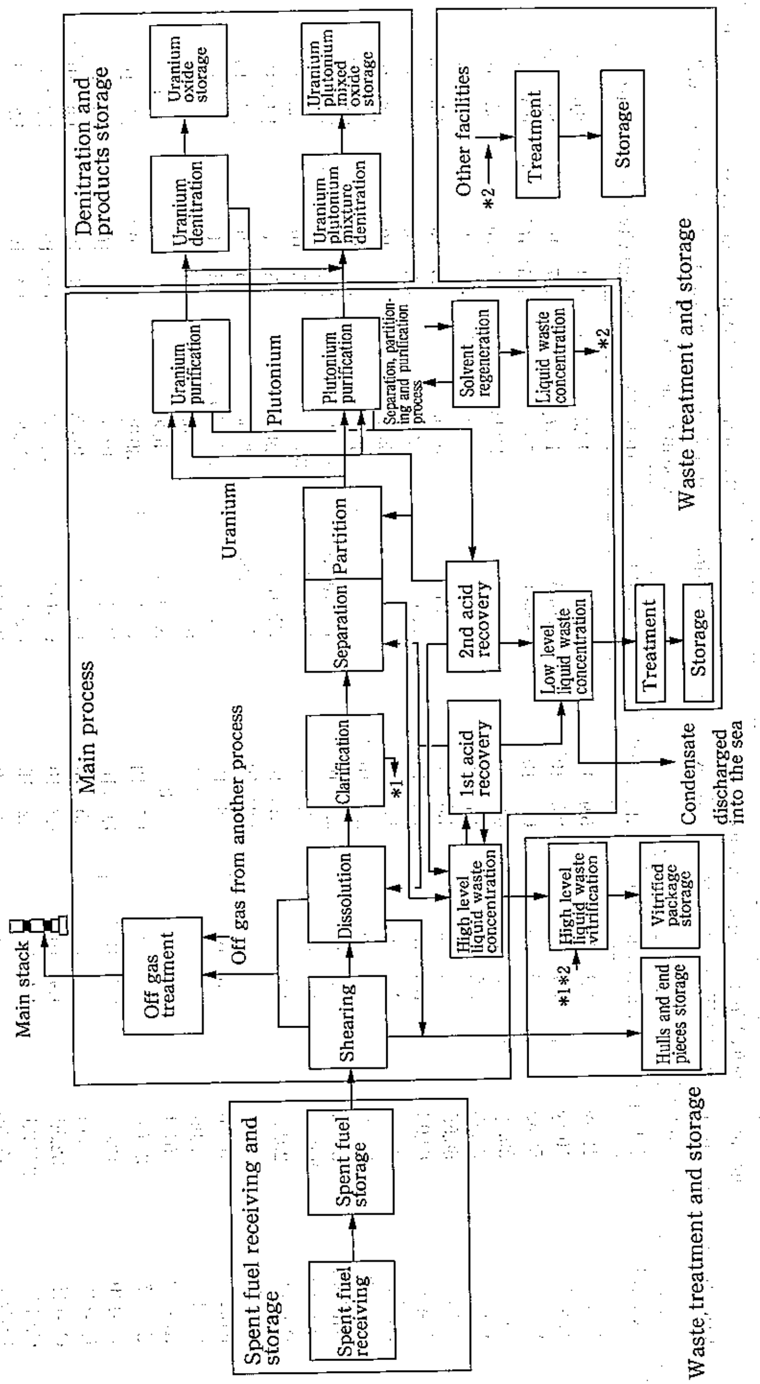
RCPS	Reactor Control Protection System (consist of RCS, RPS)
RCS	Reactor Coolant System (→RCPS)
RCWS	Reactor Building Closed Cooling Sea Water System
rem	roentgen equivalent man
RFC	Reactor Recirculation Flow Control System
RFP	Reactor Feed Water Pump
RHEX	Residual Heat Exchanger
RHR	Residual Heat Removal System
RHRS	Residual Heat Removal Sea Water System
RHRP	Residual Heat Removal Pump
RMCS	Reactor Manual Control System
RMS	Radiation Monitoring System
RPIS	Rod Position Information System
RPS	Reactor Protection System (or Emergency shutdown system)
RPV	Reactor Pressure Vessel
RSS	Remote Shutdown System
RSV	Reheat Stop Valve
RV [R/V]	Reactor Vessel (→RPV)
RWCW	Radio-active Waste Building Closed Cooling Water System
RWM	Rod Worth Minimizer
RWST (S)	Refueling Waster Storage Tank (System)
SA	Station Air
SAM	Sampling system
SD	Storm Drain System
SFP	Spent Fuel Pit
SFPCS	Spent Fuel Pit Cooling System
SG [S/G]	Steam Generator
SGBDS	Steam Generator Blow Down System
SGTS	Stand-up Gas Treatment System
SIP	Safety Injection Pump
SIS	Safety Injection System, (consist of HPCI, Steam injection system, LPCI)
SLC	Stand-by Liquid Control System
SMS	Snow Melt System
SRM	Source Range Monitor
SRST	Spent Resin Storage Tank
SS	Sampling System and Spent Sludge System
SSAS	Station Service Air System

SWP	Sea Water Pump
SWS	Sea Water System
TB	Turbine Building
TBP	Turbine Bypass System
TCCW	Turbine Building Closed Cooling Water System
TDAFP	Turbine Driven Auxiliary Feed Water Pump
TGS	Turbine Gland Steam System
ThV	Throttle Valve
TIP	Traversing In-Core Probe
TLD	Thermo Luminescence Dosimeter
TOP	Turning Gear Oil Pump
TSC	Technical Support Center
VCT	Volume Control Tank
VSS	Vibration Surveillance System
WDS	Waste Disposal System
W Evap	Waste Evaporator Package
WHT	Waste Hold-up Tank

Reference: Nuclear Power Handbook (1989) supervised by Chuichi Asada, et al. Outline of Light Water Reactor Power Plant (1984), Nuclear Safety Association, Junkoh Morishima. Nuclear Power Index (1987), Nuclear Power Dictionary (1981) edited by the Nuclear Power Dictionary Editing Committee, Corona Publishing Co., Ltd.

25-1 Reprocessing

(1) Basic Flow Diagram of Reprocessing Plant (Rokkasho Reprocessing Plant)



(2) Characteristics of Spent Fuels (example)

(per 1 ton of uranium in spent fuel)

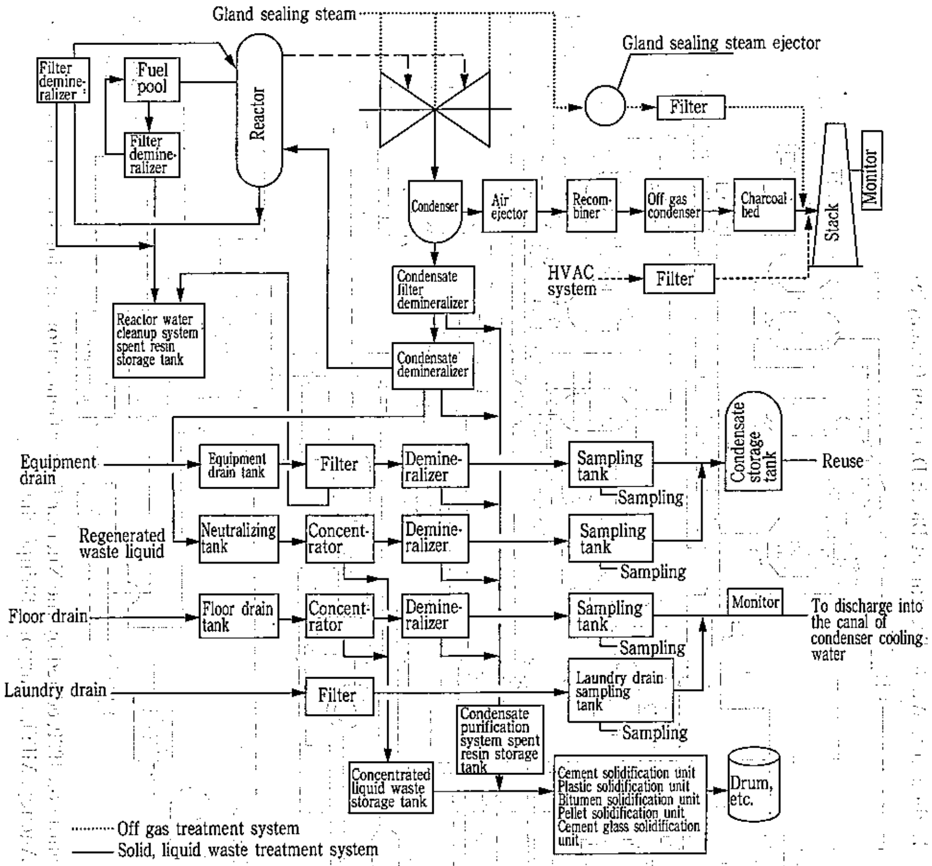
Condition	Burn-up 45,000MWd/t Initial enrichment 4.5wt% Specific power 38MW/t Reactor type BWR Cooling time 4 years		
Nuclide	Half life	Radioactivity (Bq)	Mass (g)
H-3	12.3y	2.1×10^{13}	5.9×10^{-2}
Kr-85	10.7y	3.7×10^{14}	2.6×10^{1}
Sr-89	50.5d	6.5×10^{7}	6.0×10^{-8}
Sr-90	29.1y	3.5×10^{15}	6.9×10^{2}
Y-90	64.0h	3.5×10^{15}	1.7×10^{-1}
Y-91	58.5d	1.3×10^{9}	1.5×10^{-6}
Zr-95	64.0d	8.3×10^{9}	1.0×10^{-5}
Nb-95	35.0d	1.9×10^{10}	1.3×10^{-5}
Ru-103	39.4d	3.9×10^{5}	3.3×10^{-10}
Rh-103m	56.1m	3.5×10^{5}	2.9×10^{-13}
Ru-106	368d	1.5×10^{15}	1.2×10^{1}
Rh-106	29.9s	1.5×10^{15}	1.1×10^{-5}
Te-129m	33.6d	1.5×10^{2}	1.3×10^{-13}
I-129	1.6×10^{7}y	1.5×10^{9}	2.3×10^{2}
I-131	8.0d	0	0
Xe-133	5.3d	0	0
Cs-137	30.0y	4.8×10^{15}	1.5×10^{3}
Ba-140	12.8d	2.7×10^{-18}	1.0×10^{-33}
La-140	40.3h	3.1×10^{-18}	1.5×10^{-34}
Ce-141	32.5d	1.9×10^{3}	1.8×10^{-12}
Ce-144	284.3d	1.4×10^{15}	1.2×10^{1}
Pr-144	17.3m	1.4×10^{15}	5.2×10^{-4}
Pm-147	2.6y	1.9×10^{15}	5.6×10^{1}
Total		2.0×10^{16}	2.5×10^{3}

(per 1 ton of uranium in spent fuel)

Condition	Burn-up 45,000MWd/t Initial enrichment 4.5wt% Specific power 38MW/t Reactor type PWR Cooling time 4 years		
Nuclide	Half life	Radioactivity (Bq)	Mass (g)
H-3	12.3y	2.1×10^{13}	6.0×10^{-2}
Kr-85	10.7y	3.7×10^{14}	2.5×10^{1}
Sr-89	50.5d	6.5×10^{7}	6.0×10^{-8}
Sr-90	29.1y	3.4×10^{15}	6.7×10^{2}
Y-90	64.0h	3.4×10^{15}	1.7×10^{-1}
Y-91	58.5d	1.3×10^{9}	1.5×10^{-6}
Zr-95	64.0d	8.3×10^{9}	1.0×10^{-5}
Nb-95	35.0d	1.9×10^{10}	1.3×10^{-5}
Ru-103	39.4d	3.9×10^{5}	3.3×10^{-10}
Rh-103m	56.1m	3.5×10^{5}	2.9×10^{-13}
Ru-106	368d	1.5×10^{15}	1.2×10^{1}
Rh-106	29.9s	1.5×10^{15}	1.1×10^{-5}
Te-129m	33.6d	1.5×10^{2}	1.4×10^{-13}
I-129	1.6×10^{7}y	1.5×10^{9}	2.4×10^{2}
I-131	8.0d	0	0
Xe-133	5.3d	0	0
Cs-137	30.0y	4.7×10^{15}	1.5×10^{3}
Ba-140	12.8d	2.7×10^{-18}	1.0×10^{-33}
La-140	40.3h	3.1×10^{-18}	1.5×10^{-34}
Ce-141	32.5d	1.9×10^{3}	1.8×10^{-12}
Ce-144	284.3d	1.4×10^{15}	1.2×10^{1}
Pr-144	17.3m	1.4×10^{15}	5.1×10^{-4}
Pm-147	2.6y	1.9×10^{15}	5.6×10^{1}
Total		2.0×10^{16}	2.5×10^{3}

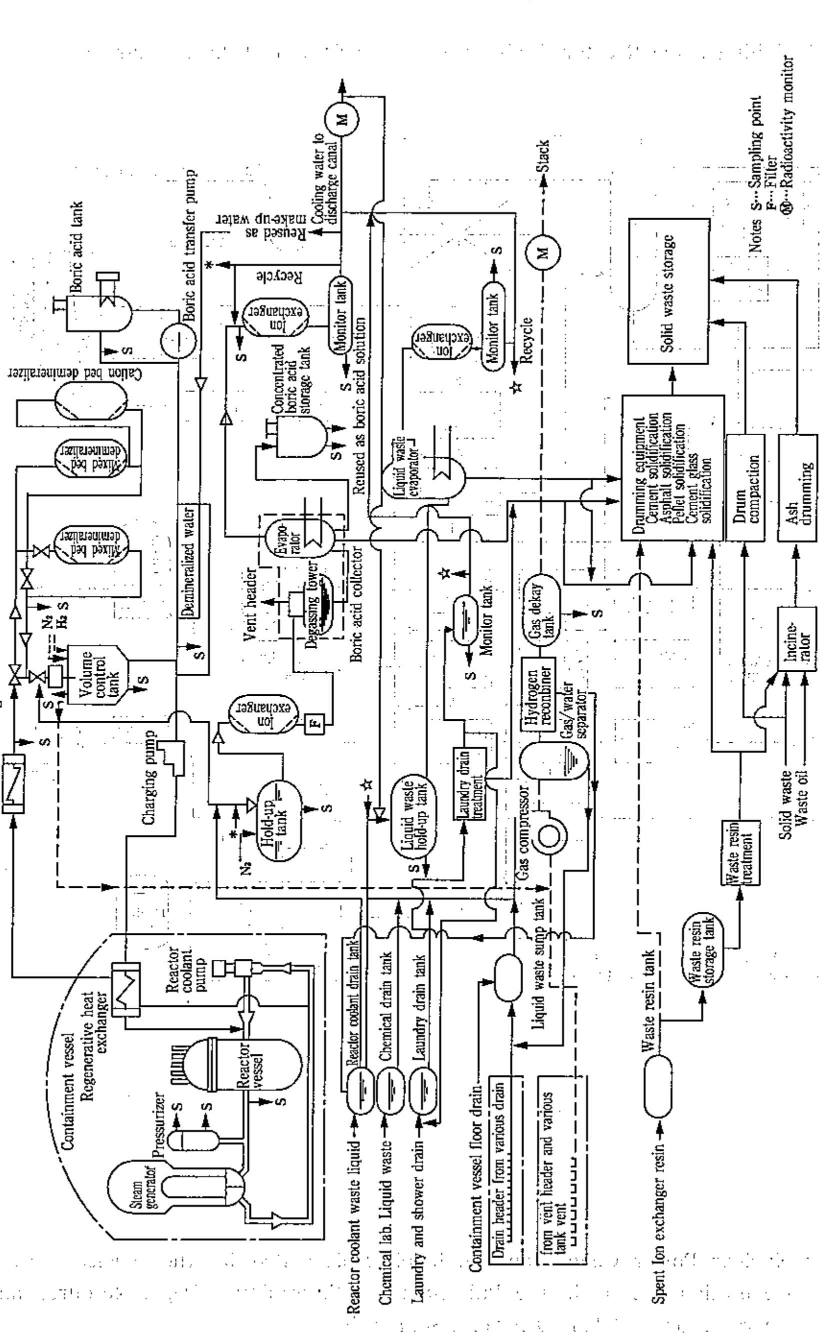
25-2 Waste Management of Light Water Reactors

(1) BWR (Boiling Water Reactor) Radioactive Waste Treatment Block Diagram



Source: Nuclear Power Generation Handbook 1999, edited by the Nuclear Power Generation Section in the Public-Service Entertaining Dept., Resource and Energy Agency, MITI, Denryoku Shinpo-sha.

(2) PWR (Pressurized Water Reactor) Radioactive Waste Treatment Block Diagram (example)



Source: Nuclear Power Generation Handbook 1999, edited by the Nuclear Power Generation Section in the Public-Service Entertaining Dept., Resource and Energy Agency, MITI, Denryoku Shinpo-sha

25-3 Waste Treatment Methods

(1) Gaseous Waste

Processing type	Processing method	Merit and demerit	Remark
(1) Adsorption method	Charcoal filter is used to adsorb iodine in gases.	Pretreatment are required such as dehumidification and removing the dust.	It is used together with a particle removal filter.
(2) Filtration method	Prefilter and absolute filters are used to correct dust in off-gas.	This method is effective to remove dust and fine particles, but cannot remove gaseous radioactivity nuclide.	
(3) Decay method	To store the tank reduce the radioactivity. Delayed pipe and charcoal bed are used for off-gas decay.	Suitable for short half-life nuclide.	For a light water reactor, usually 30 to 45 days are taken as decay time.

(2) Solid Waste

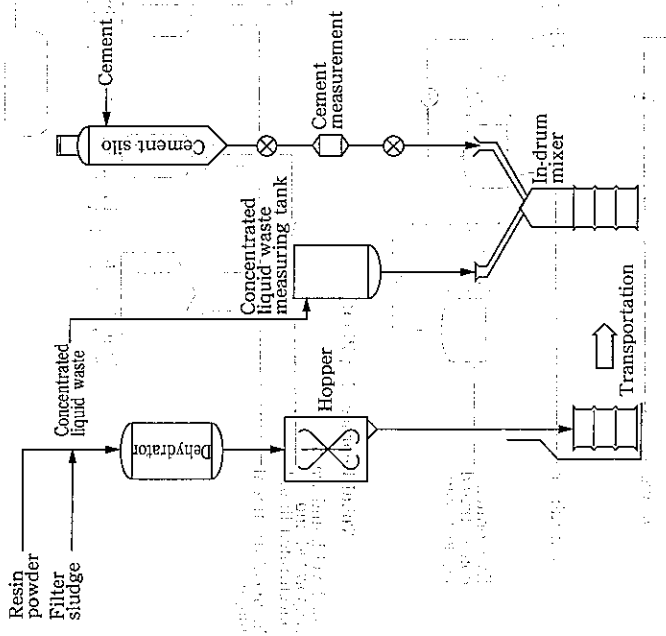
Processing type	Processing method	Merit and demerit	Remark
(1) Compaction method	Compactable waste is put in a drum then pressed and reduced the volume using a compacter.	Only applied to compactable waste, for example, paper, cloth, vinyl, etc. The volume reduction ratio is small.	
(2) Shredding method	Applied for incombustible waste, which is shredded into a shape for storage by cutter, or plasma arc.	Applicable for any shaped miscellaneous solid waste, except for waste that generate the gas when shredded.	A remote automated device is needed for high level radioactive waste.
(3) Incineration method	Applied for combustible waste, which is burned in an incinerator.	Compared with the compaction method, the volume reduction ratio is large, but the facility and operation costs are expensive.	A high temperature incinerator can melt the solid mixtures of incombustible waste.
(4) Solidification method	Waste is mixed and solidified with such as cement, bitumen, plastic, glass, etc.	Suitable for spent resin, sludge, concentrated liquid waste.	Final disposal is now under investigation.
(5) Pelletizing method	Various types of waste are dried into a powder, and then are pelletized for high volume reduction.	This method can reduce the waste volume significantly, but pellets are intermediate storage.	Pellets can be solidified by cement-glass.
(6) Melting method	Applied for incombustible solid waste, which is melted by radio frequency heating, or plasma arc.	Volume reduction ratio is significantly high.	

(3) Liquid Waste

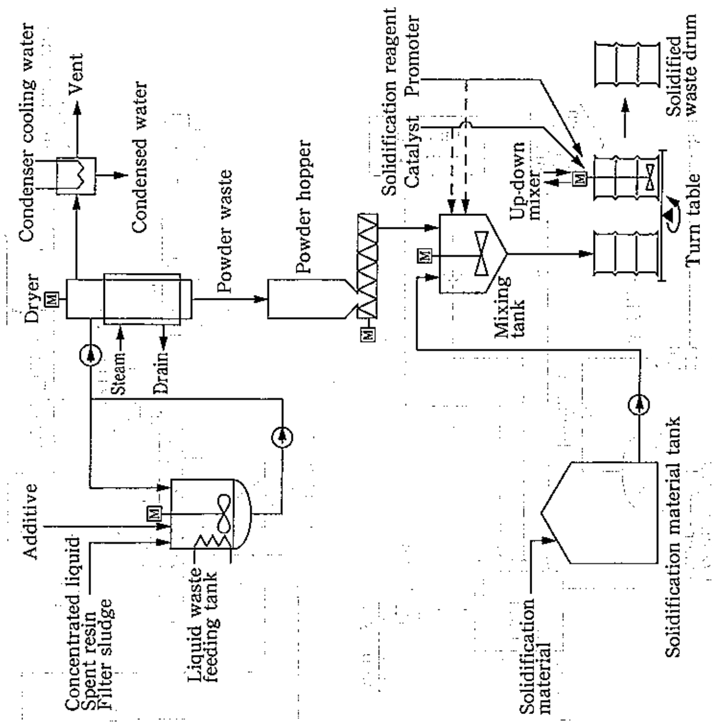
Processing type	Processing method	Merit and demerit	Remark
(1) Evaporation method	Liquid waste is steamed or heated so that it is evaporated and concentrated.	Excellent in volume reduction and decontamination performance, but the equipment and operation costs are more expensive than other methods.	Corrosion factor should be taken into consideration to select materials.
(2) Ion exchange method	Ion exchange radical in the ion exchange resin is exchanged with ion contained in water to remove waste.	Suitable for waste with less dissolved ion. Not suitable for waste with much dissolved ion and residual matter.	When resin is regenerated, regenerated waste liquid is generated. The processing for this should be considered in advance.
(3) Filtration method	Micro grains in waste are removed through a filter. The following filter types are used actually. Cartridge filter. Pre-coat filter. Electromagnetic filtration. Membrane filtration. (NPMF). Hollow fiber filter. Ultrafiltration.(UF) Sand filter.	If the filtration pressure difference is increased, then following method should restored it. Element replacement. Filter aid replacement. Back wash the filter with water or air. The suspended substances in filter can be removed with slurry.	
(4) Reverse osmosis method	If the pressure more than osmotic pressure is applied on the concentrated solution through a half-transparent film that passes only pure water, only the water in the solution passes through the film. This method uses this phenomenon.	Suspended substances must be removed with a filter in advance.	Suitable for low level laundry waste.
(5) Centrifugal separation method	Centrifugal separator type filter with multiple separation plates combined as a set and is rotated at high speeds. Liquid waste is supplied in the centrifuge and the crud content is forcibly settled and removed by centrifugal force.	Maintenance is often needed, because a high speed rotating machine.	This method is used before the membrane filtration or hollow fiber filtration.
(6) Coagulating sedimentation method	Just like drinking water processing, sedimentation agent is injected in waste so that waste may be absorbed in the agent and removed.	The equipment and operation cost are cheap. The method is suitable for large quantities of waste, but decontamination effect is not so high, and much sludge is generated as a demerit.	Suitable for processing low level waste liquid.

(4) Typical Solidification Systems

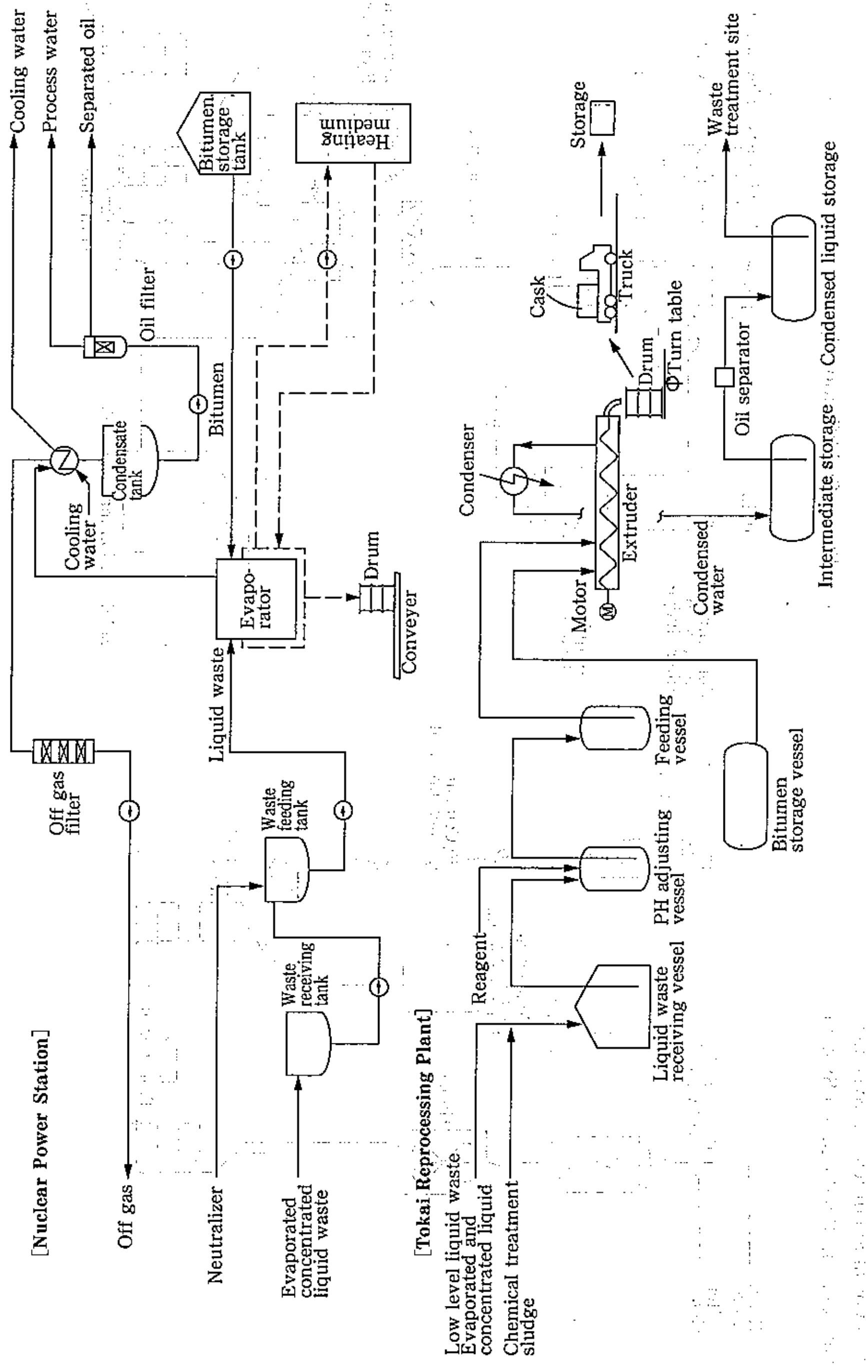
(a) Cement Solidification System



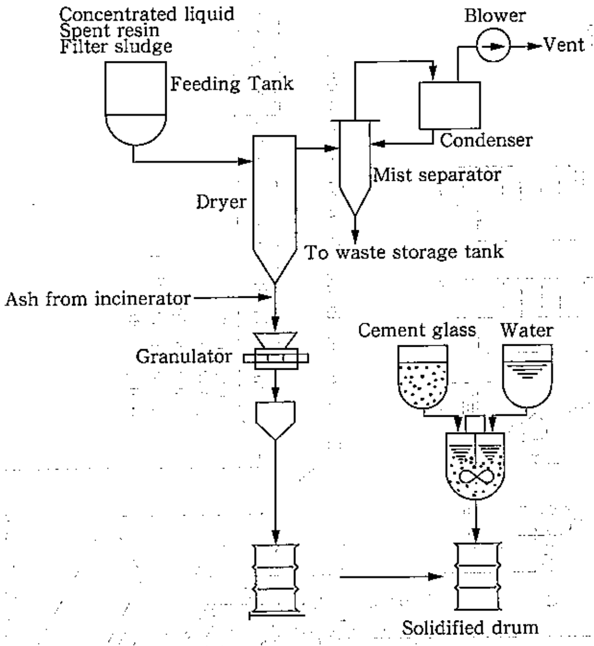
(b) Plastic Solidification System

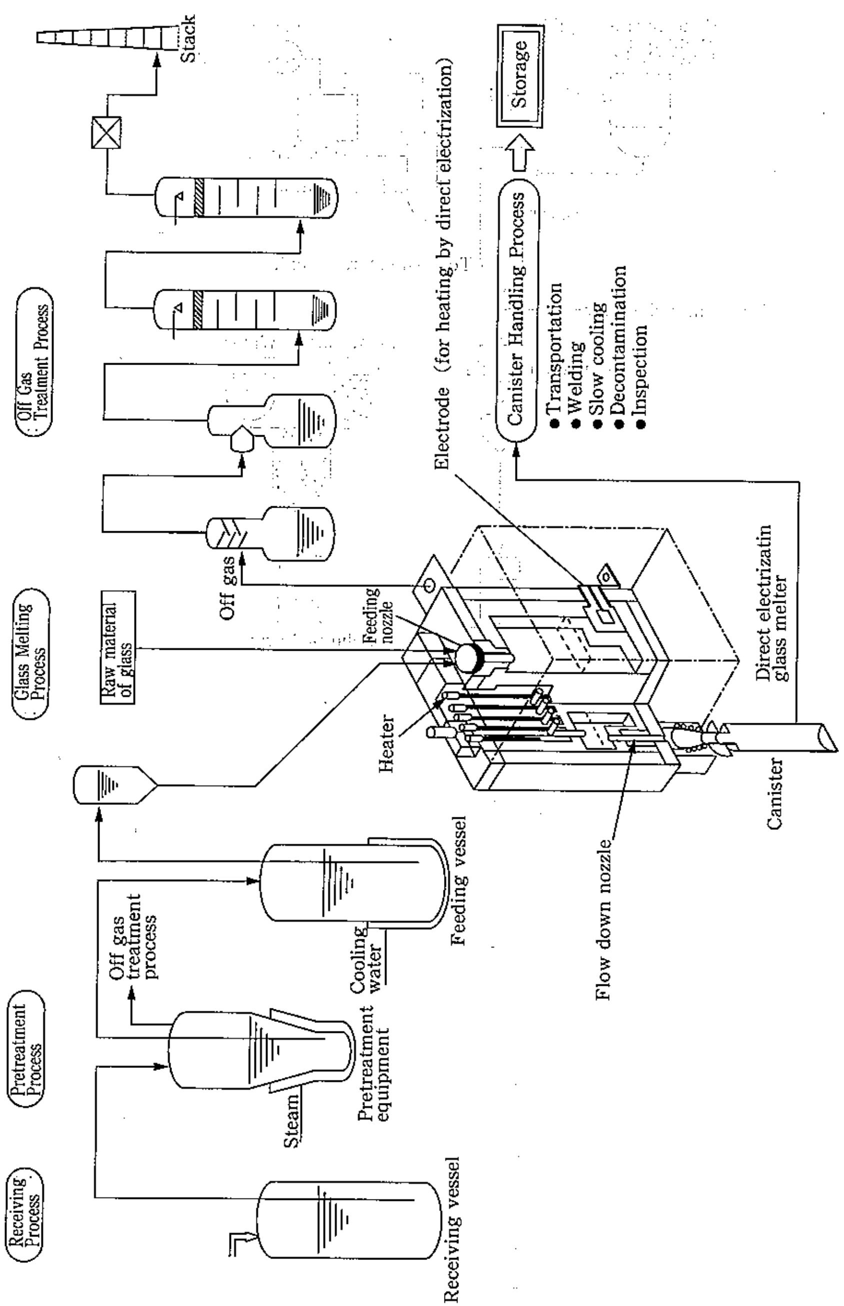


(c) Bitumen Solidification System



(d) Pelletization System





(e) Flow Sheet of High Level Liquid Waste Vitrification System

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25-4 Treatment/Conditioning and Disposal of Radioactive Wastes

[Long-Term Program for Research, Development and Utilization of Nuclear Energy. (Unofficial Translation), Part 2, Chapter 3, Article 4, Atomic Energy Commission, Japan. Nov., 2000.]

Radioactive waste is generated primarily at nuclear power plants and nuclear fuel cycle facilities (including waste returned from abroad after spent fuel reprocessing under contract), but some does come from universities, research institutes, medical institutions and other facilities. Such waste should be safely treated/conditioned and disposed of by the generators. The government should provide guidance to or regulate the generators to ensure that the treatment/conditioning and disposal are carried out properly and safely.

(1) Commitment to Waste Disposal

Some low-level radioactive waste from nuclear power plants has already been buried underground. Based on studies of methods of disposal, a basic policy has been presented on the disposal of other radioactive waste, excluding uranium waste, the disposal of which is now under investigation and discussion.

As to radioactive waste for which no specific disposal plan has yet been proposed, it is essential that the generators and other interested parties formulate and implement a specific plan through sufficient consultation and cooperation so that they can promptly start safe, efficient treatment/conditioning and disposal. During the implementation of the plan, the government should support the interested parties' efforts, whenever necessary, to prevent waste disposal problems from adversely affecting the development and utilization of nuclear energy.

Since radioactive waste varies greatly in its level of radioactivity and in the type of radioactive material contained, arrangements should be made to classify the waste by method of disposal, regardless of the facility from which it comes, and take specific measures for its treatment/conditioning and disposal.

(a) Waste for Geological Disposal

Radioactive waste having relatively high radioactivity and containing large amounts of radioactive materials with a long halflives should be disposed of by a method capable of securing safety for a long period of time, so that the living environment will not be affected. This requires the use of geological disposal, which, after providing engineering barriers to prevent radioactive materials from leaking out, buries the waste in stable underground zones several hundred meters deep, which serves as a natural barrier.

(High-Level Radioactive Waste)

Japan's policy is that high-level radioactive waste remaining after the recovery of plutonium, uranium and other useful materials from spent fuel by reprocessing should be solidified in a stable form and, after being stored for 30 to 50 years for cooling, buried under the ground by the geological disposal method. Vitrified high-level radioactive waste is already stored at a repository in Rokkasho-mura, Aomori Prefecture. According to the "Final Disposal of

Designated Radioactive Waste Program," which was issued on October 2, 2000, under the Law on Final Disposal of Designated Radioactive Waste, final disposal will start sometime in the latter half of the 2030's.

In selecting disposal sites, an important factor is gaining understanding and support from residents concerned. In order to do so, it is important to ensure transparency through thorough information disclosure. The government, electric utilities and the implementing entity, a leading player in site selection, should perform each duty with proper role sharing and mutual cooperation. For this purpose, the government should clarify the political significance of final disposal and its efforts to secure safety, and endeavor to obtain understanding from residents. It should also provide all necessary systems and setups for coexistence between the planned disposal facility and the local community; while the utilities and others having basic responsibility as the waste generators should carry out activities to gain public understanding of the disposal project, with cooperation from the implementing entity and the government, and should work actively with the implementing entity in selecting disposal sites.

From the geological disposal technologies for high-level radioactive waste, the implementing entity should take charge of developing those consistent with the safe implementation of the final disposal project and with the improvement of its economic performance and efficiency. Meanwhile, the government and related organizations should actively push forward with research and development projects necessary for safety regulation and safety assessment of the final disposal, with fundamental research and development activities, including scientific studies of the deep geological environment, and with development of technologies to enhance the reliability of geological disposal technology.

Based on the results of past research and development efforts, the Japan Nuclear Cycle Development Institute, among others, should steadily carry on research and development activities to verify the reliability of geological disposal technologies and to establish a safety assessment method, using research facilities for deep geological environments and the Quantitative Assessment Radionuclide Migration Experiment Facility in Tokai village. The research facility for deep geological environments will serve not only as a place for scientific investigation, but also as a place for deepening public understanding of research and development activities related to the geological disposal of waste. Accordingly, this research facility project should be clearly distinguished from the disposal facility mentioned above.

In order to win people's trust in the business of radioactive waste final disposal, efforts are also needed to provide full information on the disposal project and to secure its transparency at all stages.

(Radioactive Waste Other than High-Level Waste)

In addition to high-level radioactive waste, some other radioactive waste also requires geological disposal. As that waste varies widely in its chemical and physical properties, it is important for waste generators and other interested parties to closely cooperate with one another in carrying out research and development of waste treatment and disposal technologies to pave the way for reasonable disposal of this waste, taking into consideration the diversity of its properties and making use of the results of research and development efforts for the disposal of high-level radioactive waste.

(Partitioning and Transmutation Technology)

The technology to separate radioactive materials with long halflives contained in high-level radioactive waste and convert them into short-lived or non-radioactive, stable materials using a reactor or an accelerator is still at an early stage of research and development, but it should be able to contribute to reducing the burden of waste treatment and disposal, and to effective utilization of available resources. Research and development activities for partitioning and transmutation technology should be carried out based on periodic assessments, in coordination with the development of nuclear fuel cycle technology as a whole. It should be borne in mind that commercialization of partitioning and transmutation technology will not eliminate the need for geological disposal of radioactive waste.

(b) Waste for Disposal with Institutional Control

Radioactive waste whose radioactivity attenuates to a sufficiently low level as to no longer affect the living environment within a period for which institutional management is realistic can be safely disposed of in the ground at a relatively shallow depth, usually by combining engineering and natural barriers, and, after disposal, managing it properly according to its radioactivity. Even waste containing radioactive materials with long halflives can be safely disposed of by the same method and with the same post-disposal management if the concentration of such materials is low enough.

From now on, therefore, specific measures should be taken to pave the way for disposal of low-level radioactive waste, other than that which the nuclear power plants have already begun disposing of it in concrete vaults. In implementing these measures, a study should be conducted not only on the disposing of waste at different sites based on its place of origin, but on disposing of waste by two or more disposal methods at the same site, and on disposing of waste subject to the same disposal method at the same site, regardless of its place of origin.

(2) Decommissioning of Nuclear Facilities

Such nuclear installations as commercial power reactors, test and research reactors, and nuclear fuel cycle facilities, should be decommissioned when the time comes at the responsibility of their operators, under the basic principle of securing safety while gaining the local community's understanding and support. It is expected that the land, after the decommissioning of commercial power reactors, will serve as sites for new nuclear power plants, again with the understanding of their communities.

(3) Reduction of Waste Generation and Promotion of its Effective Use

Steps should be taken to reduce the amount of waste generated and to recycle/reuse it. Research and development to those ends should be actively pushed forward. Interested parties and the competent authorities should jointly conduct an extensive study on the uses of such waste and the development of systems for that purpose, including satisfactory safety checks. Waste with a radioactivity concentration below the "clearance level" need not be dealt with as radioactive material, and may be handled in the same way as conventional waste in respect of safety. In principle, it is important to recycle waste to the fullest extent practical and reasonable.

26-1 Calculation Example of Flue Gas Diffusion

(1) Equation

(a) Calculation of effective stack height

$$He = H_0 + 0.65\ (Hm + Ht)$$

$$Hm = \frac{0.795\sqrt{Q \cdot V}}{1 + \frac{2.58}{V}}$$

$$Ht = 2.01 \times 10^{-3} \cdot Q \cdot (T - 288) \cdot (2.30 \log J + \frac{1}{J} - 1)$$

$$J = \frac{1}{\sqrt{Q \cdot V}} \left(1460 - 296 \times \frac{V}{T - 288}\right) + 1$$

(b) Calculation of maximum concentration on ground and the point

$$C_{max} = 1.72 \times \frac{q'}{He^2}$$

$$X_{max} = 20.8 \times He^{1.143}$$

(c) Calculation of sulfur oxides discharge amount

$$q' = 0.7 \times \frac{S}{100} \times F$$

He = Effective stack height 〔m〕
H_0 = Actual stack height 〔m〕
Q = Amount of flue gas at 15℃ 〔m^3/s〕
V = Flue gas velocity 〔m/s〕
T = Flue gas temperature 〔K〕
C_{max} = Maximum concentration on ground 〔ppm〕
X_{max} = Distance to maximum concentration spot 〔m〕
q' = Sulfur oxides discharge amount 〔m^3_N/h〕
S = Sulfur content in fuel 〔%〕
F = Fuel consumption 〔kg/h〕

(2) Calculation example

(a) Calculation condition

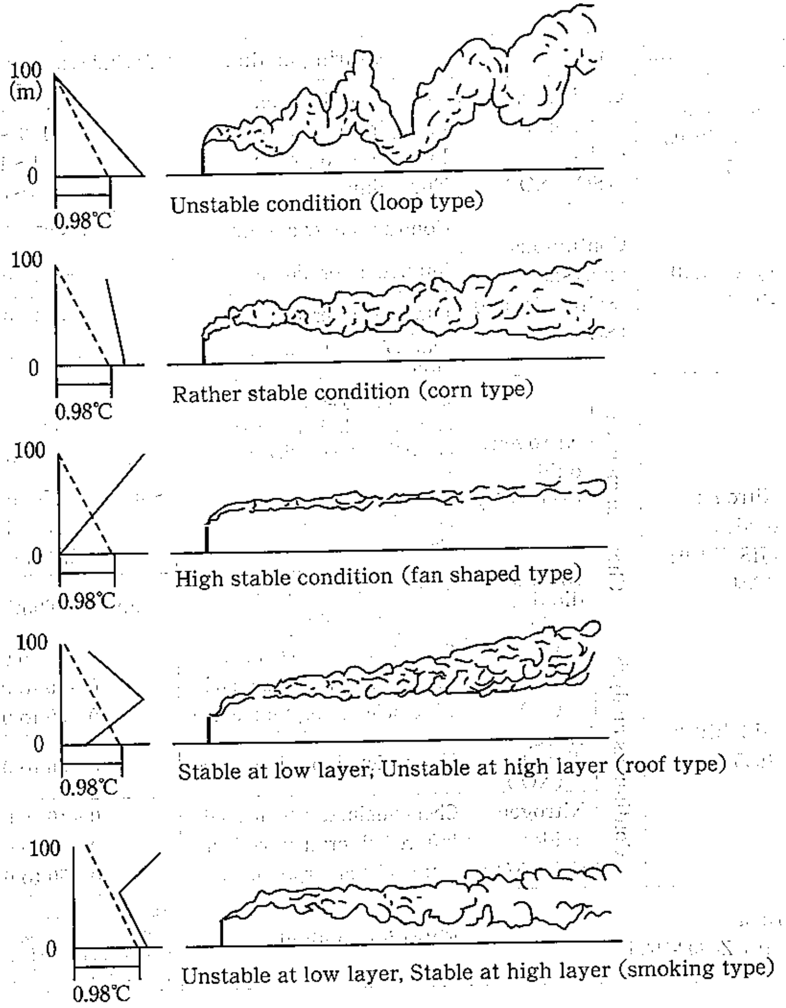
Fuel classification	Heavy oil	Heavy oil	Heavy oil	Coal
Output (MW)	10	350	600	1, 000
Evaporation (t/h)	60	1, 145	1, 950	3, 200
H_0 (m)	60	200	200	230
F (t/h)	5	72	132	391.5
S (%)	1.0	0.4	0.4	1.12
Exhaust gas ($10^3 m^3_N/h$)	71	977	1, 753	3, 560
T (K)	599	408	403	363
V (m/s)	17.1	32.0	31.8	31.5
q' (m^3_N/h)	35	202	370	320

(b) Calculation results

J	77.4	15.5	11.8	4.48
H_t (m)	43.9	124.3	184.1	195.4
H_m (m)	13.1	70.4	94.0	133.2
H_e (m)	97.0	326.0	380.8	443.6
C_{max} (ppm)	0.0065	0.0033	0.0044	0.0028
X_{max} (km)	3.8	15.5	18.5	22.1

〔Extracted from "About the format change of the manual regarding smoke and soot (related to the electricity)" No.513, Sept. 17, 1975, Notification from Chief of Public — Service Undertaking Dept., Agency of Natural Resources & Energy.〕

26-2 Stratosphere Condition and Smoke Diffusion Model



Unstable condition (loop type)

Rather stable condition (corn type)

High stable condition (fan shaped type)

Stable at low layer, Unstable at high layer (roof type)

Unstable at low layer, Stable at high layer (smoking type)

〔Source: Slade, D. H., Ed.: Metrorology and Atomic Energy, USAEC., (1968)〕

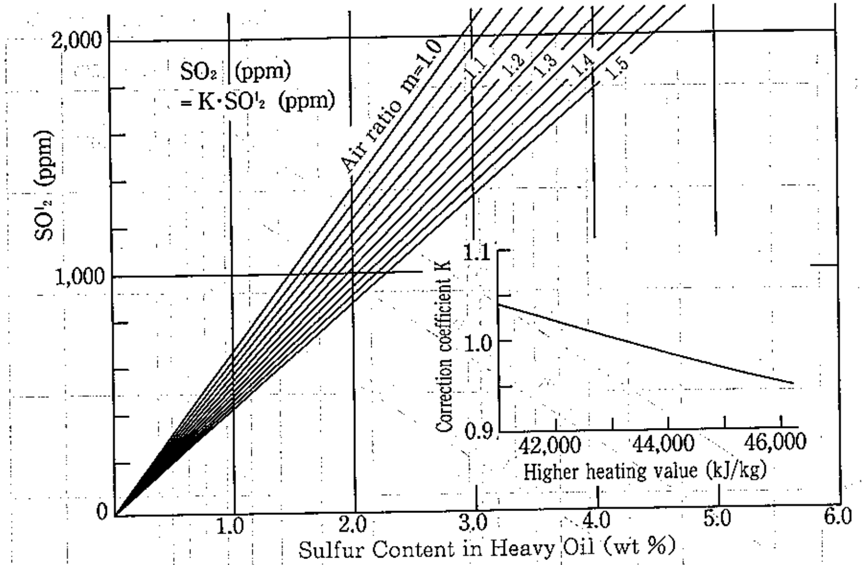
In general, when dry air carries out adiabatic change in the vertical direction, the temperature changes by 0.98℃/100m. If the atmospheric air temperature slope is smaller than the adiabatic lapse rate, then the atmospheric air is stable with less up/down turbulence. Smoke is distributed in the horizontal direction, forming a thin ellipse. If the slope is larger than the adiabatic lapse rate, then the atmospheric air is unstable with large up/down turbulence. Smoke is spread in a wide area. If the slope is equal to the adiabatic lapse rate, then the atmospheric air condition is neutral. Smoke is distributed in a corn shape. In other words, the stability of the atmospheric air affects the width of smoke diffusing significantly.

26-3 Measurement of Flue Gas Characteristics

Substance			Measuring method	Applied concentration range (ppm)	
Sulfur oxides (JIS K0103 -1995)	Chemical analysis (Total sulfur oxides) (SO_2+SO_3)		Neutralize titration	70~2,800	
			Precipitation titration	140~700	
			Ion chromatograph	1~110	
			Turbidimetry	5~300	
(JIS B7981 -1996)	Continuous analysis (Sulfur dioxide) (SO_2)		Conductometric method	0~25−0~2,000	
			Infrared absorption method	0~25−0~2,000	
			Ultraviolet absorption method	0~25−0~2,000	
			Ultraviolet radiation fluorescent method	0~10−0~1,000	
Nitrogen oxides (JIS K0104 -1984)	Chemical analysis	Nitrogen oxides ($NO+NO_2$)	Zinc reduction-naphthylethylene-di-amine method molecular absorption spectro photometry	Sample 50ml	15~800
				150ml	5~250
				800~1,000ml	1~ 50
			Phenol-di-sulfonic acid method molecular absorption spectro photometry	Sample 50ml	150~4, 900
				150ml	50~1, 600
				800~1,000ml	10~ 300
		Nitrogen dioxide (NO_2)	Salzmann method molecular absorption spectro photometry	Sample 100ml	5~ 200
(JIS B7982 -1995)	Continuous analysis	Nitrogen monoxide (NO)	Chemiluminescence method	0~10 to 0~2,000	
			Infrared absorption method	0~10 to 0~2,000	
			Ultraviolet absorptin method	0~50 to 0~2,000	
		Nitrogen dioxide (NO_2)	Ultraviolet absorptin method	0~50 to 0~2,000	
		Nitrogen oxides ($NO+NO_2$)	Chemiluminescence method	0~10 to 0~2,000	
			Infrared absorption method	0~10 to 0~2,000	
			Ultraviolet absorptin method	0~50 to 0~2,000	
Dust (JIS Z8808-1995)			Filtration method	The dust concentration in the flue gas shall be expressed by mass (g) of dust contained in 1㎥ of dried flue gas that has been converted in standard condition.	

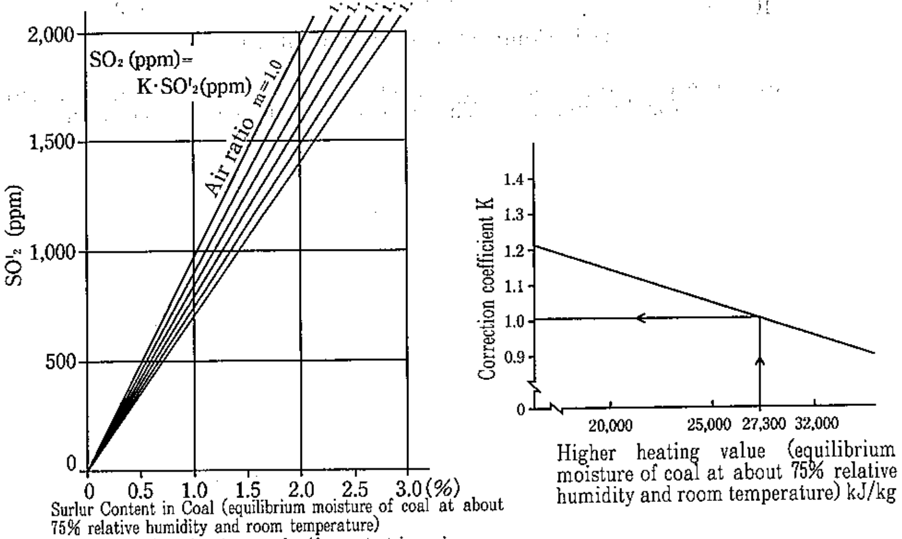
26-4 Relationship between Sulfur Content in Fuel and SO_2 Concentration in Dry Flue Gas (Estimation)

(1) For heavy oil



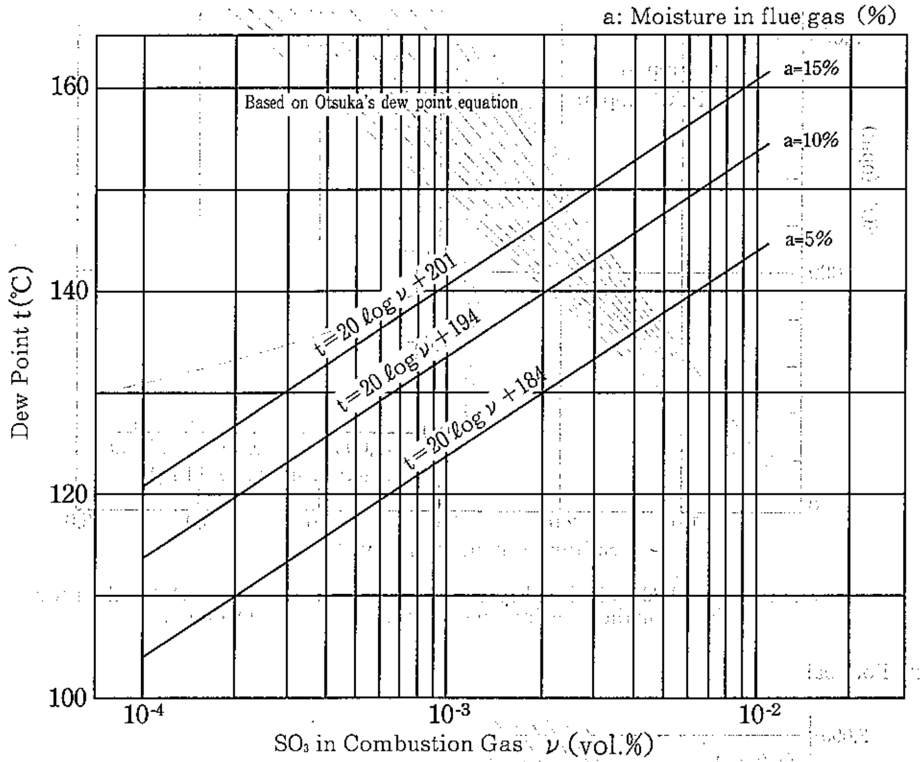
Note: Refer to 10-20 Relationship between Air Ratio and O_2, CO_2 Product for each Fuel, for the relations between air ratio and O_2 density.

(2) For coal



Pulverized coal combustion: total sulfur content in coal
Fluidized bed combustion: Combustible sulfur content in coal

26-5 Relationship between SO_3 Concentration and Dew Point (Calculated Values)



Note: The above figure shows the criteria of the corrosion by the combustion gas for the apparatus. They are not actual measurement values.

26-6 Flue Gas Desulfurization

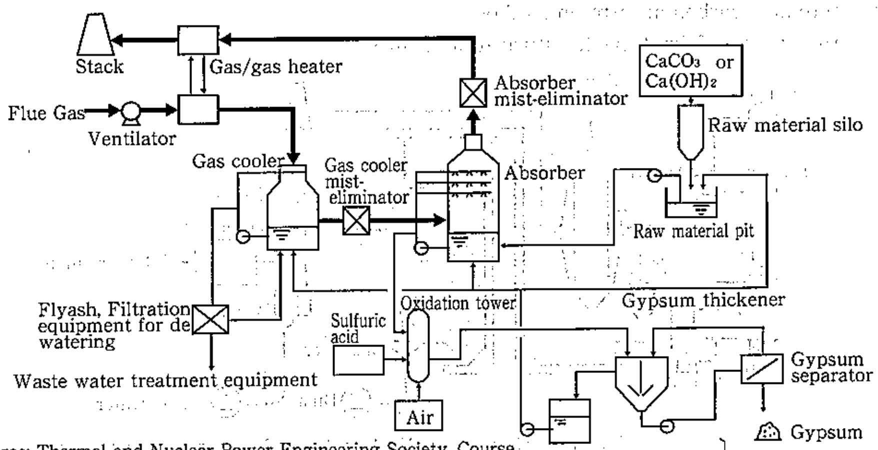
(1) Type of flue gas desulfurization processes

	Process Type	Absorbent	Properties of Absorbent	Raw Material		Byproducts
Wet process	Lime-Gypsum method	Calcium sulfite ($CaSO_3$)	Slurry	Calcium carbonate Calcium hydroxide Quick lime	$CaCO_3$ $Ca(OH)_2$ CaO	Gypsum
	Mg-Gypsum method	Magnesium sulfite $MgSO_3$ Calcium sulfite $CaSO_3$	Slurry	Calcium hydroxide Calcium carbonate	$Ca(OH)_2$ $CaCO_3$	Gypsum
	Sodium sulfite-Mirabilite method	Sodium sulfite Na_2SO_3	Solution	Caustic soda	NaOH	Mirabilite Discharge
	Sodium sulfite recovery method			Caustic soda	NaOH	Sodium sulfite
	Sodium sulfite-Gypsum method			Calcium carbonate Calcium hydroxide Quick lime	$CaCO_3$ $Ca(OH)_2$ CaO	Gypsum
	Sodium sulfite-Sulfuric acid method			–		Sulfuric acid
	Dilute sulfuric acid-Gypsum method	Dilute sulfuric acid	Solution	Calcium carbonate	$CaCO_3$	Gypsum
	NH_3-Ammonium sulfate method	Sulfurous acid ammonium $(NH_4)_2SO_3$	Solution	Ammonium	NH_4OH	Ammonium sulfate
	NH_3-Gypsum method			Calcium hydroxide	$Ca(OH)_2$	Gypsum
	Al-Gypsum method	Basic aluminum sulfite $Al_2(SO_4)_3Al_2O_3$	Slurry	Calcium carbonate	$CaCO_3$	Gypsum
	Mg method	Magnesium sulfite $MgSO_3$	Solution	Magnesium hydroxide	$Mg(OH)_2$	Magnesium sulfate Discharge
Dry process	Activated carbon absorption method	Activated carbon		Activated carbon		Sulfur
Semi-dry process	Spray-dryer method	$Ca(OH)_2$ Na_2CO_3	Slurry	Calcium hydroxide Sodium carbonate	$Ca(OH)_2$ Na_2CO_3	Gypsum Other

(Source: Thermal and Nuclear Power Engineering Society, Course No.16 "Environmental protection technologies•facilities of thermal power station")

(2) Lime-Gypsum method

(a) System diagram of desulfurizer by the Lime-Gypsum method



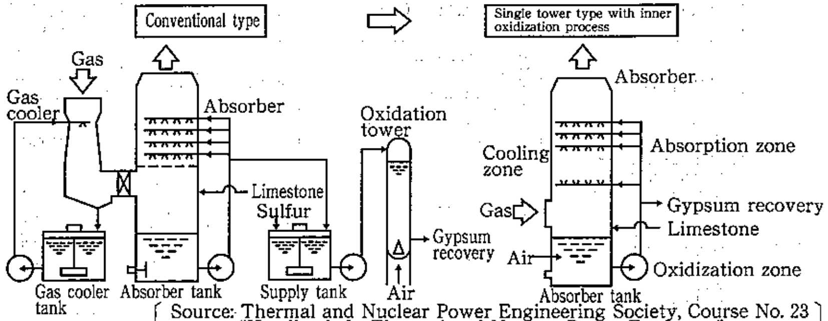
(Source: Thermal and Nuclear Power Engineering Society, Course No.16 "Environmentalprotection technologies•facilities of thermal power station")

(b) Desulfurization equation

$$SO_2 + 2H_2O + CaCO_3 \text{ (Limestone) } + \frac{1}{2}O_2$$

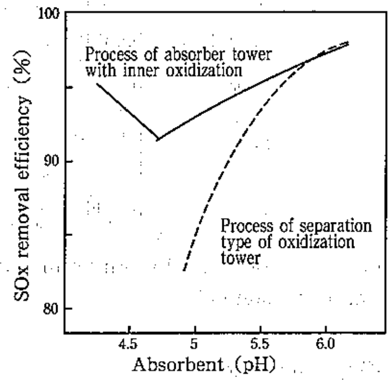
$$\rightarrow CaSO_4 \cdot 2H_2O \text{ (Gypsum) } + CO_2$$

(c) Transition of desulfurization system configuration



[Source: Thermal and Nuclear Power Engineering Society, Course No. 23 "Handbook for Thermal and Nuclear Power Engineers"]

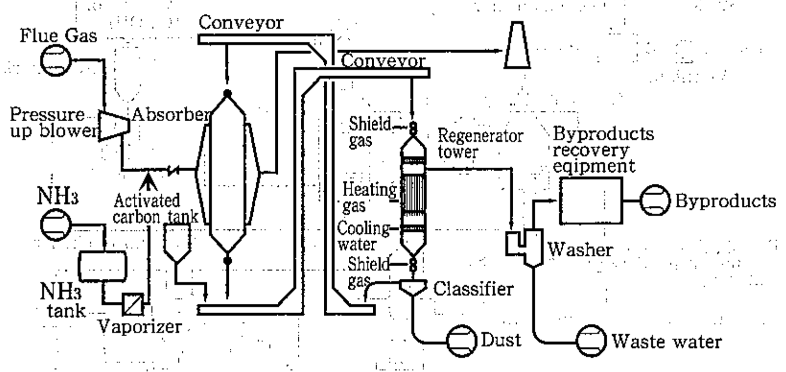
(d) Oxidization system and desulfurization performance



[Source: Thermal and Nuclear Power Engineering Society, Course No. 16 "Environmental protection technologies•facilities of thermal power station"]

(3) Activated carbon absorption method

An example of dry type desulfurization facility



[Source: Thermal and Nuclear Power Engineering Society, Course No. 23 "Handbook for Thermal and Nuclear Power Engineers"]

26-7 NOx Control Methods

As preventive measures to NOx emissions, various methods have been performed for improving the combustion process. Reduction of flame temperature is most effective to suppress the thermal NOx generation. Decreasing O_2 concentration in the gas of burning process is useful to prevent both formations of thermal NOx and fuel Nox. The followings are the main measures taken with regard to combustion in boilers.

(1) Exhaust gas recirculation

In this method, a part of the exhaust gas is mixed with air for combustion to make low oxygen concentration gases and reduce combustion temperature, therefore to be capable of controlling NOx generation.

(2) Two-stage combustion

In this method, the air for combustion is supplied to the furnace dividing into two stages. At the first stage, the air of 80～95% of theoretical air quantity is supplied in the vicinity of fuel burners. Combustion takes place with less air than stoichiometric. Then, the temperature of this main combustion zone is reduced to control thermal NOx generation. After passing the main combustion zone, the additional air is injected for completing the combustion.

(3) Low NOx burner

① Oil/gas firing boiler

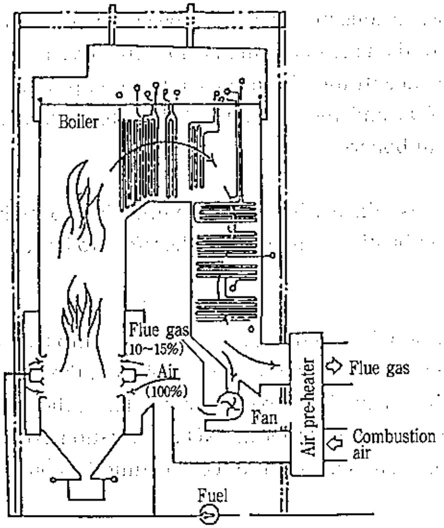
In order to control NOx generation, it is necessary to make fuel burn slowly and lower the combustion temperature. There are some types of low NOx burners. In one type, exhaust gas recirculation or action of two-stage combustion is performed in the burner itself. In another type, premixed fuel and air flows are supplied to produce thick fuel CONC flame and thin fuel WEAK flame, for lowering the combustion temperature. Charge a small amount of hydrocarbon(fuel) into the upper portion of burner may be applied. This type is utilizing the NOx decomposition taken place in activated reduction zone of combustion.

② Pulverized coal firing boiler

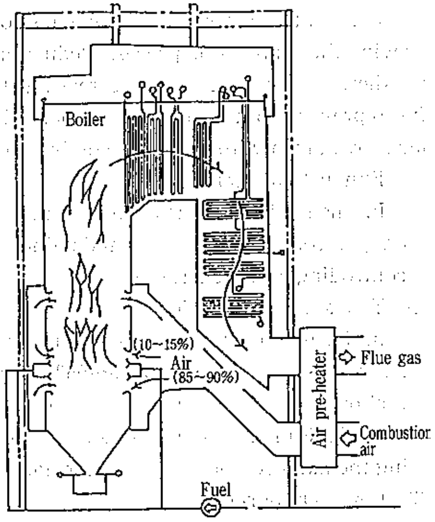
When pulverized coal is burnt, both thermal NOx and fuel NOx are generated, and more than 90% of NOx is frequently occupied by the fuel NOx. The low NOx burner for pulverized coal firing has unique design features with a separator at the burner inlet where produces two off-stoichiometric primary coal-air flows of dense-phase and lean-phase. In this case, two types of flames (Conc and Weak) are formed to reduce the fuel NOx effectively. This method is to take advantage of decomposing characteristic of NOx with hydrocarbon (CnHm) generated in the Conc flame.

In addition, there is another NOx reduction method —— In furnace DeNOx —— in which the mechanism of NOx reduction by CnHm is applied to an overall furnace system by arranging the burner, air inlet, etc., properly.

(1) Principle of exhaust gas recirculation

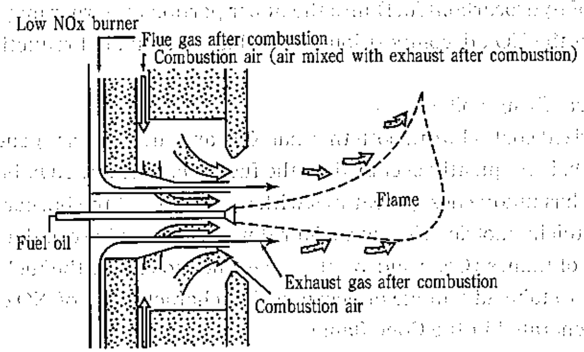


(2) Principle of two-stage combustion method



[Source: Thermal and Nuclear Power Engineering Society, Course No.16 "Environmental protection technologies and facilities of thermal power station"]

(3) Principle of Low NOx burner (Example)



[Source: Thermal and Nuclear Power Engineering Society, Course No.16 "Environmental protection technologies and facilities of thermal power station"]

26-8 Flue Gas Denitrification

(1) The state of research and development of flue gas denitrification

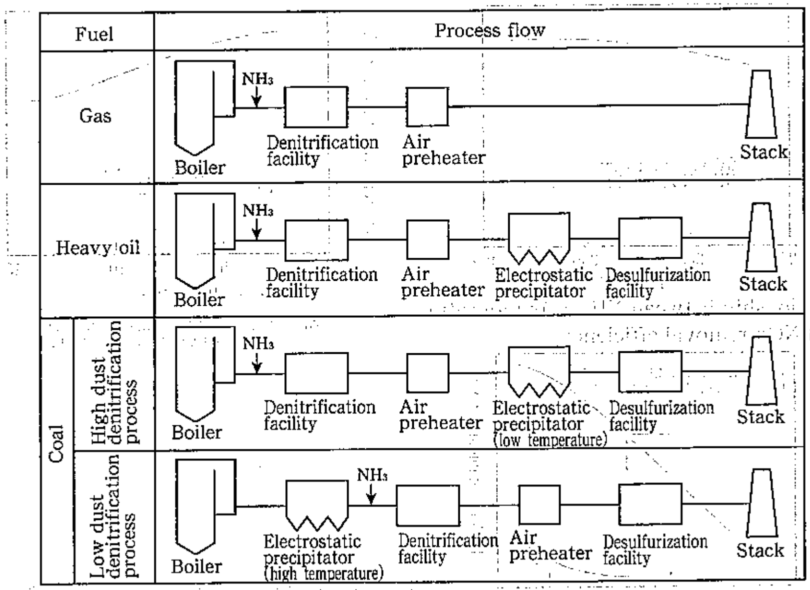
Type	Process name	Principle	Development situation at present
Dry type	Catalytic reduction process: Selective catalytic reduction process Non-selective catalytic reduction process	Using NH_3 as a reducing agent, NOx is selectively reduced according to a catalyst removed. Using H_2•CO as a reducing agent, NOx is nonselectively reduced according to a catalyst removed.	Practical stage Cancellation of development at bench test stage
	Non-catalytic reduction process	Under the condition which high temperature range without using a catalyst, NH_3 is infused, and NOx is reduced and removed.	NOx removal efficiency is low though there is an actual case.
	Catalytic cracking process	Under the condition of high temperature, using a catalyst, it cracks into N_2 and O_2 directly, and NOx is removed.	Laboratory research stage
	Absorption process＊	Using copper oxide system solid absorbent, NOx and SOx are absorbed and removed.	Cancellation of development though pilot test was carried into execution.
	Activated carbon absorption process＊	SOx is absorbed and removed at the same time NOx is selectively reduced by injecting NH_3 and using activated carbon.	Under development at the pilot test
	Zeolite absorption process	Using zeolite system absorbent, NOx is absorbed and removed.	Laboratory research stage
	Electron beam irradiation process＊	An electron beam is irradiated at exhaust gas, and NOx and SOx are activated, and made to react with the alkali, thus collected as a solid material.	Under development at the pilot test
Wet type	Alkali absorption process＊	NOx and SOx are absorbed and removed by alkali absorption solution.	It is not suited for large scale facility because of absorption rate is low.
	Complex salt generation absorption process＊	NOx is absorbed and removed at the same time SOx is absorbed using EDTA/Sodium sulfide.	Under development at the pilot test
	Oxidation-absorption process＊	NOx and SOx are absorbed simultaneously with alkali absorption solution adding oxidization agent.	Development during pilot test using O_3/NH_3 absorption solution method.
	Oxidation-reduction process＊	NH_3 solution is used for an absorbent, and NOx is reduced and removed by absorbed SOx.	Laboratory research stage

＊ : NOx•SOx simultaneous removal process

[Source: Thermal and Nuclear Power Engineering Society, Course No. 16 "Environmental protection technologies•facilities of thermal power station"]

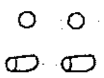
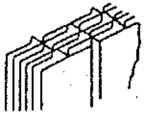
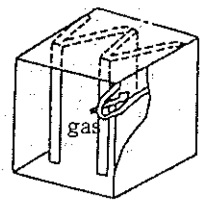
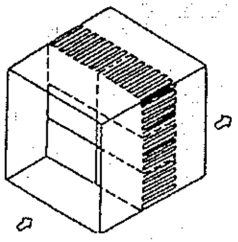
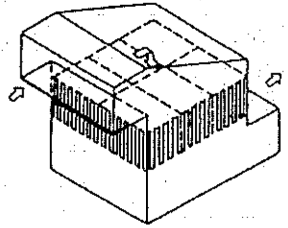
(2) Denitrification techniques by selective catalyst process

(a) Denitrization systems



[Source: Thermal and Nuclear Power Engineering Society, Course No. 16 "Environmental protection technologies•facilities of thermal power station"]

(b) Catalyst types and reactor shapes

	Vertical gas flow type	Parallel gas flow type		
	Grain type	Grid type	Plate type	Cylindrical type
Catalyst				
Reactor	Fixed bed type	Fixed bed type		
				

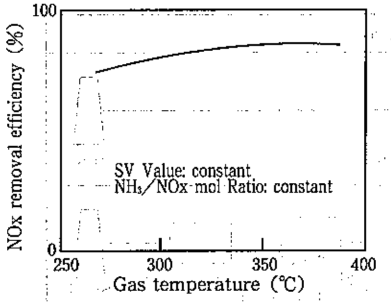
(c) Denitrification equation

$4\,NO + 4\,NH_3 + O_2 \rightarrow 4\,N_2 + 6\,H_2O$

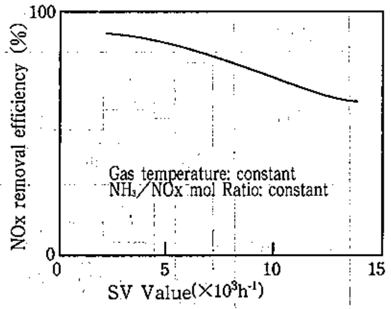
$2\,NO_2 + 4\,NH_3 + O_2 \rightarrow 3\,N_2 + 6\,H_2O$

(d) Denitrification characteristics

a. Relationship between gas temperature and NOx removal efficiency

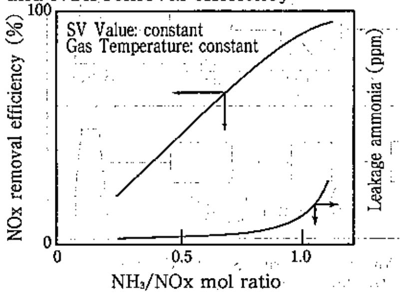


b. Relationship between SV Value and NOx removal efficiency



SV value: Space Velocity (amount of flue gas /activated carbon packed volume)

c. Relationship between NH₃/NOx mol ratio and NOx removal efficiency



Source: Thermal and Nuclear Power Engineering Society, Course No. 16 "Environmental protection technologies•facilities of thermal power station"

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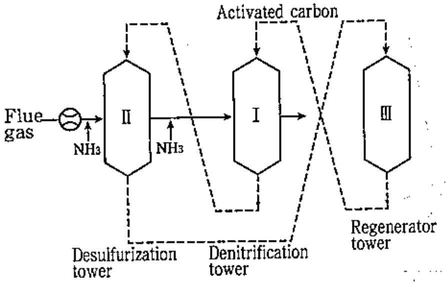
(3) Simultaneous desulfurization and denitrification technologies by dry method

(a) Exhaust treatment system of simultaneous desulfurization and denitrification process by dry method



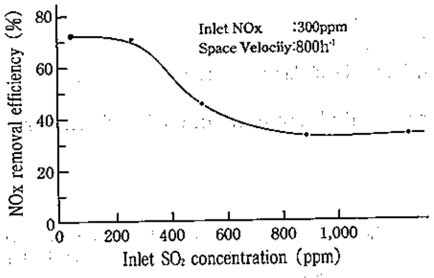
I. Denitrification reaction : $4\,NO + 4\,NO_3 + O_2 \xrightarrow{AC} 4\,N_2 + 6\,H_2O$

II. Desulfurization reaction : $2\,SO_2 + 2\,H_2O + O_2 \xrightarrow{AC} 2\,H_2SO_4/AC$

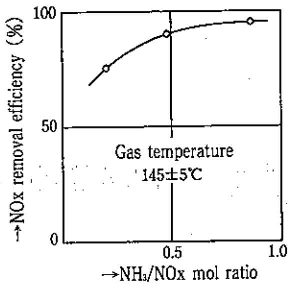
III. Elimination reaction : $2\,H_2SO_4 + C \rightarrow 2\,SO_2 + 2\,H_2O + CO_2$

AC : Activated carbon

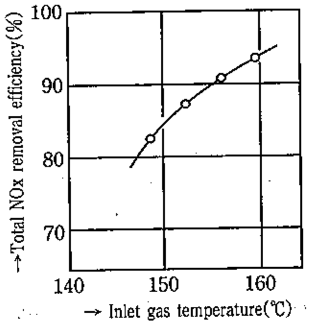
(b) Relationship between inlet SO₂ concentration and NOx removal efficiency



(c) Relationship between NH₃/NOx mol ratio and NOx removal efficiency



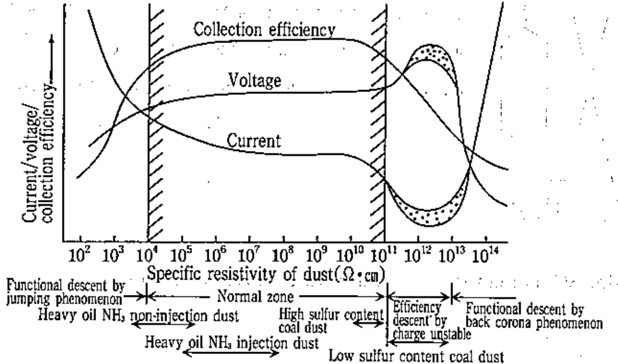
(d) Relationship between exhaust temperature and NOx removal efficiency



Source: Thermal and Nuclear Power Engineering Society, Course No. 16 "Environmental protection technologies•facilities of thermal power station"

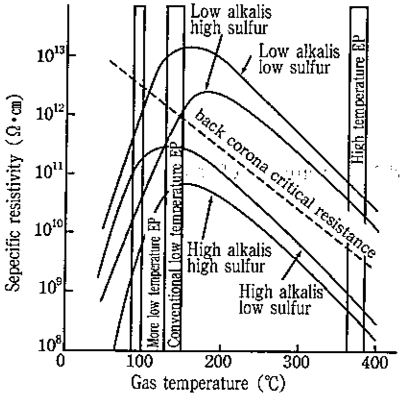
26-9 Precipitator Characteristics

(1) Electrostatic precipitator



(Source: Thermal and Nuclear Power Engineering Society, Course No. 16 "Environmental protection technologies•facilities of thermal power station")

(2) Dust apparent resistivity related to sulfur and alkali contents in coal and temperature



Note: High alkali means about 1 wt% or more Na_2O content and high sulfur means about 1 wt% or more sulfur content.

(Source: Thermal and Nuclear Power Engineering Society, Course No. 23 "Commentary on Handbook for Thermal and Nuclear Power Engineers)

(3) Equation for collection efficiency

(a) Conventional Deutsch equation

$$\eta = 1 - exp(-w \times \frac{F}{Q}) = 1 - exp(-w \cdot f)$$

Where,

η : Dust collection efficiency
w : Apparent average dust mobility (m/s)
F : Dust collection area (m²)
Q : Treated gas volume (m³/s)
f : Specific collecting area (m²/m³/s)

(b) Corrected Deutsch equation

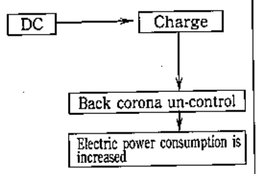
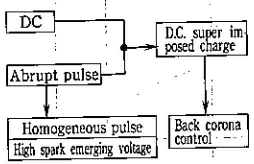
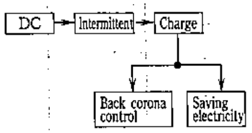
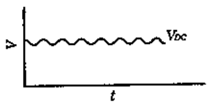
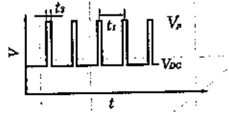
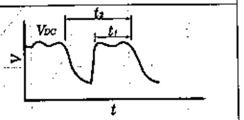
$$\eta = 1 - exp\{-(w \cdot f)^K\}$$

Where,

K : Constant determined through experience according to the dust type, etc.

---

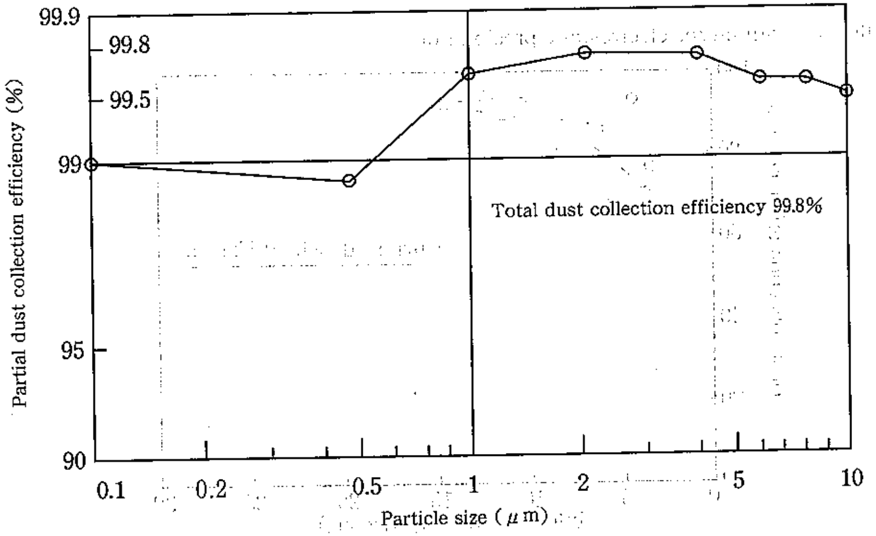
(4) Comparison between conventional charging method and new charging method

No.	Method / Item	Conventional charging method	New charging method	
		D.C. charging method	D.C. pulse super impose charging method	D.C. intermittent charging method
1	Method• Principle			
2	Applied voltage waveform		 t_1 : 5～10ms t_2 : 1～100μs	 t_1 : 10～100ms t_2 : 20～200ms
3	Effect of dust collecting performance	100	100～180	100～120
4	Circuit component	Simplicity	Complexity	Simplicity
5	Maintainability	Good	Troublesome	Good
6	Characteristics	• Base (Inferiority collection to high resistance dust)	• In order to gain a higher peak value of voltage, dust can be electrostatic charged strongly. • Wave density is so homogenized that it has an advantage for high resistance dust due to the high average.	• Collection efficiency is improved for the high resistance dust according to progress with the voltage peak value. • Remarkable effect for saving energy

(Source: Thermal and Nuclear Power Engineering Society, Course No. 16 "Environmental protection technologies•facilities of thermal power station")

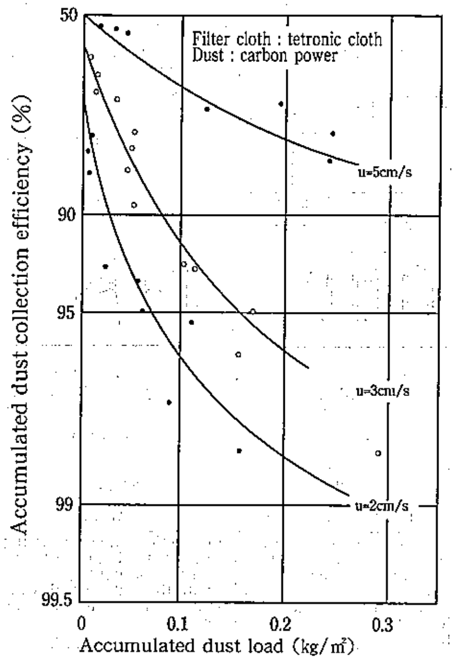
(5) Bug filter

① Partial dust collection efficiency of boiler bug filter



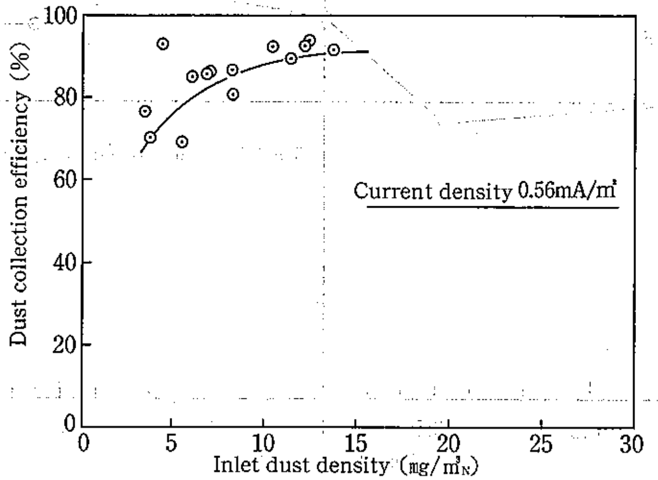
(Source: Iitani Koichi, Journal of The Society of Powder Technology, Japan, V-13 (1976))

② Dust collection efficiency improvement by accumulation dust load



〔Source: D. Leith and M. W. First: "Particle Collection by a Pulse Jet Fabric Filter", 68th Annual Meeting of APCA, 75-57.1 (June 1975), Boston.〕

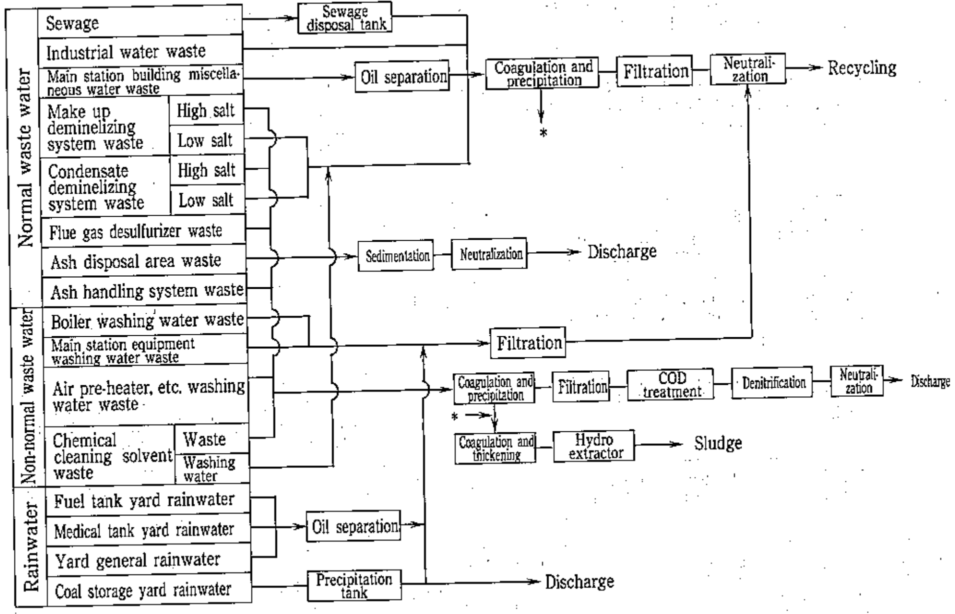
(6) Water-film-type electrostatic precipitator



〔Source: Investigation by Thermal and Nuclear Power Engineering Society.〕

26-10 Waste Water Treatment

(1) Waste water treatment system diagram



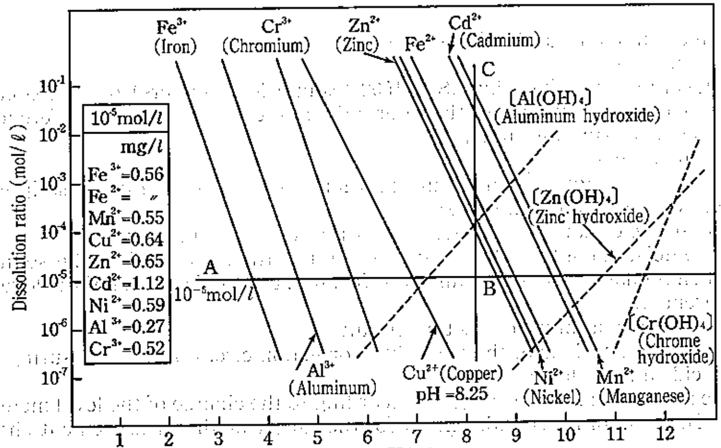
(2) Sewage types and water quality

Sewage type			Water quality item						
			PH	SS	COD	Heavy metal	Oil content	Total nitrogen	Fluorine
Normal waste water	Sewage		Neutral	○	(BOD)	—	—	○	—
	Industrial water waste		Neutral	○	—	—	—	—	—
	Main station building miscellaneous water waste		Neutral	○	—	—	○	—	—
	Make up demineli-zing system waste	High salt	High	○	—	○	—	—	—
		Low salt	Neutral	○	—	—	—	—	—
	Condensate demineli-zing system waste	High salt	High	○	—	○	—	—	—
		Low salt	Neutral	○	—	—	—	—	—
	Flue gas desulfurizer waste		Neutral	○	○	○	—	○	○
	Ash disposal area waste		High	○	—	—	—	—	—
	Ash handling system waste		High	○	—	—	—	—	—
Non-normal waste water	Boiler washing water waste		High	○	○	(Fe)	—	○	—
	Main station equipment washing water waste		Neutral	○	—	○	○	—	—
	Air pre-heater, etc. washing water waste		Low	○	○	○	—	○	—
	Chemical cleaning solvent waste	Waste	Low	○	○	○	—	—	—
		Washing water	Neutral	○	—	○	—	—	—
Rainwater	Fuel tank yard rainwater		Neutral	○	—	—	○	—	—
	Medical tank yard rainwater		Neutral	○	—	—	○	—	—
	Yard general rainwater		Neutral	○	—	—	—	—	—
	Coal storage yard rainwater		Neutral	○	—	—	—	—	—

(3) Main processing methods

Water quality	Method	Outline	Quality of treated water (general standard)	Using process agent	Remarks
pH	Neutralization method	Acid or alkalis is charged/mixed to make pH 5.8 to 8.6.	5.8~ 8.6	Caustic soda, slaked lime, sulfuric acid, hydrochloric acid, etc.	
SS	Coagulation and precipitation method	Flocculant is charged/mixed to precipitate and separate SS content as large blocks.	20ppm or less	Slaked lime, ferric chloride, ferrous sulfate, aluminum sulfate, polychlorinated aluminum, polymer flocculant, etc.	
	Rapid filtration method	SS content is caught and eliminated by anthracite and cleaning sand charged furnace layers.	5ppm or less		
COD	Oxidation aeration method	A blower, etc. are used to aerate and oxidize COD with oxygen in the air.	10ppm or less		This method is used for inorganic COD such as Fe^{2+}, etc.
	Chemical oxidation method	Strong oxidation chemical is charged and mixed.	10 to 20ppm or less	Chlorine gas, bleaching powder, persulfuric acid ammonium, hypochlorite soda.	Boiler blowing water, chemical cleaning solvent, leak test for waste-water.
	Absorb method	Activated coal, composite absorbent used to absorb COD content.	10ppm or less		Used for de-SOx waste and a very small quantity of organic contents.
Heavy metal	pH adjust + coagulation and precipitation method	Acid or alkalis is mixed to adjust pH and generate insolable metallic oxidized deposit, then flocculant is added to precipitate and eliminate heavy metal.	Fe 10ppm or less Cu 3ppm or less Cr 2ppm or less Ni 2 pm or less Zn 5ppm or less V 10ppm or less	Same as the neutralization and the coagulation and precipitation method.	
Oil content	Natural floating method	API, PPI, or CPI oil separator is used to make it float and separate.	10~30ppm		
	Coagulation, pressuring and floating method	Air-mixed pressurized water is mixed to make stick generated micro bubbles to oil and float them to be separated.	1~ 5ppm	Aluminum sulfate, etc.	
Total nitrogen	Ammonia stripping method	This method vaporizes ammonia in the liquid contacting with mass air or steam.	Removal efficiency: 80 to 95%		The steam stripping method can collect ammonia.
	Break point chlorine processing method	Chlorine oxidization action is used to decompose ammonia to nitrogen gas.	Removal efficiency: 95% or more	Chlorine gas, hypochlorite soda, etc.	
	Biological treatment method	Nitrifying bacteria and denitrifying bacteria activities are used to decompose to nitrogen gas.	Removal efficiency: 90% or more	Phosphoric acid, methanol	
Fluorine	Coagulation and precipitation method with addition of calcium	Slaked lime is added to generate insoluble fluoride calcium, then make it precipitate and eliminated.	15ppm or less	Slated lime	

(4) Relationship between dissolution ratio of metallic ion and pH

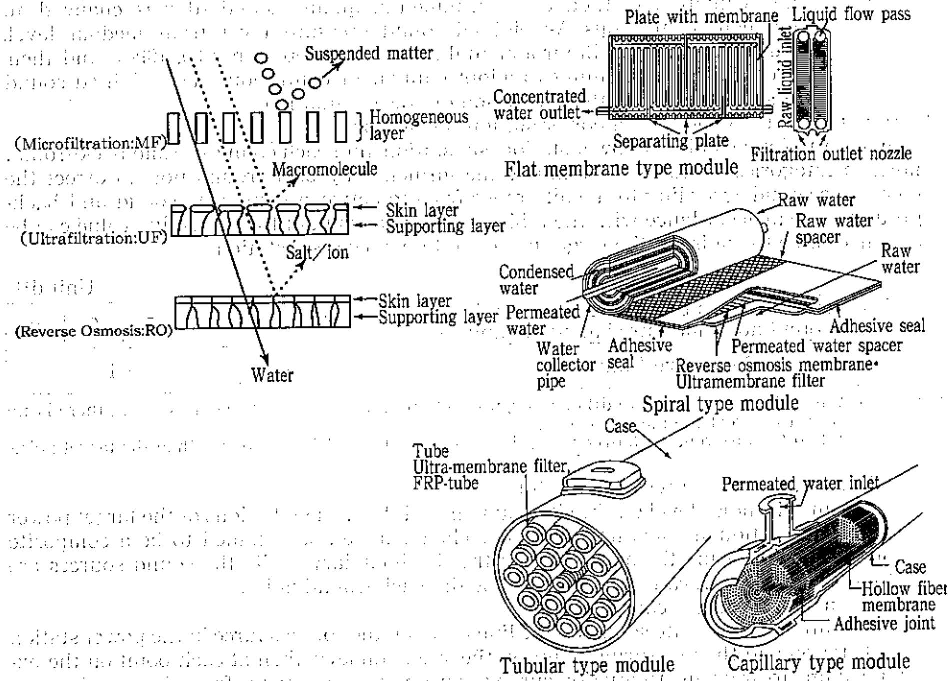


[Source: Thermal and Nuclear Power Engineering Society, Course No. 16 "Environmental protection technologies•facilities of thermal power station"]

(5) Membrane separation method

It is also advancing to apply membrane separation method to waste water treatment recently, besides seawater desalination.

(a) Typical figure by separation membrane (b) Example of structure of membrane module



[Source: Thermal and Nuclear Power Engineering Society, Course No. 16 "Environmental protection technologies•facilities of thermal power station"]

26-11 Noise

(1) Noise level measurement (JEAG 5001-1971)

(a) Measuring instruments

A sound level meter defined by JIS C 1502 (Sound level meters) or precision sound level meters defined by Pub. 179 of the International Electric Standard Conference shall be used as the measuring instrument.

(b) Measuring method

The measurement should be done in accordance with JIS Z 8731 (Description and measurement of environmental noise).

a. How to use the dynamic characteristics of the sound level meter

When the noise is continued at a fixed level, use the slow level of the sound level meter. When it changes suddenly and significantly, use the fast level of the level meter for measurement.

b. How to use the audibility correction circuit

Use the A characteristic of the audibility correction circuit as the measuring scale.

(c) How to decide a noise level

Decide the noise level in each category according to the change of the level meter value with time. But temporary sounds except for the target of the measurement should be excluded.

a. When the level meter value is not changed or changed less, the value can be assumed to be the noise level.

b. When the level meter value changes cyclically or intermittently and the maximum noise level value is almost fixed, read the maximum value of each changed level and average the read values. The averaged value can be assumed to be the noise level.

c. When the level meter value is unstable and changed significantly, the upper end value in the 90% range of the measured value can be assumed to be the noise level.

Note: The evaluation method of environmental quality standard was changed to equivalent continuous A-weighted sound pressure level from median level. (Ordinance No. 64 of Environmental Agency on September 30, 1998) And then, the country is examining to adopt equivalent continuous A－weighted sound pressure level as for the evaluation of noise regulation.

(2) How to decide the noise of a power station/substation

In order to fix the noise of power station/substation, find each composite and background noise in categories (a) and (b) to eliminate the influence by background noise. Correct the composite sound according to the difference from to between composite sound and background noise in accordance with the table below. The result of the corrective value can be assumed to be the noise of the target power station/power substation.

Unit dB

Difference between composite sound and background noise measured at site boundary	3	4	5	6	7	8	9
Corrective Value	−3	−2		−1			

Remark: 1. When the difference is 10 dB or more, no background noise influence exists. Thus, there is no need to correct the measured value.
2. When the difference is 3 dB or less, the background noise shows greater than the target noise.

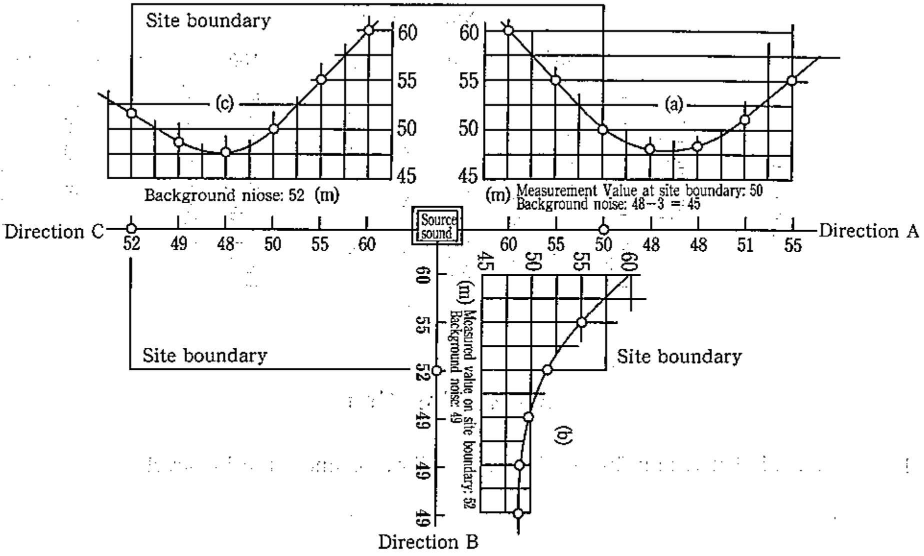
(a) When the sound sources can be shut;

Measure the noise level on the site boundary while the installations of the target power station/substation are operated normally. The result can be assumed to be a composite sound. Then, measure the noise level on the site boundary while the sound sources are stopped. The result can be assumed to be the background noise.

(b) When sound sources cannot be shut;

Measure the composite sound on the line between the sound source in the power station /substation and the measuring point on the site boundary, then at each point on the extended line to draw an attenuation curve according to the distance from the sound source and decide the background noise as follows.

Figure A Example of the distance attenuation curve from the sound source.

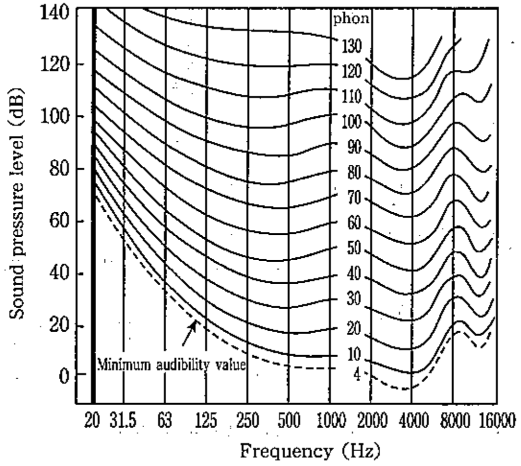


a. If the min. value of the composite sound distance attenuation curve is outside the site boundary of the power station/substation, the value obtained by subtracting 3dB from the min. value can be assumed to be the background noise of the power plant/substation. (Figure A(a))

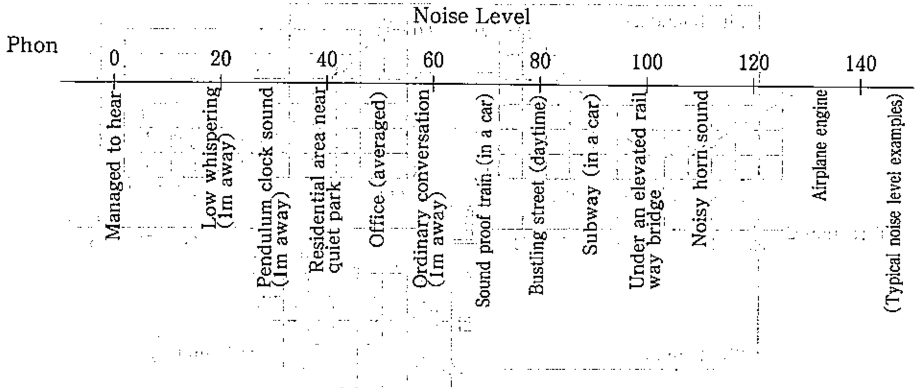
b. If the value of the composite sound distance attenuation curve is reduced gradually as it goes outward, then the convergence value can be assumed to be the background noise of the power station/substation. (Figure A(b))

c. If the minimum value of the composite sound distance attenuation curve is within the site boundary of the power station/substation, then the value measured on the site boundary can be assumed to be the background noise of the power plant/substation. (Figure A(c))

(3) Equivalent audible noise curve (from Chronological Scientific Tables, 1999, published by Maruzen Co.,Ltd.)

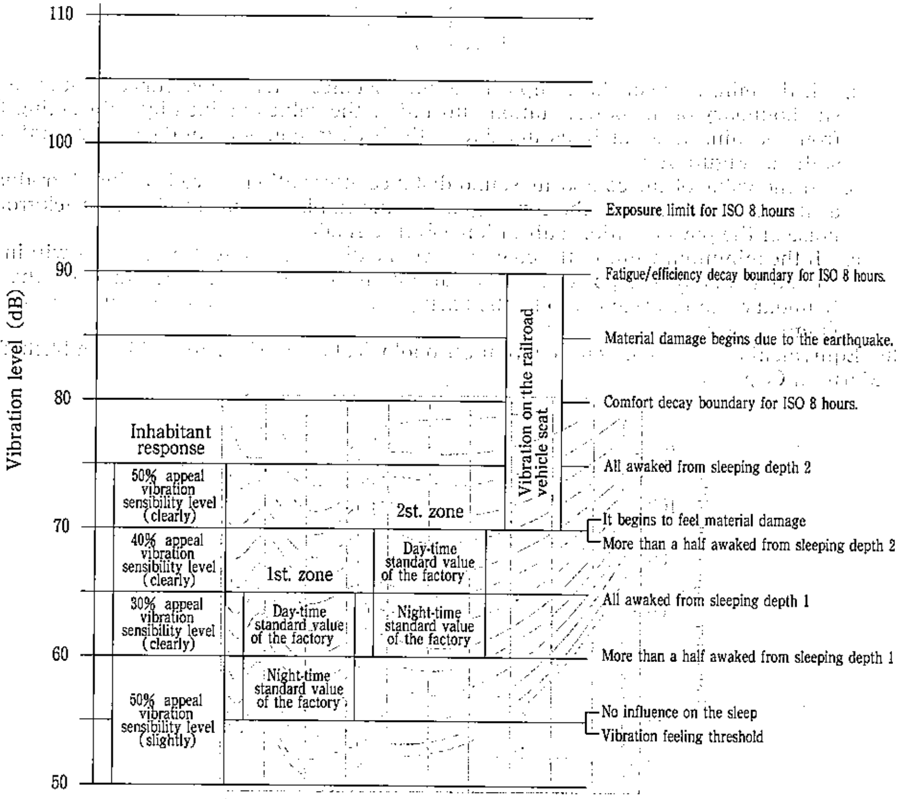


(4) Noise level example (from Chronological Scientific Table, 1999, published by Maruzen Co., Ltd.)



26-12 Vibration

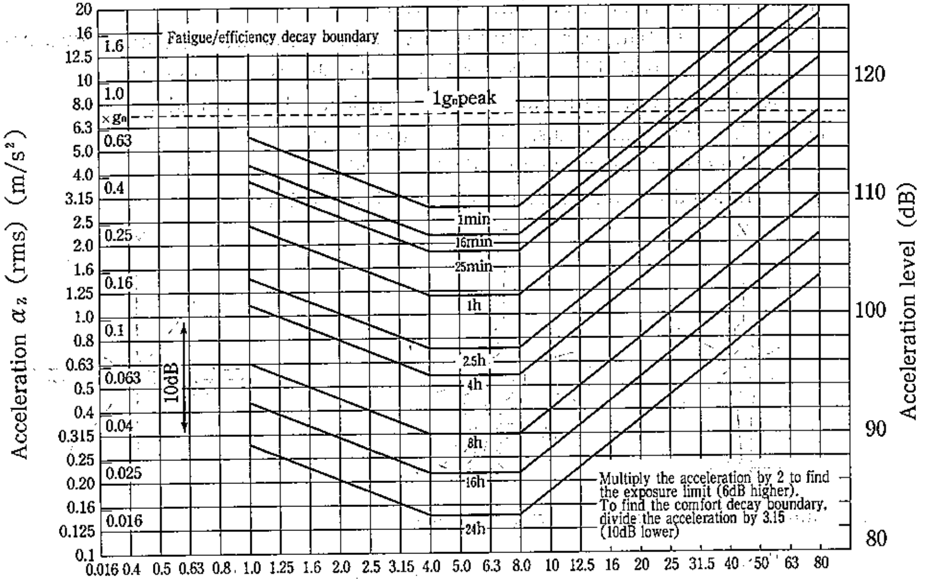
(1) Relationship between influence due to the vibration and vibration level



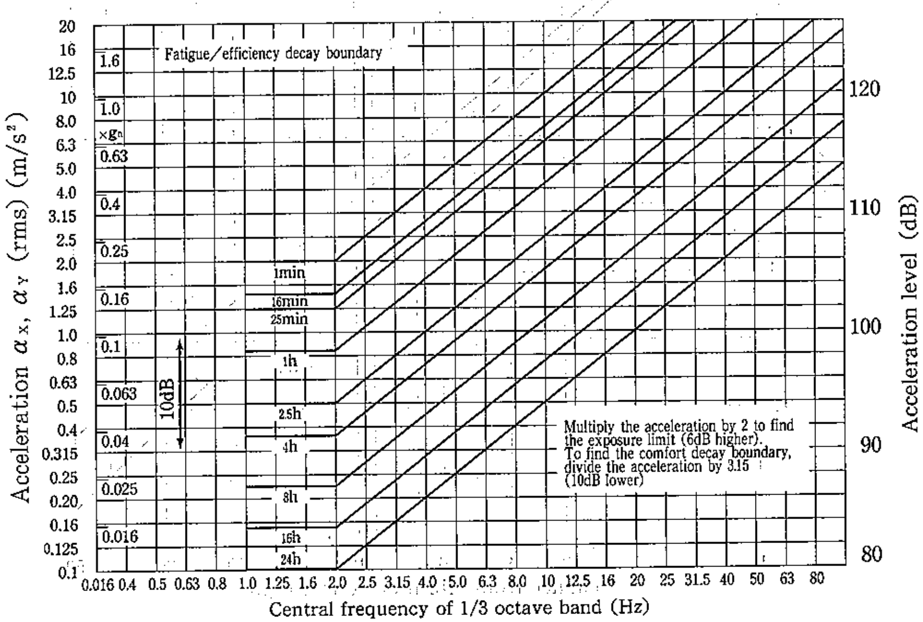
Note: As for the influence on the sleep, it is converted into the value on the ground.

(Source: The technology of prevention of pollution and regulation (Vibration edition))

(2) Human body vibratory sensibility curve



Vibration exposure standard in vertical direction



Vibration exposure standard in horizontal direction

Note: 1) The above figure is defined by the ISO (International Organization for Standardization).

2) rms: Root mean square value (effective value).

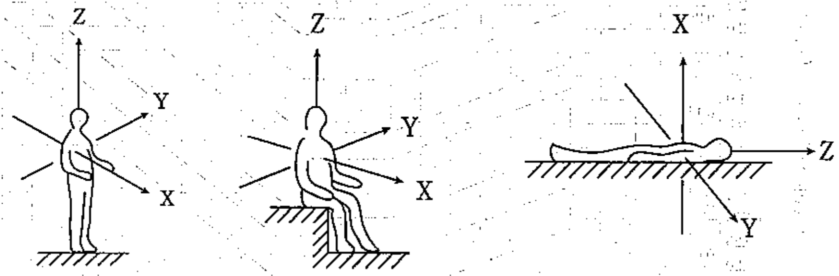
3) According to the "Guideline to full body vibration exposure evaluation (ISO-2631)", the category is divided into three and the figure shows the (a) item.

(a) Holding the work efficiency (fatigue/efficiency decay boundary)

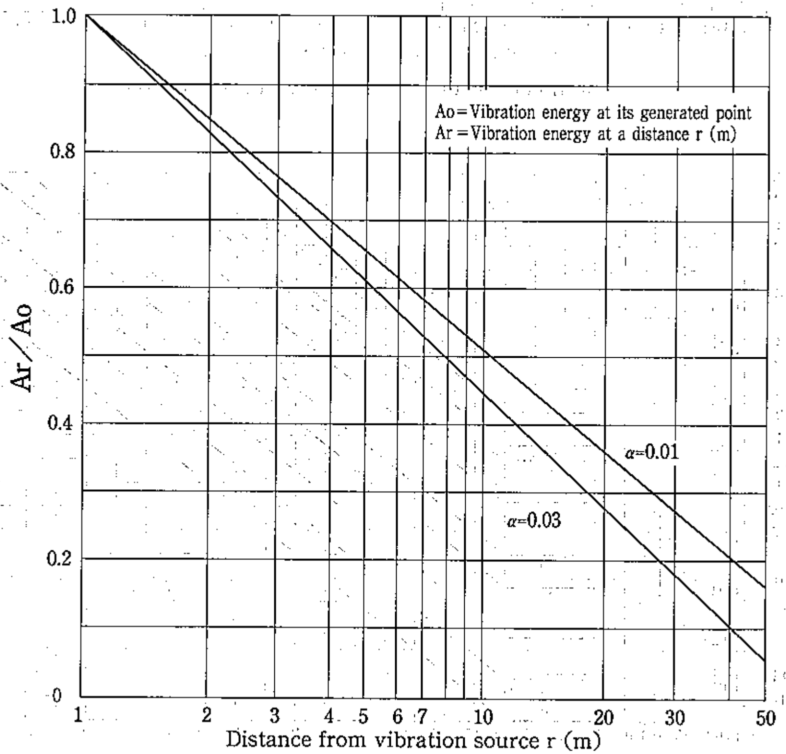
(b) Holding the health and safety (exposure limit)

(c) Holding the comfort (comfort decay boundary)

4) The vibration directions X, Y, and Z are as shown below.

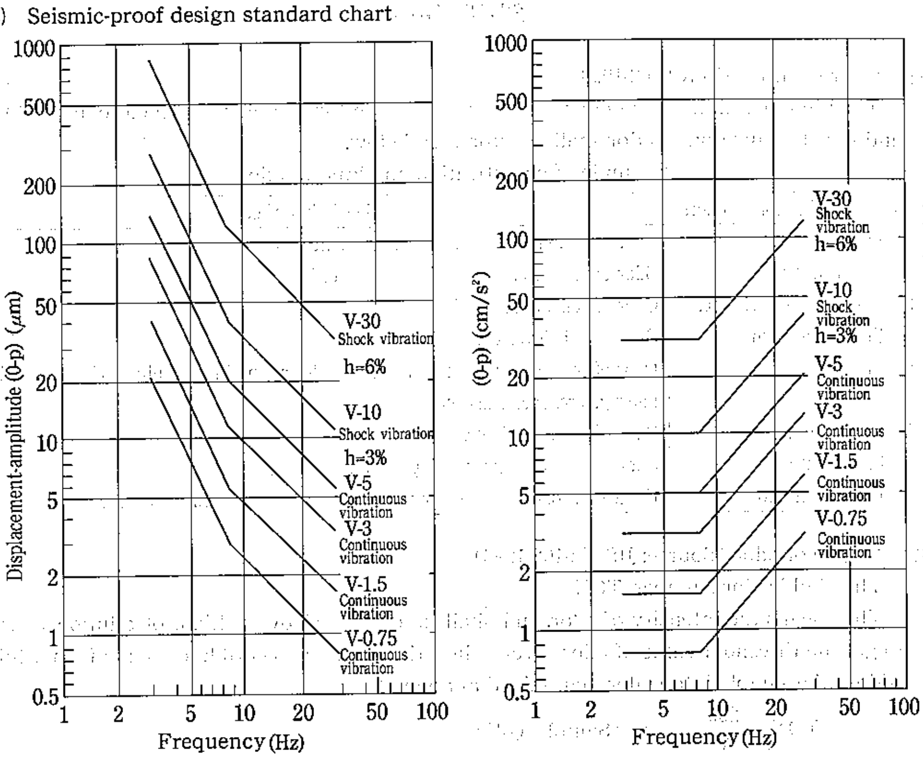


(3) An example of vibration damping by distance



General equation $A_r/A_o = 2r^{-\frac{1}{2}} \times e^{-ar}$ (where, α =0.01～0.03)
(It changes linearly within 20 m.)

(4) Seismic-proof design standard chart



Performance evaluation standard about the floor vibration

The standard of residence performance evaluation by the Architectural Institute of Japan

Use for the building /room	Classification of vibration type	Vibration type 1			Vibration type 2	Vibration type 3
	Rank	Rank Ⅰ	Rank Ⅱ	Rank Ⅲ	Rank Ⅲ	Rank Ⅲ
Residence	Living room /bed room	V-0.75	V-1.5	V-3	V- 5	V-10
Office	Conference room /meeting room	V-1.5	V-3	V-5	V-10	V-30
	General office	V-3	V-5	V-5 degree	V-10 degree	V-30 degree

Vibration type Ⅰ

The floor which receives continuous vibration and intermittently repetitive vibration. : V−5 degree or less.

Vibration type Ⅱ

The low damping floor which receives shock vibration (damping constant h=3% or less): V−10 degree or less.

Vibration type Ⅲ

The high damping floor which receives shock vibration (damping constant h=3～6% degree): V−30 degree or less.

Note: Though the rank just indicates a grade in residence performance, generally it is based on the rank Ⅱ. And the rank Ⅰ should make lower level than this range in residence performance, rank Ⅲ should make a level not exceed this range in the same way.

[Source: "Guideline of residence performance evaluation on the vibration of buildings" (April 20, 1991), Commentary (1991 enactment) by Architectural Institute of Japan.]

26-13 Odor

(1) Odor (Source: JIS K 0102-1998)

The kind of and degree of odor shall be tested when the sample is warmed to about 40℃ and the classification of odor shall be expressed below.

Example of classification and kind of odor

Gross classification of odors	Example of kind of odor
1) Fragrant odor	Odor of melon, violet, cucumber, aromatics, etc.
2) Botanical odor	Odor of alga, green grass, timber, seaweed, etc.
3) Soil odor and moldy odor	Odor of soil, swamp, mold, etc.
4) Fish or shellfish odor	Odor of fish, lever oil, clam, etc.
5) Chemical odor	Odor of phenols, tar, oil, fats, paraffin, chlorine, hydrogen sulfide, chlorophenol, in-drugstore, chemicals, etc.
6) Metallic odor	Odor of iron, metal, etc.
7) Putrescent odor	Odor of garbage, sewage, pigpen, putrescence, etc.
8) Unpleasant odor	Unpleasant odor such as strong odors of fish, pigpen, putrescence, etc.

(2) Degree of odor (Source: JIS K 0102-1998)

Threshold Odor Number: TON

This means the intensity of odor, and shall be expressed by multiple of dilution factor to get the threshold value of odor given when the cleary perceptible odor is given while adding the sample into water maintained at about 40℃.

$$TON = \frac{200}{V} \quad V = \text{Sample (ml)}$$

And the test methods of odor and threshold odor number are specified in JIS K 0102.

Degree of odor (pO)

$$pO = \frac{1}{\log 2} \times \log TON = 3.32 \times \log TON$$

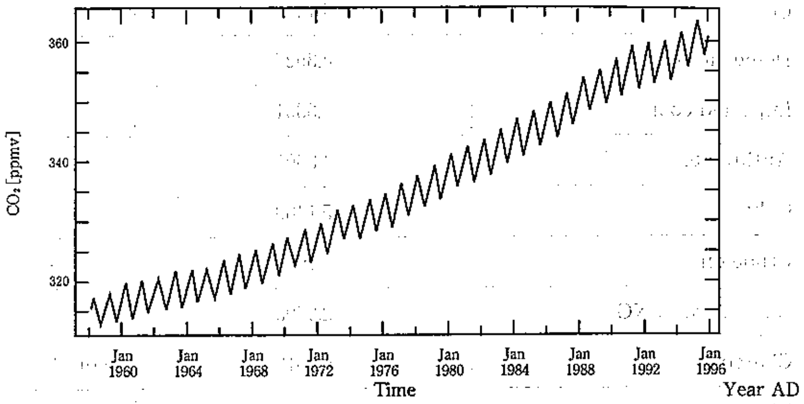
(3) Offensive odor substance

(Source: Cabinet Order, Article 1 for Offensive Odor Control Law)

At present, 22 kinds of substances are specified with the Offensive Odor Control Law. Items: Ammonia, Methylbutane, Hydrogen sulfide, Methyl sulfide, Dimethyl disulfide, Trimethylamine, Acetic aldehyde, Propional dehyde, Normal butyraldehyde, Iso－valeraldehyde, Normal barrel aldehyde, Iso－barrel aldehyde, Isobutanl, Ethyl acetate, Methyl isobutyl ketone, Toluene, Styrene, Xylene, Propionic acid, Normalbutyric acid, Normalvaleric acid, Isovaleric acid.

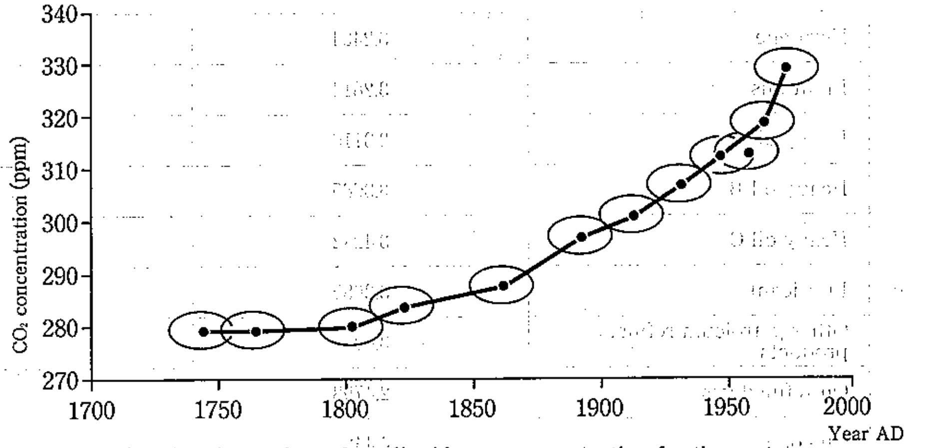
26-14 Global Warming Problem

(1) Secular change in the carbon dioxide concentration



The observation results of CO2 concentration at Mauna Loa (Hawaii)

〔Source : Keeling C.D. et al〕



Secular change in carbon dioxide gas concentration for the past 200 years estimated from analysis of air enclosed in glacier.

〔Source: Neftel, A.H.Oeschger, J.Schwander, B. Stouffer and R. Zumbrunn, 1982 : Nature, 295, 220-223〕

(2) CO_2 emission coefficient of each fuel (reference)

Kind of fuel	Emission coefficient (Gg－C/10^{10}kJ)	Remark
Coking coal	4.1442	
Domestic coal	4.3627	
Imported coal	4.3301	
Anthracite	4.3301	
Coke	5.1488	
Crude oil	3.2697	
Natural gas•LNG	2.3605	
Charcoal	5.2619	Note 1
Wood•pulp•black liquor	4.5004	Note 1
Gasoline	3.2057	
Naphtha	3.1835	
Jet fuel oils	3.2086	
Kerosene	3.2434	
Light oils	3.2814	
Heavy oil A	3.3116	
Heavy oil B	3.3685	
Heavy oil C	3.4242	
Lubricant	3.3685	
Other petroleum refinery products	3.6389	
Oil refined gas	2.4798	
Oil coke	4.4422	
LPG	2.8603	
Biomass fuel for house-hold	4.6716	Note 1

Note 1: The amount of CO_2 emissions resulting from biomass fuel combustion is not included for total emission of the state by the international agreement.

〔Source: Report of survey for CO_2 emissions by the Environment Agency (1992)〕

(3) CO_2 emissions in the world

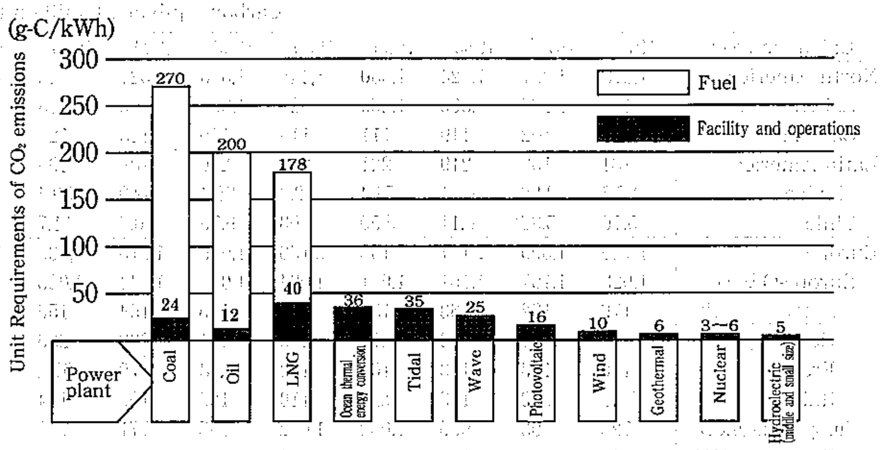
Carbon equivalent, million tons

Calendar year	1971	1973	1980	1985	1990	1993	1994	1995	1996
North America	1,278	1,387	1,424	1,380	1,448	1,510	1,527	1,543	1,580
The United States of America	1,184	1,285	1,305	1,269	1,329	1,391	1,405	1,418	1,452
Canada	93.6	102	119	111	118	119	123	126	129
Latin America	131	153	219	221	253	276	288	296	317
Mexico	27.6	34.8	68.1	74.4	82.9	88.4	92.9	89.4	94.2
Chile	5.70	5.86	6.11	5.59	9.03	9.76	10.8	11.7	13.3
Europe	1,746	1,899	2,147	2,153	2,166	1,939	1,815	1,809	1,819
Europe-OECD	1,023	1,107	1,151	1,091	1,084	1,054	1,044	1,063	1,101
United Kingdom of Great Britain and Northern Ireland	179	182	163	156	161	155	154	156	160
Germany	274	292	292	277	263	241	238	236	243
France	120	133	133	105	103	99.8	93.9	97.4	104
Italy	83.5	94.3	103	98.4	110	109	108	114	113
Europe non-OECD	723	793	996	1,062	1,082	885	771	746	718
The former USSR	656	719	896	954	977	807	700	671	642
Russian Federation	N.A.	N.A.	N.A.	694	663	511	440	427	418
Africa	67.2	75.4	111	149	164	166	177	182	182
Middle East	39.7	48.7	100	143	175	210	214	219	233
Asia	593	672	901	1,075	1,388	1,565	1,652	1,745	1,838
China	239	264	407	516	656	733	777	831	863
Japan	205	245	251	249	291	296	310	313	321
Hong Kong	2.88	3.07	4.78	7.10	10.1	12.9	11.6	12.1	10.4
Taiwan	8.78	11.6	20.4	19.4	30.8	39.4	41.2	44.1	46.8
Korea	14.6	18.5	34.4	43.0	64.1	84.2	90.5	98.0	111
Singapore	2.11	2.87	4.65	5.19	9.17	14.9	18.7	15.7	17.6
Brunei	0.099	0.120	0.244	1.38	1.76	1.98	2.04	2.23	2.23
Indonesia	7.02	9.09	20.3	27.4	44.0	55.6	55.3	60.3	66.8
Malaysia	4.05	3.96	7.44	11.3	16.5	24.2	25.4	23.6	28.1
Philippines	6.81	7.82	9.30	7.68	11.2	13.2	14.1	16.1	17.9
Thailand.	5.13	6.79	10.0	12.6	24.3	33.2	36.7	41.5	47.5
India	57.0	60.1	84.2	117	165	195	207	225	237
Viet Nam	6.24	6.35	3.72	4.34	4.77	5.45	5.80	6.19	10.8
Oceania	47.1	52.5	63.2	67.0	78.5	83.1	83.7	85.2	91.4
Australia	42.9	47.5	58.3	60.8	71.5	75.9	75.9	77.0	82.4
New Zealand	4.20	5.02	4.95	6.26	7.04	7.22	7.81	8.20	8.93
Total of OECD	2.595	2,845	2,992	2,905	3,048	3,116	3,149	3,191	3,299
Total of non-OECD	1,313	1,451	1,983	2,293	2,636	2,644	2,619	2,699	2,774
Total of EU	843	913	920	853	871	847	846	858	885
Total of APEC	1,853	2,053	2,331	2,428	2,777	3,000	3,097	3,187	3,311
Total of ASEAN	31.5	37.0	55.6	70.0	112	149	158	166	191
Total of World	3,908	4,296	4,975	5,198	5,684	5,759	5,768	5,890	6,073

Source: The one for the petrochemistry and non-energy is subtracted from primary energy consumption, and then multiplied by the emission coefficient, and calculated.
Solid fuels: 1.08 (T－C/TOE), Crude oil: 0.837, Natural gas: 0.641, Gasoline: 0.791, Nsphtha: 0.837, Jet fuel oils: 0.816, Kerosene: 0.821, Light oil: 0.846, Heavey oil: 0.883, LPG: 0.72, Others: 0.837

〔Source: Energy and Economic Statistics Handbook, the Energy Conservation Center (1999)〕

(4) Comparison of unit requirements of CO_2 emissions by electric power generation in Japan



Note: Calculation include all CO_2 emissions generated as a result of consumption of energy through its life cycle, in which from mining of raw materials to construction, transport, refining, opretions (in service) and maintenance etc. (Nuclear power generation includes reprocessing, waste treatment and decommissioning.)

(Example) Coal Power Generation: Mining of coal/Selection of coal → Transport → Operation → ash waste

[Source: Report published by the Central Research Institute of the Electric Power Industry "Evaluation of power generation technologies in life cycle CO_2 emissions - Re-estimation by the latest data and effects of the difference in the preconditions"]

(5) Outline of Kyoto Protocol adopted in COP3

(a) Commitment period: 2008 to 2012

(b) Base year: 1990 (It is possible to select HFC, PFC and SF_6 in 1995.)

(c) Kind of gases: 6 gases (CO_2, CH_4, N_2O, HFC, PFC, SF_6)

(d) Sinks: The sources and removals by afforestation etc. shall be counted to achieve the commitment.

(e) Quantified targets: At least 5% will be reduced in the whole of the advanced countries.

+10% Iceland
+ 8 % Australia
+ 1 % Norway
Stabilization (0 %) New Zealand, Russian Federation, Ukraine
− 5 % Croatia
− 6 % Japan, Canada, Hungary, Poland
− 7 % United States of America
− 8 % EU (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom of Great Britain and Northern Ireland), Liechtenstein, Monaco, Switzerland, Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Romania, Slovakia, Slovenia

(f) Flexibility mechanism

Introducing the Emissions Trading and the Joint Implementation by the advanced countries, the Clean Development Mechanism by which advanced and developing countries.

(g) Developing countries problem

While the condition was incorporated about promoting steadily on the existing agreement, such as sending of the information of each countries, the clean development mechanism was newly specified as what support for sustainable development of developing countries.

(h) Requirement to be proposed

The protocol shall enter to force on which not less 55 parties to the convention and incorporating parties included in annex I which accounted into total at least 55% of the total carbon dioxide emissions for 1990 of the parties included Annex I.

Items of the greenhouse gases reduction by 6% in Japan

▲2.5%	Emissions control of CO_2, CH_4, N_2O Items 0% : CO_2 emissions control generated from energy (A maximum countermeasure is pile up for the both side of energy supply and demand) ▲0.5% : CH_4, N_2O, etc. emissions control ▲2.0% : Innovative development of technology and more effort in the nation each layer
▲3.7%	Sinks by land-use change and forestry activities
+2.0%	Emissions control of Alternative Freon, etc. (HFC, PFC, SF_6)
Rest (▲1.8%)	Utilizing of the joint implementation and the emissions allowance trading etc.

〔Source: Energy 2000, P.40, published by Denryoku shinposha〕

(6) Converting method of greenhouse gases to CO_2 equivalent

Potentials used to calculate the carbon dioxide equivalence of gases (global warming potentials)

Greenhouse Gases	Chemical formula	Global warming potentials (100 years)
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide (Dinitoration monoxide)	N_2O	310
HFC		
HFC-23	CHF_3	11,700
HFC-32	CH_2F_2	650
HFC-41	CH_3F	150
HFC-43-10mee	$C_5H_2F_{10}$	1,300
HFC-125	C_2HF_5	2,800
HFC-134	$C_2H_2F_4$	1,000
HFC-134a	CH_2FCF_3	1,300
HFC-152a	$C_2H_4F_2$	140
HFC-143	$C_2H_3F_3$	300
HFC-143a	$C_2H_3F_3$	3,800
HFC-227ea	C_3HF_7	2,900
HFC-236fa	$C_3H_2F_6$	6,300
HFC-245ca	$C_3H_3F_5$	560
PFC		
Perfluoremethane	CF_4	6,500
Perfluorethane	C_2F_6	9,200
Perfluorepropane	C_3F_8	7,000
Perfluorebutane	C_4F_{10}	7,000
Perfluorecyclobutane	$c\text{-}C_4F_8$	8,700
Perfluorepentane	C_5F_{12}	7,500
Perfluorehexane	C_6F_{14}	7,400
Sulfur hexafluoride	SF_6	23,900

Emissions of greenhouse gases (CO_2 equivalent) =
Emissions of greenhouse gases × Global warming potentials

[Source: The IPCC Second Assessment Report (1995) translated by the Meteorological Agency]

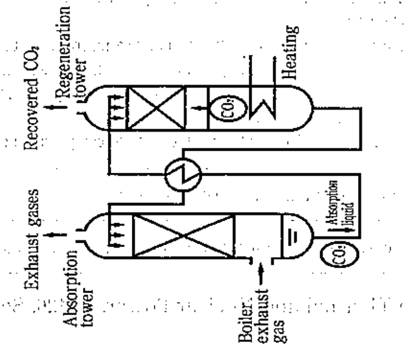
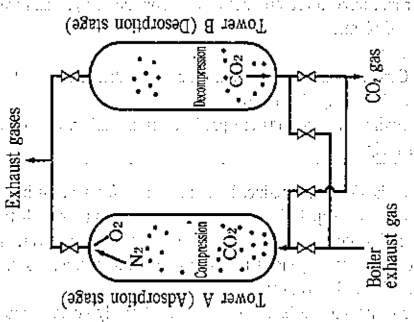
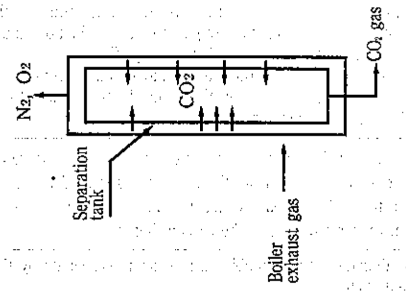
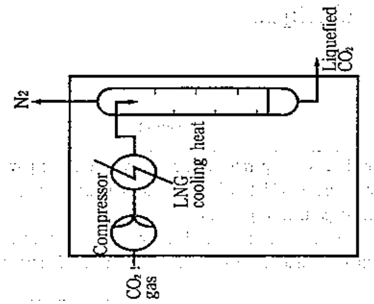
26-15 Summary of Separation and Recovery of Carbon Dioxide Gas and Processing Technique

(1) Outline of methods

Item			Outline
Separation and recovery	Absorption	Physical absorption	• Carbon dioxide gas is separated and recovered by using physical absorption characteristics that solubility of carbon dioxide gas in physical absorption liquid increases in proportion to pressure.
		Chemical absorption	• Carbon dioxide gas is separated and removed by using chemical reaction between carbon dioxide gas and absorption liquid (Solution of amine,potassium carbonate solution, etc.).
	Physical absorption		• Carbon dioxide gas is separated and removed by solid absorbent (zeolite, activated carbon) that easily absorb carbon dioxide gas, using the characteristics that absorption varies with pressure and temperature.
	Cryogenic distillation (Cryogenic separation)		• Carbon dioxide gas is separated and recovered according to the different in boiling points of various components, by gas pressure reduction and distillation after the processed gas is pressurized, cooled and liquefied.
	Membrane separation		• Carbon dioxide gas is separated and removed on micromolecular membranes by making use of the difference in the permeability coefficient of the various gases passed through the membranes.
	Combustion of carbon dioxide gas and oxygen		• For combustion in boilers and other equipment, the mixture of oxygen and the carbon dioxide recycled from the exhaust gas is used in place of normal air. As a result, the carbon dioxide concentration in the exhaust gas is increased,which facilitates the recovering of the carbon dioxide.
Immobilization	Biological immobilization	Immobilization by marine creatures	• Carbon dioxide gas is immobilized as calcium carbonate by the action of coral, lime and shell.
		Immobilization by plants	• Sugar and oxygen are produced by carbon dioxide gas and water through photosynthesis of plants.
		Immobilization by microbes	• By microbes ① Carbon dioxide gas is immobilized as calcium carbonate by the action of microbes (Haptophyceae) ② Hydrogen and lipids are produced from carbon dioxide gas and water (by microalgae)
	Chemical immobilization	Photochemical reaction	• Carbon dioxide gas is reduced and made into formic acid in the presence of catalyst with electrons supplied by excitation of the sensitizer with the visible light.
		Semiconductor-photocatalytic reaction	• Carbon dioxide gas is blown into the water containing various powdered semiconductors suspended therein as photocatalyst, and is made into formic acid and methanol by irradiation.
		Electrochemical reaction	• Water containing carbon dioxide gas is electrolyzed to produce carbon monoxide gas, formic acid and methane. (Different products are formed depending on the electrode used.)
		Macromolecular synthesis	• A certain metal is used as catalyst to produce macro molecular compounds such as polyethylene carbonate composed of carbon dioxide gas and organic substance.
		Organism synthesis	• Carbon dioxide gas is made to react with different types of reagent to produce the organic compound such as urea.
		Catalytic hydro generation	• Solid catalyst is used to synthesize the organic compound such as methnol etc..
Waste treatment	Storage at deep sea		• Stored as liquid at a depth of 3,000 m or more.
	Underground disposal		• Carbon dioxide gas to be put into the waste gas field and waste oil field.

[Source: M. Kiyohara, The Thermal and Nuclear Power, 42-420, Sept. 1991, P. 1116]

(2) Principle of CO_2 separation and recovery technologies

Chemical absorption	Physical absorption	Membrane separation	Cryogenic separation
			
CO_2 is absorbed and separated by chemical reaction between CO_2 and absorption liquid ; CO_2 is released from absorption liquid by heating.	CO_2 is adsorbed on a solid adsorbent capable of readily adsorbing CO_2. The adsorbed CO_2 is then released and separated for recovery.	CO_2 is separated on a macro-molecular membrane by making use of the differences in the permeability coefficient of the various gases passed through the membrane.	The CO_2 containing fuel gas is compressed and the CO_2 is separated for recovery by distillation.

[Source: "Energy and the Environment 1998.11" published by the Federation of Electric Power Companies.]

26-16 Environmental Terms

(1) Atmosphere

Down wash:

A phenomenon that flue gas diffusion is extremely disturbed by the wind whirled by a barometric pressure difference at the back of a building or funnel.

Photochemical smog:

Smog mainly composed by oxidants such as ozone (O_3), aldehyde (RCHO), alkyl nitrate ($RONO_2$) , peroxy acetylnitrate (RCO_2NO_3) which is usually called PAN, or peroxy acyl nitrate(RCO_3NO_2), etc. that has extremely strong oxidization potential generated by a chemical change when hydrocarbon in nitrogen oxide is exposed to strong sunlight.

Atmospheric stability:

This is a large factor for flue gas diffusion. When the "air temperature attenuation rate" that according to the altitude that goes high is greater than 1℃/100m of adiabatic expansion, the atmospheric air is unstable. On the contrary, when the temperature rises as the altitude goes high, the atmospheric air is stable. This atmospheric air stability is affected significantly with wind speed, amount of sunlight, etc..

NOx (nitrogen oxides):

Generic term of nitrogen oxides generated in combustion processes. NO and NO_2 occupy most of the NOx. In general, it is divided into "thermal NOx" generated when nitrogen in the air is combined with oxygen during combustion and "fuel NOx" generated when nitrogen oxides in fuel are oxidized.

SOx (sulphur oxides)

Generic term of sulfur oxides, which are generated as fuel with much amount of sulfur is burnt.

Suspended particulate matter:

Refers to the floating dust with a diameter of 10 μm or less.

Soot and dust:

Solid grains contained in combustion gases, such as soot, ash, etc. generated in combustion processes.

K-value regulation:

A kind of regulation applied for sulfur oxides. Permissible emissions of sulfur oxides are decided from the effective stack height (He) and the corrected coefficient K value which defined for each area. The lower K value becomes more the regulation tight.

Total mass emission control:

This regulation is applied to high pollution areas. According to this regulation, the allowable total amount of pollution substance is defined for each area and assigned to each factory in the area. The larger the stack is, the more this regulation becomes severe.

Inversion layer:

Generally, the more the altitude becomes high, the lower the temperature becomes. On the contrary, in this inversion layer, the higher the altitude becomes, the higher the temperature is.

Sulfuric-acid mist:

Foggy sulfuric acid, which is one of the harmful air pollution substance. It is said that this mist is generated when sulfurous acid gas is mixed with water content in the air to form sulfurous acid, then oxidization by oxidant and changes in sulfuric-acid mist.

Acid rain:

A phenomenon that sulfurous oxides (mainly SO_2) discharged by high sulfurous fuel combustion, etc. and oxidized gradually in the air into dilute sulfuric acid mist and it is solved in raindrops in a distant place area.

Dust:

Substances generated or scattered as a result of mechanical treatment, such as crushing and selection of material or heaping of material.

(2) Water quality

pH (potential of hydrogen):

A symbol used to indicate the concentration of hydrogen ion (hydrogen ion gram quantity existing in 1,000 ml). It is represented by a common logarithm of the inverse number of the hydrogen concentration in water.

$$pH = \log \frac{1}{[H^+]} = -\log[H^+]$$

Pure water pH is 7.

ABS (alkyl benzene sulfonates):

Typical synthetic detergent, which is contained in sewage water and causes bubbles.

Red tide:

A phenomenon in which seawater is turned red due to abnormal breeding of plant plankton. It is said that this red tide is caused by nutritious substances such as phosphate, nitrate, ammonium salt, etc. generated when organic substances contained in factory effluence and city sewage are decomposed, as well as small quantity substances such as vitamins.

Blue tide:

The phenomenon that the water surface comes pale as a result of the mass of water with the few of dissolved oxygen comes floating to the water surface.

Eutrophication:

It is said as the eutrophication that nutrition salt kinds such as nitrogen, phosphorus, etc. increase by domestic waste water and industry drainage flowing in to the sea area, the lake swamp. The red tide and the blue tide are caused by an eutrophication. To prevent this, Water pollution Control Law, Law Concerning Special Measures of the Environment of the Seto Inland Sea countermeasure etc. are applied.

BOD (biochemical oxygen demand):

This BOD indicates the amount of oxygen consumed when organic substances in water are decomposed by breeding or breathing of aerobic bacteria. This value is desirable 5ppm or less in rivers.

COD (chemical oxygen demand):

Indicates the amount of oxygen consumed by oxidized substances in water, which is analyzed by a chemical method. This value is desirable 5ppm or less.

DO (dissolved oxygen):

This DO in clean water is 7 to 14ppm. At least, 5ppm is needed for fishes.

Activated sludge:

Flocked deposit generated by rapid breeding of aerobic micro organism in sewage and waste water. It can decompose sludge significantly.

SS (suspended solids):

Substances floating in water. It is harmful, since it sticks on living organisms in water and is precipitated on river beds. The SS value is desirable 10ppm or less.

TLm (medium tolerance limit):

Rapid toxicological test value for fishes. This value indicates the toxicological density with which 50% of the sample fishes die within a certain hour (24 - 48 hours).

TOC (total organic carbon):

This value is obtained as follows; Sample water is burnt and the total carbonic acid is measured using an infrared radiation CO_2 indicator, then nonorganic carbonates are eliminated separately from the result.

TOD (total oxygen demand):

This value is obtained as follows; the sample water is burnt in a certain amount of oxygen and the difference from the oxygen is measured in the gas using a fuel battery-driven detector.

This measurement can be done quickly, so this value is often used as an index of water pollution instead of COD and BOD.

(3) Noise

Sone:

A unit of sound volume. The pure sound of frequency 1,000 Hz, which is 40 dB higher than the audible sound of human beings, is one sone. When the level of a sound, which is judged to be n times of this sone is referred to as n sone.

Sound pressure level (dB):

20 times of the common logarithm of the ratio between sound pressure P and reference sound pressure P_o. In other words, it means $20 \log_{10} (P/P_o)$. In this case, $P_o = 0.0002\mu b$. In the case of parallel progressive waves, it can be assumed to be the same sound strength level for practical use.

Volume level of sound:

The sound pressure level of 1,000Hz pure sound it judged that the volume that a listening person was the same as could hear it. For example, it is 60 phon when the volume that is the same as 1,000Hz pure sound of 60dB can hear it.

Noise level (phon or dB value):

Value measured using a noise level meter defined in JIS C 1502.

Equivalent sound level:

When a noise level changes together with the time, the noise level of continuous steady sound that gives it the average squire sound pressure which is equal to this in the measurement time.

Background noise:

When a specific noise is measured at a place, if no sound is detected there, then the noise heard at that place is referred to as the ground noise at that place.

Low frequency air vibration:

How to call sounds below 20 Hz or special low sounds is not unified in Japan. They are referred to as low frequency sound, low frequency micro barometric pressure change, low frequency noise, etc.

Silencer:

Usually, this is provided in a middle position of a suction/exhaust pipe (or duct) and used to reduce the noise from the noise source and suppress the noise to be emitted into the air while disturbance of the gas flowing is avoided.

(4) Waste

Industrial waste:

Combustion residue, sludge, waste oil, waste acid, waste alkalis, waste plastic, etc., generated from business activities.

Municipal waste:

Waste other than industrial one.

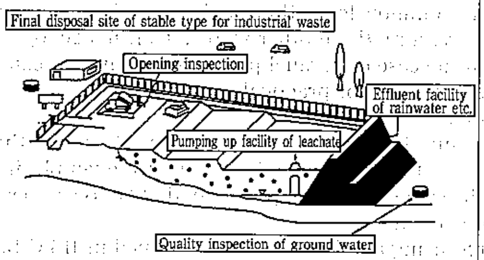
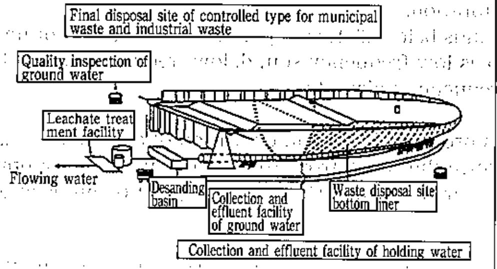
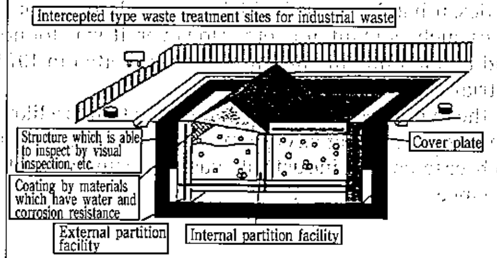
PCB (polychlorinated biphenyl):

One of organic chlorine compound. Since it is excellent in heat resistance and insulation properties, it had been used widely for insulator of the electric equipment, as well as additives such as paint, ink, etc. However, it was found to be harmful for human bodies and its manufacture and use was prohibited in 1972.

Special control industrial waste:

The waste that the explosion, the toxicity, the infection are likely to cause damage in the human health or the living environment. Specific harmful industrial waste is prescribed in such case as the industrial waste, waste PCB, etc. specified in the government ordinance.

Classification of final disposal sites of the waste

	Kinds of disposal waste	Outline of sites	Number of the sites (fiscal year 1994)	Disposal volume (estimation) (fiscal year 1994)
Stable type waste treatment sites (Waste Disposal and Public Cleaning Law, Enforcement Article 7, No. 14b.)	Waste plastic, rubber waste, scrap, glass/ ceramics waste, debris. It was excluded from excepted the waste containers/ packaging etc. with a possibility that the waste printed circuit boards and foreign bodies may be mixed by the amendment of the Waste Disposal Law Enforcement on December, 1997.	○ Facilities which reclaim land in a soil, as it is, the waste which dose not dissolve into water and not rotting. ○ Area condition (3,000m^2) was abolished from December, 1997.  	1653 places (Items) Enterprise trader … 168 places Treatment trader … 1408 places Public … 77 places	31,542 (Unit: 1,000ton)
Controlled type waste treatment sites (Waste Disposal and Public Cleaning Law Enforcement Article 7, No.14c)	Paper, wood, residual of plants or animals, soot and dust, mud, sludge, etc. with detrimental nature not more than a fixed level.	○ Although there is no detrimental nature to the extent that it reclaims land at an intercepted type disposal facilities, it is the facilities which reclaims land from and dispose of the waste with a possibility that the sewage of organic nature may arise, and it covers with a liner facilities, and has the installation for sewage disposal. ○ Area condition (1,000m^2) was abolished from December, 1997.  	988 places Enterprise trader … 412 places Treatment trader … 467 places Public … 109 places	43,577 (Unit: 1,000ton)
Intercepted type waste treatment sites (Waste Disposal and Public Cleaning Law, Enforcement Article 7, No. 14a)	Sinder, soot and dust, mud, sludge, etc. with detrimental nature more than a fixed level.	○ Facilities reclaimed land from and disposal of in the form where rainwater or a soil are not made to contact by confining the industrial waste containing detrimental heavy metal etc. in a concrete tub.  	40 places Enterprise trader • • • 17 places Treatment trader • • • 21 places Public • • • 2 places	14 (Unit: 1,000ton)

〔Source: "The Waste Disposal and Public Cleaning Law revision understood at once (Revised edition)", edited and published by Kokusei Information Center Co., Ltd.〕

(5) Others

LD_{50} (lethal dose 50 value):

A unit of lethal dose of poisonous medicines. In Japan, it indicates the amount (mg quantity of the medicine per kg of body weight) of medicine that kills 50% of the sample animal (generally, mouse is used in Japan).

Environmental standard:

Defined by the Japanese government for the atmospheric air, water quality, soil, noise, etc. in order to protect the human health and preservation of the living environment.

ppm (parts per million):

In the case of gases, this value indicates the ml quantity of the substance existing $1 m^3$. In case of solid or liquid, it indicates the mg quantity of the substance existing in 1 kg.

ppb (parts per billion):

Indicates the concentration of 1/1,000 of 1 ppm.

pphm (parts per hundred million):

Indicates the concentration of 1/100 of 1ppm.

Global warming problem:

It has been found through climate data analysis that the temperatures on the earth are getting steady higher and higher in these 100 years, although there are some exceptions in some years. If this phenomenon is continued on, then, it will affect many things including agriculture, sea level, etc. Increasing of the concentration of greenhouse gases such as CO_2, methane, freon, N_{20}, etc. in the air is pointed out as the main factor.

Depletion of ozone layer:

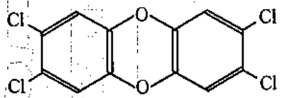
When CFC (chlorofluorocarbon, a kind of the so-called freon) and Halon which are widely used for the refrigerant, the cleaning agent, the foaming agent, etc. are released into the environment, it reaches the stratosphere, and so it is exposed to the strong ultraviolet radiation there, chlorine is emitted, and an ozone layer is destroyed.

Endocrine disrupters:

The formal name by the Environment Agency is an exogenous Endocrine Disrupters. The foreign substance with many obstruct process, which is characterized such as a synthesis, storage, in-the-body transportation, bond about the constancy of a living body, reproduction, generating, or action, or its clearance.

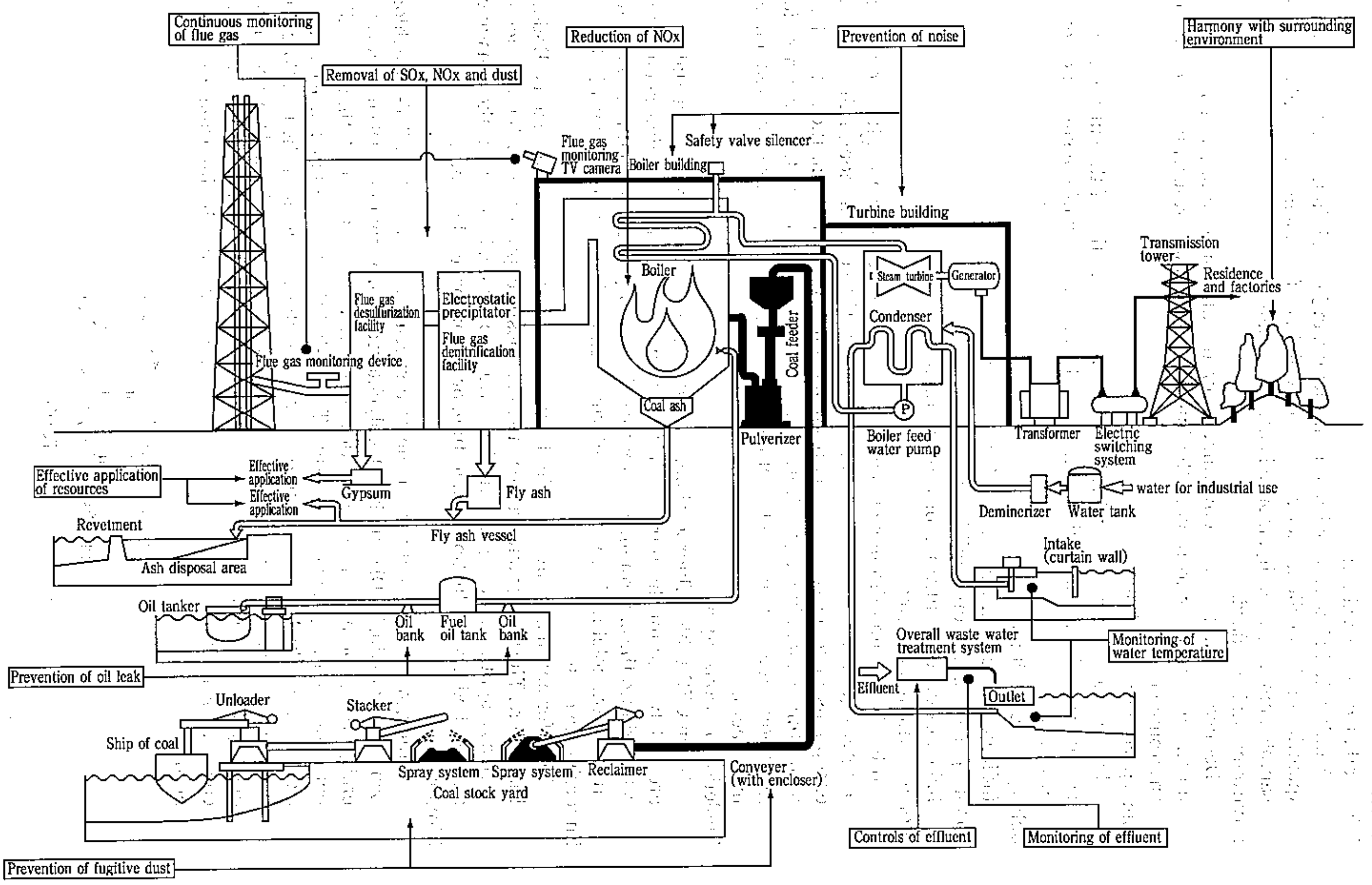
Dioxin:

Although it is originally the name of a specific molecule (2, 3, 7, 8-tetrachlorodibenzopara-dioxin, TCDD for short), polychlorodibenzo-dioxin (PCDD for short), generally, the general term of varieties indicate. It was presumed that the all are poisonous and they had carcinogenic, TCDD slightly contained in 2, 4, 5-T of a herbicide especially had the strongest toxicity as tetratogen, and after the U.S. Forces used it for defoliation operation by the Vietnam War, malformed children occurred frequently. Generating dioxin in large quantities by incineration of the organic chlorine compounds including vinyl chloride is pointed out, and the immediate measure is needed.



TCDD

26-17 Example of Environmental Measures in Thermal Power Plants (Coal)



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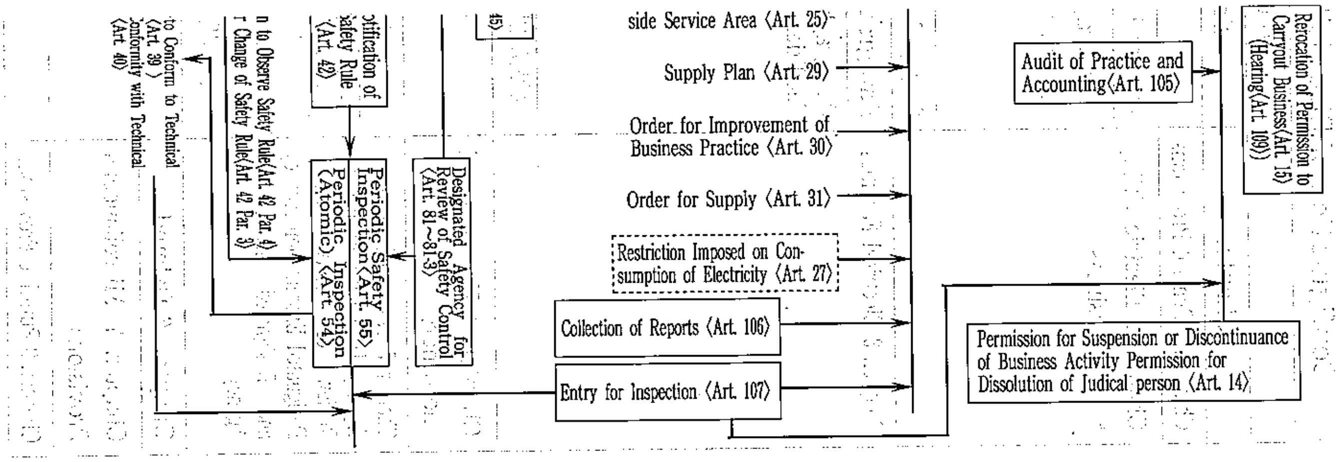
ledge as an informal presentation.



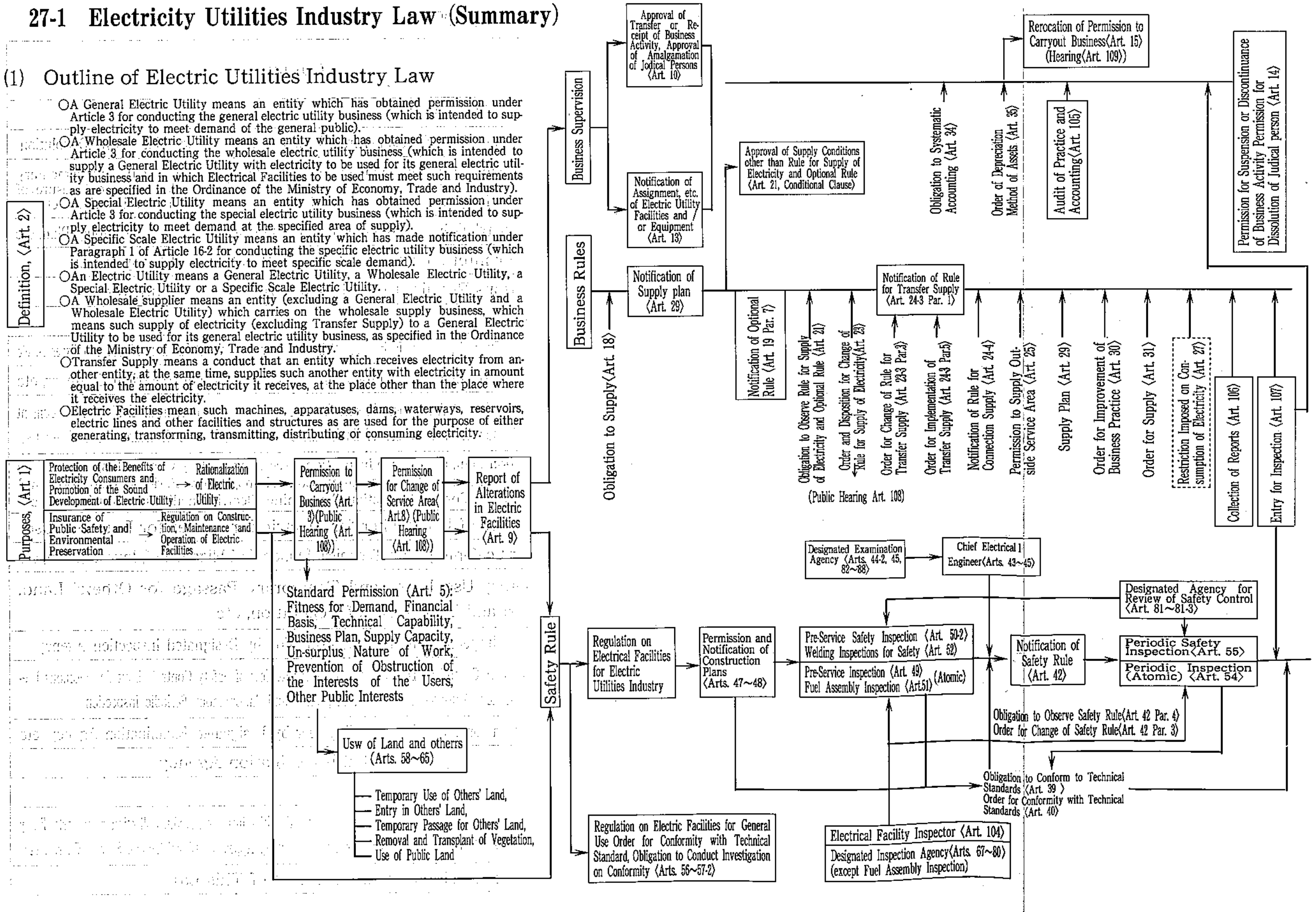
The laws and Standards described in this chapter are translated by the Thermal and Nuclear Power Engineering Society, Japan. This translation is not official, it has been made with the best of our knowledge as an informal presentation.

27-1 Electricity Utilities Industry Law (Summary)

(1) Outline of Electric Utilities Industry Law

Definition, 〈Art. 2〉

- ○A General Electric Utility means an entity which has obtained permission under Article 3 for conducting the general electric utility business (which is intended to supply electricity to meet demand of the general public).
- ○A Wholesale Electric Utility means an entity which has obtained permission under Article 3 for conducting the wholesale electric utility business (which is intended to supply a General Electric Utility with electricity to be used for its general electric utility business and in which Electrical Facilities to be used must meet such requirements as are specified in the Ordinance of the Ministry of Economy, Trade and Industry).
- ○A Special Electric Utility means an entity which has obtained permission under Article 3 for conducting the special electric utility business (which is intended to supply electricity to meet demand at the specified area of supply).
- ○A Specific Scale Electric Utility means an entity which has made notification under Paragraph 1 of Article 16-2 for conducting the specific electric utility business (which is intended to supply electricity to meet specific scale demand).
- ○An Electric Utility means a General Electric Utility, a Wholesale Electric Utility, a Special Electric Utility or a Specific Scale Electric Utility.
- ○A Wholesale supplier means an entity (excluding a General Electric Utility and a Wholesale Electric Utility) which carries on the wholesale supply business, which means such supply of electricity (excluding Transfer Supply) to a General Electric Utility to be used for its general electric utility business, as specified in the Ordinance of the Ministry of Economy, Trade and Industry.
- ○Transfer Supply means a conduct that an entity which receives electricity from another entity, at the same time, supplies such another entity with electricity in amount equal to the amount of electricity it receives, at the place other than the place where it receives the electricity.
- ○Electric Facilities mean such machines, apparatuses, dams, waterways, reservoirs, electric lines and other facilities and structures as are used for the purpose of either generating, transforming, transmitting, distributing or consuming electricity.



(2) Configuration of Electricity Utilities Industry Law (Law No. 170-Last Revision Aug. 1999)

Configuration of This Law				Outline
Chapter	Paragraph	Clauses	Artiche	
Chapter. 1 General Provisions	———	———	Articles 1 to 2	Purposes, Definition
Chapter. 2 Electric Utility Supply Business	Paragraph. 1 Permission of Business	———	Articles 3 to 17	Required Supervisory Regulation from Foundation of Electric Utility to Its Dissolution
	Paragraph. 2 Business Activity	Clause 1 Supply	Articles 18 to 27	Electric Utility's Obligation to Supply, Rules for Supply of Electricity, Supplementary Supply, Transfer Supply, Connection Supply, Obligation to Maintain and Measure of Voltage and Frequency, and Restriction Imposed on Consumption of Electricity, etc.
		Clause 2 Wide area Operation	Articles 28 to 29	Electric Utility's Obligation of Mutual Cooperation and Notification of Supply Plan, etc
		Clause 3 Supervision	Articles 30 to 33	Order for improvement of Business Practice and Supply, etc
	Paragraph. 3 Accounting and Finance	———	Articles 34 to 37	Regulations Required for Electric Utility on Accounting
Chapter. 3 Electrical Facilities	Paragraph. 1 Definition	———	Article 38	Definition
	Paragraph. 2 Electrical Facilities for Business Use	Clause 1 Conformity with Technical Standards	Articles 39 to 41	Maintenance of Electric Facilities for Business Use, Order to Conform to Technical Standards, Allotment of Expenses, etc
		Clause 2 Voluntary Preservation of Security	Articles 42 to 45	Safety Rule on Electric Facilities for Business Use, Chief Electrical Engineer, etc
		Clause 2-2 Exception Concerning Environment Assessment	Article 46-2 to 46-22	Environmental Impact Assessment, Process Document, Preparation Document, Evaluation Document and Consideration for Preservation of Environment Concerning Electric Structures for Business Use
		Clause 3 Plan for Construction Work and Inspection	Articles 47 to 55	Construction Plan, Pre-service Inspection, Pre-service Safety Control Inspection, Fuel Assembly Inspection, Welding Safety Control Inspection, Periodic Inspection and Periodic Safety Control Inspection Concerning Electric Facilities for Business Use
		Clause 4 Succession	Article 55-2	Inheritance of Establisher for Electric Structures for Business Use
	Paragraph. 3 Electric Facilities for General Use	———	Articles 56 to 57-2	Order for Conformity with Technical Standards Obligation of, Investigation, etc
Chapter. 4 Use of Land and others	———	———	Articles 58 to 66	Temporary Use, Entry and Temporary Passage for Others' Land, Removal and Transplant of Vegetation, etc
Chapter. 5 Designated Inspection Agency, Designated Agency for Review of Safety Control, Designated Examination Agency and Designated Investigation Agency	Paragraph. 1 Designated Inspection Agency	———	Articles 67 to 80	Pre-service Inspection and Periodic Inspection by Designated Inspection Agency
	Paragraph. 2 Designated Agency for Review of Safety Control	———	Article 81 to 81-3	Review of Safety Control by Designated Agency for Review of Safety Control about Autonomous Pre-service Inspection, Autonomous Welding Inspection and Autonomous Periodic Inspection
	Paragraph. 3 Designated Examination Agency	———	Article 82 to 88	Examination for Chief Electrical Engineer by Designated Examination Agency, etc
	Paragraph. 4 Designated Investigation Agency	———	Article 89 to 92-4	Investigation by Designated Investigation Agency
Chapter. 6 Deleted	———	———	Article 93 to 99	Deleted
Chapter. 7 Miscellaneous Provisions	———	———	Article 100 to 114	Conditions for Permission, Hydroelectric Power, Electric Facilities Inspector, Audit, Collection of Reports, Entry for Inspection, Public Hearing, Exception Concerning Heaving, Appeal of Dissatisfaction, Service Charge, etc
Chapter. 8 Punitive Provisions	———	———	Article 115 to 123	Punitive Provisions for Enforcement of This Law

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Outline
Definition
ervisory Regulation from Foundation of Electric Utility to Its Dissolution
y's Obligation to Supply, Rules for Supply of Electricity, Supplementary sfer Supply, Connection Supply, Obligation to Maintain and Measure of Frequency, and Restriction Imposed on Consumption of Electricity, etc.
y's Obligation of Mutual Cooperation and Notification of Supply Plan, etc
mprovement of Business Practice and Supply, etc
s Required for Electric Utility on Accounting
ctric Facilities for Business Use, Order to Conform to Technical Standards, Allotment of Expenses, etc
on Electric Facilities for Business Use, Chief Electrical Engineer, etc
mpact Assessment, Process Document, Preparation Document, Evaluation Document on for Preservation of Environment Concerning Electric Structures for Business Use
Plan, Pre-service Inspection, Pre-service Safety Control Inspection, Fuel spection, Welding Safety Control Inspection, Periodic Inspection and ty Control Inspection Concerning Electric Facilities for Business Use
e of Establisher for Electric Structures for Business Use
nformity with Technical Standards Obligation of, Investigation, etc
y Use, Entry and Temporary Passage for Others' Land, nd Transplant of Vegetation, etc
spection and Periodic Inspection by Designated Inspection Agency
y Control by Designated Agency for Review of Safety Control about Autonomous Pre- n, Autonomous Welding Inspection and Autonomous Periodic Inspection
for Chief Electrical Engineer by Designated Examination Agency, etc
on by Designated Investigation Agency
mission, Hydroelectric Power, Electric Facilities Inspector, Audit, Collection of Reports, Entry blic Hearing, Exception Concerning Heaving, Appeal of Dissatisfaction, Service Charge, etc
rovisions for Enforcement of This Law

27-2 Outline of the Technical Standards for Thermal Power Generating Facilities

The ministerial ordinance for the technical standards of thermal power generating facilities (International Trade and Industry ministerial ordinance No. 60, June 15, 1965, last revision: Ordinance No. 51, March 27, 1997)
The notification which defines the details of the technical standards for thermal power generating facilities (Ministry of International Trade and Industry notification No. 270, June 15, 1965, last revision: Ministry of International Trade and Industry ordinance No. 149, March 27, 1997)
Interpretation of the technical standards for thermal power generating facilities
Thermal power generating facilities are required to satisfy technical standards by the Electric Utility Industry Law. The standards are defined by the above mentioned ministerial ordinance, the notification, and the interpretation. The outline is as follows.

Item	Article Number of Technical Standards						Summary of Articles of Ministerial Ordinances
	Boiler	Steam turbine	Gas turbine	Internal combustion engine	Fuel cells facility	Liquefied gas facility	
Material	Article 5 Interpretation Article 2 (Materials of boiler etc.)	Article 12 Interpretation Article 18 (Materials of facilities attached to steam turbines)	Article 18 Interpretation Article 28 (Materials of facilities attached to gas turbines)	Article 24 Interpretation Article 36 (Materials of facilities attached to internal combustion engines)	Article 30 Interpretation Article 43 (Materials of fuel cells facilities)	Article 40 Interpretation Article 55 (Materials of liquefied gas facilities) Article 56 (Specified steel rod etc.)	The material used for pressure parts of vessels and pipes of equipment and related facilities (except pump, compressor, and liquefied gas facility) is required to have safe chemical ingredients and mechanical strength, and specified by the attached table 1 (Ferrous material) and table 2 (Non-ferrous material) for interpretation. For liquefied gas facilities, the material of iron rod and concrete, etc. is specified by the attached table 3 for interpretation, etc.
Structure	Article 6 Interpretation Article 3 (Structure of boiler etc.) Article 4 (Allowable stress of materials) Article 5 (Hydraulic pressure test) Article 6 (Shell of vessel) Article 7 (Rectangular header) Article 8 (End plate of vessel) Article 9 (Flat plate of vessel) Article 10 (Circular dished cap plate of vessel) Article 11 (Tube plate of vessel) Article 12 (Pipe and nozzle stub) Article 13 (Flange) Article 14 (Shell boiler)	Article 13 Interpretation Article 19 (Emergency governor actuating speed) Article 20 (Maximum vibration) Article 21 (Lubricating equipment) Article 22 (Critical speed) Article 23 (Others)	Article 19 Interpretation Article 29 (Emergency governor actuating speed) Article 30 (Lubricating equipment) Article 31 (Critical speed) Article 32 (Others)	Article 23 Interpretation Article 37 (Emergency governor actuating speed) Article 38 (Lubricating equipment) Article 39 (Others)	Article 31 Interpretation Article 44 (Structure of fuel facility) Article 45(Pressure test) Article 46 (Pneumatic test)	Article 41 Interpretation Article 57 (Structure of liquefied gas facility) Article 58 (Allowable stress of materials) Article 59 (Shell of vessel) Article 60 (End plate of vessel) Article 61 (Flat plate of vessel) Article 62 (Cap plate of vessel) Article 63 (Tube plate of vessel) Article 64 (Vessel for tank etc.) Article 65 (Tank etc) Article 66 (Gas holder) Article 67 (Pipe) Article 68 (Pipe line) Article 69 (Fitting) Article 70(Measure of flexible tube)	The maximum stress of pressure parts of equipment and its related facilities at the maximum allowable pressure or temperature (lowest temperature for liquefied gas) shall be safe. The interpretation: attached table 1 and 2 prescribe it. And it is required that the rotating machines such as a steam turbine, a gas turbine and an internal combustion engine have sufficient mechanical strength and their bearings do not abnormally deform at the emergency governor actuating speed.

(Continued)

Item	Article Number of Technical Standards						Summary of Articles of Ministerial Ordinances
	Boiler	Steam turbine	Gas turbine	Internal combustion engine	Fuel cells facility	Liquefied gas facility	
						Article 71 (Installation of pipe line) Article 72 (Pressure test and pneumatic test) Article 73 (Leakage test of pipe line)	
Safety valve	Article 7 Interpretation Article 15 (Structure and materials, etc of safety valve)				Article 32 Interpretation Article 47 (Safety valve etc.)	Article 42 Interpretation Article 74 (Safety valve etc.) Article 75 (It has specified the installation of pressure instrument for the storage tank)	A suitable safety valve is required for possible overpressure of each equipment and related facilities.
Feed water equipments	Article 8 Interpretation Article 16 (Feed water equipments)						The feed water equipment is required to be installed that does not cause thermal damage at the maximum continuous steam generation operation. And also, the standby feed water equipment is required in case that heat remains to cause damage to boiler, even with rapid fuel shutoff due to feed water equipment malfunction.
Shutoff of steam and feed water	Article 9						The structure is specified to be capable to shutoff steam discharge at the outlet of the boiler and to shut off feed water passage rapidly and automatically at the inlet of the feed water equipment.
Drainage of boiler	Article 10						For circulation boilers, installation of the drainage is specified for boiler water concentration prevention and water level adjustment.
Speed governing device		Article 14	Article 20	Article 26			Installation of the speed governing device, which adjusts automatically the inlet steam flow (GT: energy, internal combustion engine: fuel), is specified to be installed, in order to prevent the continuous fluctuation of rotating speed and output power at the load change.
Emergency shutdown device		Article 15 Interpretation Article 24 (Alarm setting of vibration) Article 25 (Explanation of unusual occurrence)	Article 21 (Lubricating equipment) Interpretation Article 33 (Explanation of unusual occurrence)	Article 27 Interpretation Article 40 (Explanation of unusual occurrence)	Article 34 Interpretation Article 49 (Explanation of unusual occurrence)	Article 47 Interpretation Article 78 (Alarm device) Article 79 (Specified location of installation of interception device)	For each equipment and related facilities, installation of the emergency shutdown device, such as the emergency governor device which shutdown a turbine automatically and quickly at the unusual occurrence of over-speed (Liquefied gas: shutoff of inlet and outlet gas) is specified. Steam

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(Continued)

Item	Article Number of Technical Standards						Summary of Articles of Ministerial Ordinances
	Boiler	Steam turbine	Gas turbine	Internal combustion engine	Fuel cells facility	Liquefied gas facility	
							turbines with the output of 400,000kW or more are required to have a device, which detects the vibration to cause a trouble and sends the alarm. As for the liquefied gas, the facility to monitor the condition of the control equipment and send the alarm is specified to be installed.
Overpressure prevention device		Article 16 Interpretation Article 26 (Overpressure prevention device)	Article 22 Interpretation Article 34 (Overpressure prevention device)	Article 28 nterpretation Article 41 (Overpressure prevention device)			Suitable overpressure prevention device is specified to be installed where overpressure may occur in equipment and related facilities.
Instrument	Article 11 (Tube plate of vessel) Interpretation Article 17 (Items to be measured)	Article 17 Interpretation Article 27 (Items to be measured)	Article 23 Interpretation Article 35 (Items to be measured)	Article 29 Interpretation Article 42 (Items to be measured)		Article 46 Interpretation Article 77 (Items to be measured)	The instrument to measure operating conditions for the prevention of equipment damage is specified to be installed.
Measure against gas leakage					Article 33 Interpretation Article 48 (Measure against gas leakage)	Article 43 Interpretation Article 76 (Measure against gas leakage)	To prevent the injury by gas leakage, proper measure is specified to be taken.
Replacement of fuel gas					Article 35	Article 49	The structure of the parts where the fuel gas passes is specified to be capable to replace the gas with the inert gas safely.
Facility of air system equipment					Article 36		For air compressors and auxiliary burners, the automatic shutdown device at the time of their malfunctions is specified to be installed.
Isolation distance						Article 37 Interpretation Article 50 (Isolation distance) Article 51 (Isolation distance between gas storage tanks, etc) Notification Article 1 (Facility required of isolation distance) Article 2 (Safety-preservation object) Article 3 (Isolation distance)	Liquefied gas equipment and tanks are specified to be installed with required distance for the prevention of hazard such as leakage, fire, etc.

(Continued)

Item	Article Number of Technical Standards						Summary of Articles of Ministerial Ordinances
	Boiler	Steam turbine	Gas turbine	Internal combustion engine	Fuel cells facility	Liquefied gas facility	
Security division						Article 38 Interpretation Article 52 (Security division)	The liquefied gas equipment is specified to be installed in divided area suitable for safety preservation, depending on its type and scale of the equipment and have a distance between each equipment, in order to prevent hazard such as leakage, fire, etc.
Location of facility installation						Article 39 Interpretation Article 53 (Location of facility installation) Article 54 (Location prohibited for installation of storage tanks and pipe lines)	Facilities are specified not to be installed in the area from the outer surface of safety bank to the distance necessary for disaster prevention work, except the facilities which do not disturb preventive activities to avoid expansion of leakage, fire, etc. Storage tanks and pipelines shall not be installed in the area where those may be damaged or where the place may cause leakage or fire.
Static electricity removal						Article 44	Static electricity removal measure is required where a fire breaks out by static electricity.
Fire prevention and extinguishing						Article 45	Installation of suitable fire prevention and extinguishing equipment is specified.
Shut-off device						Article 48 Interpretation Article 80 (Shat-off device)	The necessity of installing the equipments that shuts off the inlet and outlet flow of gas or liquefied gas at the main inlet and outlet is specified.
Sign						Article 50	Storage tanks and gasholders shall have signs to indicate what those are.
Measure of heat resistance						Article 51 Interpretation Article 81 (Measure of heat resistance)	A storage tank and its supports are specified to have heat insulation and resistance capability, and a cooling device to be installed depending on the scale.
Preventing measure						Article 52 Interpretation Article 82 (Preventing measure) Article 83 (Exposure length of pipe lines)	The preventing measure for damage or corrosion is specified to be taken.

(Continued)

Item	Article Number of Technical Standards						Summary of Articles of Ministerial Ordinances
	Boiler	Steam turbine	Gas turbine	Internal combustion engine	Fuel cells facility	Liquefied gas facility	
Heating parts of vaporizer						Article 52 Interpretation Article 84 (Measure for freeze prevention)	The heating part of vaporizers shall not be heated in the open flame. And, when there is a possibility of freeze of warm water for the heating part, it is specified that a freeze prevention measure shall be taken.
Measure of odor addition						Article 54	In case of gas transportation by pipe lines, it is specified that odor shall be added for leakage gas detection by the smell.

Contents of attached tables list of the Technical Standards for Thermal Power Generating Facilities

Attached table No.1 Allowable tensile stress of steel ferrous materials at each temperature.
  (1) JIS standard materials, thermal power technical standard materials, and API standard materials
  (2) ASME standard materials
Attached table No.2 Allowable tensile stress of non-ferrous materials at each temperature.
  (1) JIS standard materials
  (2) ASME standard materials
Attached table No.3 Allowable tensile stress of main materials to be used for the support of the storage tank and the gasholder and foundation.
Attached table No.4 Efficiency of longitudinal joint for pipe of the liquefied gas facilities.
Attached table No.5 K value

Of the above tables, table No.1 (1) is shown as the following table.

Attached table No.1 Allowable tensile stress of ferrous materials at each temperature

(1) JIS standard materials • thermal power technical standard materials and API standard materials

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																						
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
Carbon steel and molybdenum alloy steel plates for boilers and other pressure vessels JIS G3103 (1987)	SB410		410		○	○	○						102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	97	88	76	57														
	SB450		450		○	○	○						112	112	112	112	112	112	112	112	112	112	112	112	112	112	112	112	106	95	80	58														
	SB480		480		○	○	○						120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	113	101	84	58														
	SB450M	0.5Mo	450		○	○	○						112	112	112	112	112	112	112	112	112	112	112	112	112	112	112	112	112	112	108	101														
	SB480M	0.5Mo	480		○	○	○						120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	115	106														
Steel plates for pressure vessels for intermediate temperature service JIS G3115 (1990)	SPV235		400		○	○	○						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100																		
	SPV315		490		○	○	○						122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122																		
				(35)								141	141	141	141	141	133	131	128	128	126	126	126	126	126	126	126	126																		
	SPV355		520		○	○	○						130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130																		
				(35)								159	159	159	159	159	155	151	147	143	143	143	143	143	143	143	143	143																		
	SPV450		570		○	○	○						142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142																		
				(35)								181	181	181	181	181	176	172	169	163	163	163	163	163	163	163	163	163																		
	SPV490		610		○	○	○						152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152																		
				(35)								194	194	194	194	194	189	185	179	175	175	175	175	175	175	175	175	175																		
Carbon steel plates for pressure vessels for intermediate and moderate temperature service JIS G3118 (1990)	SGV410		410		○	○									102	102	102	102	102	102	102	102	102	102	102	102	102	102																		
	SGV450		450		○	○									112	112	112	112	112	112	112	112	112	112	112	112	112	112																		
	SGV480		480		○	○									120	120	120	120	120	120	120	120	120	120	120	120	120	120																		
Manganese-molybdenum and manganese-molybdenum-nickel alloy steel plates for boilers and other pressure vessels JIS G3119 (1987)	SBV1A	Mn, 0.5Mo	520		○	○									130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	125	112														
	SBV1B		550		○	○									138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	135	130	118														
	SBV2	Mn, 0.6Ni,0.5Mo	550		○	○									138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	135	130	118														
	SBV3	Mn, 0.9Ni,0.5Mo	550		○	○									138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	135	130	118														
Manganese-molybdenum and manganese-molybdenum-nickel alloy steel plates quenched and tempered for pressure vessels JIS G3120 (1987)	SQV1A	Mn, 0.5Mo	550		○	○							138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138																		
	SQV1B		620		○	○							155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155																		
				(35)									197	197	197	192	187	182	177	177	177	177	177	177	177	177	177	177																		
	SQV2A	Mn, 0.6Ni,0.5Mo	550		○	○							138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138																		
	SQV2B		620		○	○							155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155																		
				(35)									197	197	197	192	187	182	177	177	177	177	177	177	177	177	177	177																		
	SQV3A	Mn, 0.9Ni,0.5Mo	550		○	○							138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138																		
	SQV3B		620		○	○							155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155																		
				(35)									197	197	197	192	187	182	177	177	177	177	177	177	177	177	177	177																		

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																						
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
Chromium-molybdenum alloy steel plates for boilers and pressure vessels JIS G4109 (1987)	SCMV1	0.5Cr, 0.5Mo	380		○	○								95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	92	90	87	78	55											
	SCMV2	1Cr, 0.5Mo	380		○	○								95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	94	90	80	63	44	29	17								
	SCMV3	1.25Cr, 0.5Mo	410		○	○								102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	100	92	81	64	47	34	25								
	SCMV4	2.25Cr, 1Mo	410		○	○								102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	100	92	81	64	48	36	27								
	SCMV5	3Cr, 1Mo	410		○	○								102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	100	96	92	85	70	55	44	34	25									
	SCMV6	5Cr, 0.5Mo	410		○	○								102	102	102	102	102	102	102	102	102	102	101	99	97	96	94	92	90	88	83	75	59	45	34	25	19								
	SCMV1	0.5Cr, 0.5Mo	480		○	○								120	120	120	120	120	120	120	120	120	120	120	120	120	120	115	94	94	92	90	87	78	55											
	SCMV2	1Cr, 0.5Mo	450		○	○								112	112	112	110	108	106	104	104	104	104	104	104	104	104	104	104	104	104	101	96	82	63	44	29	17								
	SCMV3	1.25Cr, 0.5Mo	520		○	○								130	130	130	125	123	121	119	119	119	119	119	119	119	119	119	119	119	119	116	107	85	64	47	34	25								
	SCMV4	2.25Cr, 1Mo	520		○	○								130	130	130	128	127	126	124	122	121	120	119	119	119	119	119	118	117	116	113	104	85	64	48	36	27								
	SCMV5	3Cr, 1Mo	520		○	○								130	130	130	128	127	126	124	122	121	120	119	119	119	119	119	118	117	116	110	89	70	55	44	34	25								
	SCMV6	5Cr, 0.5Mo	520		○	○								130	130	130	128	128	125	122	122	122	122	122	122	122	122	120	118	115	111	106	80	59	45	34	25	19								
Molybdenum ally steel plate for pressure vessel of power plant (Remark 6)	KA−SB520M	0.5Mo	520		○	○							130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	129	127													
Chromium-molybdenum ally steel plate for pressure vessel of power plant (Remark 7)	KA−SCMV28	9Cr, 1Mo, Nb, V	590		○	○							148	148	148	148	148	148	148	146	146	146	146	145	145	144	142	140	137	133	128	124	117	110	102	94	83	66	45	29						
	KA−SCMV4J1	2.25Cr, 1.6W	510		○	○						128	128	128	128	128	128	128	128	128	127	127	126	123	123	123	123	123	123	122	120	116	113	110	101	85	70	54	35							
Rolled steel for general structure JIS G3101 (1995)	SS330		330	(6)(10)	○	○	○						82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82																		
	SS400		400	(6)(10)	○	○	○						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100																		
Rolled steel for welded structure JIS G3106 (1995)	SM400A		400	(7)	○	○	○						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100																		
	SM400B		400	(7)	○	○	○						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100																		
	SM400C		400	(7)	○	○	○						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100																		
	SM490A		490	(7)	○	○	○						122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122																		
	SM490B		490	(7)	○	○	○						122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122																		
	SM490C		490	(7)	○	○	○						122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122																		
	SM490YA		490	(7)	○	○	○						122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122																		
	SM490YB		490	(7)	○	○	○						122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122																		
	SM520B		520	(7)	○	○	○						130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130																		
	SM520C		520	(7)	○	○	○						130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130																		
	SM570		570	(7)	○	○	○						142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142																		

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable										
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100
Hot rolled stainless steel plates JIS G4304 (1991) Cold rolled stainless steel plates, sheets and strip JIS G4305 (1991)	SUS304	18Cr, 8Ni	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	109
	SUS304L	18Cr, 8Ni very low C	480		○	○	○	109	109	109	109	109	109	109	109	109	109	104
	SUS309S	23Cr,12Ni	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	121	116
	SUS310S	25Cr,20Ni	520	(18) (15)	○	○	○	128 128	128 128	128 128	128 128	128 128	128 128	128 128	128 128	128 128	121 121	116 116
	SUS316	16Cr, 12Ni, 2Mo	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	110
	SUS316L	16Cr, 12Ni 2Mo, very low C	480		○	○	○	109	109	109	109	109	109	109	109	109	109	109
	SUS317	18Cr, 13Ni 3Mo	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	110
	SUS317L	18Cr, 13Ni 3Mo, very low C	480		○	○	○	109	109	109	109	109	109	109	109	109	109	109
	SUS321	18Cr, 10Ni Ti	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	119	113
	SUS347	18Cr, 10Ni Nb	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	119	113
Stainless steel plates for power plant (Remark 8)	KA−SUS410J3	11Cr, 2W, 0.4Mo	620		○	○						155	155	155	155	155	155	155
Carbon steel boiler and heat exchanger tubes JIS G3461 (1988)	STB340		340	(1)(13) (1)(12) (14)	○	○	○						85 72	85 72	85 72	85 72	85 72	85 72
	STB410		410	(1)(13) (1)(12) (14)	○	○	○						102 87	102 87	102 87	102 87	102 87	102 87
	STB510		510	(13) (12)(14)	○	○	○						128 108	128 108	128 108	128 108	128 108	128 108
Carbon steel boiler tubes for power plant (Remark 9)	KA−STB480		480		○	○							120	120	120	120	120	120
Alloy steel boiler and heat exchanger tubes JIS G3462 (1988)	STBA12	0.5Mo	380	(13) (12)(14)	○	○							95 81	95 81	95 81	95 81	95 81	95 81
	STBA13	0.5Mo	410	(13) (12)(14)	○	○							102 87	102 87	102 87	102 87	102 87	102 87
	STBA20	0.5Cr, 0.5Mo	410	(13) (12)(14)	○	○							102 87	102 87	102 87	102 87	102 87	102 87
	STBA22	1Cr, 0.5Mo	410	(13) (12)(14)	○	○							102 87	102 87	102 87	102 87	102 87	102 87
	STBA23	1.25Cr, 0.5Mo	410		○	○							102	102	102	102	102	102
	STBA24	2.25Cr, 1Mo	410		○	○							102	102	102	102	102	102
	STBA25	5Cr, 0.5Mo	410		○	○							102	102	102	102	102	102
	STBA26	9Cr, 1Mo	410		○	○							102	102	102	102	102	102
Alloy steel boiler tubes for power plant (Remark 10)	KA−STBA10	1.25Cr, 0.3Cu	410		○	○							102	102	102	102	102	102
	KA−STBA21	1Cr, 0.3Mo	410		○	○							102	102	102	102	102	102

Symbol	tensile stress at each temperature (N/㎟)																											
	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
SUS304	102	94	90	85	82	79	77	76	75	74	73	72	71	70	69	68	66	64	60	55	46	37	30	25	20	16	13	10
SUS304L	97	90	83	76	73	69	66	63	62	60	59	57	56															
SUS309S	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	78	74	65	54	42	33	25	21	17	13	10	8	6
SUS310S	113 113	109 109	106 106	103 103	101 101	98 98	96 96	93 93	91 91	89 89	87 87	86 86	84 84	82 82	80 80	77 79	72 76	60 72	44 65	32 57	24 49	17 41	11 33	6 25	4 19	3 13	2 9	2 7
SUS316	105	100	97	94	91	88	85	83	81	79	77	76	75	74	72	71	69	67	66	64	58	47	37	29	21	16	12	9
SUS316L	105	98	91	84	80	77	74	72	69	67	65	63	61	59														
SUS317	105	100	97	94	91	88	85	83	81	79	77	76	75	74	72	71	69	67	66	64	58	47	37	29	21	16	12	9
SUS317L	108	98	95	84	80	77	74	72	69	67	65	63	61	59														
SUS321	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	76	76	75	70	58	40	30	24	17	12	9	7	6
SUS347	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	76	76	75	70	58	40	30	24	17	12	9	7	6
KA−SUS410J3	155	153	150	147	146	144	142	140	138	136	134	132	129	125	122	118	112	106	100	85	65	45	30					
STB340	85 72	85 72	85 72	85 72	85 72	85 72	85 72	85 72	85 72	85 72	82 70	76 64	66 56	53 45														
STB410	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	97 82	88 75	76 64	57 48														
STB510	128 108	128 108	128 108	128 108	128 108	128 108	128 108	128 108	128 108	128 108	128 108	115 97	98 83	69 59														
KA−STB480	120	120	120	120	120	120	120	120	120	120	113	101	84	58														
STBA12	95 81	95 81	95 81	95 81	95 81	95 81	95 81	95 81	95 81	95 81	95 81	95 81	93 79	90 76	88 76	68 58												
STBA13	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 86	99 84	95 82	94 80	70 59												
STBA20	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 86	101 86	99 84	98 83	96 81	93 79	91 77	89 76	73 62	51 43											
STBA22	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	99 84	92 78	81 70	60 51	38 32										
STBA23	102	102	102	102	102	102	102	102	102	102	102	102	102	100	92	81	60	38	25									
STBA24	102	102	102	102	102	102	102	102	102	102	102	102	102	100	92	81	64	48	36	27	20							
STBA25	102	102	102	102	102	101	99	97	96	94	92	90	88	83	75	60	45	34	26	20								
STBA26	102	102	102	102	102	101	99	97	96	94	92	90	88	86	83	77	66	49	32	21	15	10						
KA−STBA10	102	102	102	102	102	102	102	102	102	102	97	88	76	57														
KA−STBA21	102	102	102	102	102	102	102	102	102	102	102	102	102	98	92	74	51	28										

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																						
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
(Continued)	KA−STBA24 E-G	2.25Cr, 1Mo	410	(36)	○	○							102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	102 87	100 85	92 78	81 69	64 54	48 41	36 31	27 23	20 17							
	KA−STBA24 J1	2.25Cr, 1.6W	510		○	○						128	128	128	128	128	128	128	128	128	128	128	128	127	127	126	126	125	124	122	120	117	114	111	104	90	71	53	34							
	KA−STBA27	9Cr, 2Mo	510		○	○							128	128	128	128	128	128	125	122	121	119	117	115	115	114	112	110	110	110	108	105	102	99	93	84	61	41	27	17						
	KA−STBA28	9Cr,1Mo,Nb.V.	590		○	○							148	148	148	148	148	148	148	146	146	146	146	145	145	144	142	140	137	133	128	124	117	110	102	94	83	66	45	29						
	KA−STBA29	9Cr. 1.8W	620		○	○							155	155	155	155	155	155	155	153	151	148	146	145	143	141	139	137	134	132	129	126	122	118	113	107	101	91	69	48	29					
Stainless steel boiler and heat exchanger tubes JIS G3463 (1994)	SUS304TB	18Cr, 8Ni	520	(3)(17)(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	109	102	94	90	85	82	79	77	76	75	74	73	72	71	70	69	68	66	64	60	55	46	37	30	25	20	16	13	10
				(3)(17)(16)(18)				128	128	128	128	128	128	128	128	128	119	114	111	107	105	103	102	101	100	99	99	98	98	97	96	95	94	93	89	82	71	57	46	37	30	25	20	10	13	10
	SUS304HTB	18Cr, 8Ni	520	(2)	○	○	○					128	128	128	128	128	117	109	102	94	90	85	82	79	77	76	75	74	73	72	71	70	69	68	66	64	60	55	46	37	30	25	20	16	13	10
				(2)(16)								128	128	128	128	128	119	114	111	107	105	103	102	101	100	99	99	98	98	97	96	95	94	93	89	82	71	57	46	37	30	25	20	10	13	10
	SUS304LTB	18Cr, 8Ni, very low C	480	(17)	○	○	○	109	109	109	109	109	109	109	109	109	109	104	97	90	83	76	73	69	66	63	62	60	59	57	56															
	SUS309TB	23Cr, 12Ni	520	(3)(17)(18)	○	○	○	128	128	128	128	128	128	128	128	128	121	116	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	78	74	65	54	42	33	25	21	17	13	10	8	6
				(3)(17)(16)(18)				128	128	128	128	128	128	128	128	128	123	118	116	113	112	110	109	107	107	106	105	105	104	103	103	101	97	89	78	67	54	42	33	25	21	17	13	10	8	6
	SUS310TB	25Cr, 20Ni	520	(3)(17)(15)(18)	○	○	○	128	128	128	128	128	128	128	128	128	121	116	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	77	72	60	44	32	24	17	11	6	4	3	2	2
				(3)(17)(18)				128	128	128	128	128	128	128	128	128	121	116	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	79	76	72	65	57	49	41	33	25	19	13	9	7
				(3)(17)(16)(18)				128	128	128	128	128	128	128	128	128	123	118	116	113	112	110	109	107	107	106	105	105	104	103	103	101	97	89	80	64	44	32	24	17	11	6	4	3	2	2
				(3)(17)(15)(16)(18)				128	128	128	128	128	128	128	128	128	123	118	116	113	112	110	109	107	107	106	105	105	104	103	103	101	97	89	80	72	65	57	49	41	33	25	19	13	9	7
	SUS316TB	16Cr, 12Ni 2Mo	520	(3)(17)(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	110	105	100	97	94	91	88	85	83	81	79	77	76	75	74	72	71	69	67	66	64	58	47	37	29	21	16	12	9
				(3)(16)(17)(18)				128	128	128	128	128	128	128	128	128	124	121	119	117	115	113	112	111	110	110	110	110	110	109	107	106	103	101	98	94	88	78	63	47	37	29	21	16	12	9
	SUS316HTB	16Cr, 12Ni 2Mo	520	(2)	○	○	○					128	128	128	128	128	117	110	105	100	97	94	91	88	85	83	81	79	77	76	75	74	72	71	69	67	66	64	58	47	37	29	21	16	12	9
				(2)(16)								128	128	128	128	128	124	121	119	117	115	113	112	111	110	110	110	110	110	109	107	106	103	101	98	94	88	78	63	47	37	29	21	16	12	9
	SUS316LTB	16Cr, 12Ni 2Mo, very low C	480	(17)	○	○	○	109	109	109	109	109	109	109	109	109	109	109	105	98	91	84	80	77	74	72	69	67	65	63	61	59														
	SUS321TB	18Cr, 10Ni Ti	520	(3)(17)	○	○	○	128	128	128	128	128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	77	76											
				(3)(16)(17)				128	128	128	128	128	128	128	128	128	121	115	112	109	108	107	106	105	104	104	104	104	104	104	104	104	103	102	99											
	SUS321HTB	18Cr, 10Ni Ti	520	(2)(19)	○	○	○					128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	77	76	76	73	65	51	38	28	22	17	13	9	7
				(2)(16)(19)								128	128	128	128	128	121	115	112	109	108	107	106	105	104	104	104	104	104	104	104	104	103	102	101	97	87	68	51	38	28	22	17	13	9	7
	SUS347TB	18Cr, 10Ni Nb	520	(3)(17)(18)	○	○	○	128	128	128	128	128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	77	76	75	70	57	40	30	24	17	12	9	7	6
				(3)(16)(17)(18)				128	128	128	128	128	128	128	128	128	121	115	112	109	108	107	106	105	104	104	104	104	104	104	104	104	103	102	99	91	76	58	40	30	24	17	12	9	7	6

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																										
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	7775	800	825	850
(Continued)	SUS347HTB	18Cr, 10Ni Nb	520	(2)(17)	○	○	○					128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	77	76	76	74	68	56	41	31	25	19	14	11	9		
				(2)(16) (17)								128	128	128	128	128	121	115	112	109	108	107	106	105	104	104	104	104	104	104	104	104	103	102	101	98	91	76	56	41	31	25	19	14	11	9		
	SUS410TB	13Cr	410	(3)	○	○	○					102	102	102	102	102	100	98	97	95	94	92	90	89	87	86	85	84	82	80	76	73	68	61	50	38	26	18	12									
	SUS430TB	16Cr	410	(3)	○	○	○					102	102	102	102	102	100	98	97	95	94	92	90	89	87	86	85	84	82	80	76																	
Stainless steel boiler tubes for power plant use (Remark 11)	KA−SUS304 J1HTB	18Cr, 9Ni 3Cu,Nb,N	590		○	○						148	148	148	148	148	136	128	124	121	118	114	111	109	106	103	102	101	100	99	97	96	94	92	91	90	89	89	88	80	63	47	33	23				
				(16)								148	148	148	148	148	147	147	145	142	140	137	137	137	137	137	137	136	136	136	134	132	130	128	126	123	119	115	101	80	63	47	33	23				
	KA−SUS309 J1TB	24Cr, 15Ni 1Mo, N	690		○	○						128	128	128	128	128	121	115	112	109	108	107	106	105	104	104	104	104	104	104	104	104	103	102	101	97	87	68	51	38								
	KA−SUS309 J2TB	22Cr, 14Ni 1.5Mo, N	590		○	○						148	148	148	148	148	136	124	118	111	104	98	95	92	90	87	87	87	86	86	84	82	80	78	76	75	74	73	73									
				(16)								148	148	148	148	148	147	146	142	138	134	131	129	127	126	124	123	122	122	121	120	118	116	113	111	108	106	95	73									
	KA−SUS309 J3LTB	25Cr, 14Ni 0.8Mo, N 0.2Si	690		○	○						172	172	172	172	172	159	149	145	141	137	133	130	128	126	123	122	121	120	119	117	115	113	111	108	106	96	86	65	42								
				(16)								172	172	172	172	172	159	149	146	142	139	136	134	132	131	129	128	128	127	126	124	121	118	116	113	110	98	86	65	42								
	KA−SUS309 J4HTB	22Cr, 15Ni Nb	590		○	○						148	148	148	148	148	145	137	135	132	129	126	123	120	117	114	111	108	105	101	100	98	97	96	96	96	93	93	85	67	54	44	34	27	21	17		
				(16)								148	148	148	148	148	145	142	138	135	131	128	127	126	126	125	125	125	125	125	124	122	121	120	116	113	109	106	85	67	54	44	34	27	21	17		
	KA−SUS310 J1TB	25Cr, 20Ni Nb, V	660		○	○		165	165	165	165	165	165	165	165	165	159	152	148	145	136	128	127	125	123	121	121	121	118	116	112	109	109	109	106	103	103	102	99	76	59	44	33	25	21	17		
				(16)				165	165	165	165	165	165	165	165	165	164	162	159	156	154	149	148	146	144	144	144	144	144	144	144	143	142	140	137	134	131	124	99	76	59	44	33	25	21	17		
	KA−SUS310 J2TB	20Cr, 25Ni 1.5Mo	640		○	○						160	160	160	160	160	156	149	144	140	137	135	133	131	130	128	126	124	122	120	118	116	114	112	110	109	108	107	102	83	69	57	48	40	32	26	21	17
				(16)								160	160	160	160	160	160	160	159	156	154	152	151	150	149	149	149	149	149	149	149	148	148	146	145	143	140	127	102	83	69	57	48	40	32	26	21	17
	KA−SUS321 J1HTB	18Cr, 10Ni Ti, Nb	520		○	○						128	128	128	128	128	122	117	112	108	103	98	97	97	96	95	93	91	90	88	86	84	83	81	80	80	79	79	78	62	49	39	29	23	17	13		
				(16)								128	128	128	128	128	124	121	119	116	114	111	111	111	110	110	110	110	109	108	107	105	104	103	100	98	95	93	78	62	49	39	29	23	17	13		
	KA−SUSTP 347HTB	18Cr, 10Ni Nb	520		○	○						128	128	128	128	128	123	119	115	111	108	104	101	98	96	94	92	90	88	88	87	87	87	87	87	86	85	80	70	54	41	32	25	19	15	11		
				(16)								128	128	128	128	128	126	123	118	113	110	107	105	104	102	102	101	101	101	101	101	101	101	101	100	98	95	85	70	54	41	32	25	19	15	11		
	KA−SUS410 J2TB	12Cr, 1Mo W, V, Nb	590		○	○						148	148	148	148	148	148	148	147	146	146	145	143	141	139	137	136	134	132	131	128	125	119	113	106	99	88	69	51	34								
	KA−SUS410 J3TB	11Cr, 2W 0.4Mo	620		○	○						155	155	155	155	155	155	155	153	151	148	146	144	143	141	140	138	136	134	132	129	126	123	120	115	111	102	93	69	46	33							
Carbon steel pipes for ordinary piping JIS G3452 (1997)	SGP		290	(9)(10) (14)	○	○	○						62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62																				
				(9)(10) (37)									47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47																				
arbon steel pipes for pressure service JIS G3454 (1988)	STPG370		370	(13)	○	○	○						92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92																				
				(14)									79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79																				
	STPG410		410	(13)	○	○	○						102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102																				
				(14)									87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87																				
Carbon steel pipes for high pressure service JIS G3455 (1988)	STS370		370		○	○	○						92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92																				
	STS410		410		○	○	○						102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102																				
	STS480		480		○	○	○						120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120																				

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable										
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100
Carbon steel pipes for high temperature service JIS G3456 (1988)	STPT370		370	(13)	○	○	○						92	92	92	92	92	92
				(14)									79	79	79	79	79	79
	STPT410		410	(13)	○	○	○						102	102	102	102	102	102
				(14)									87	87	87	87	87	87
	STPT480		480		○	○	○						120	120	120	120	120	120
Arc welded carbon steel pipes JIS G3457 (1988)	STPY400		400	(9)(10)	○	○	○						65	65	65	65	65	65
Alloy steel pipes JIS G3458 (1988)	STPA12	0.5Mo	380		○	○	○						95	95	95	95	95	95
	STPA20	0.5Cr, 0.5Mo	410		○	○	○						102	102	102	102	102	102
	STPA22	1Cr, 0.5Mo	410		○	○	○						102	102	102	102	102	102
	STPA23	1.25Cr, 0.5Mo	410		○	○	○						102	102	102	102	102	102
	STPA24	2.25Cr, 1Mo	410		○	○	○						102	102	102	102	102	102
	STPA25	5Cr, 0.5Mo	410		○	○	○						102	102	102	102	102	102
	STPA26	9Cr, 1Mo	410		○	○	○						102	102	102	102	102	102

Symbol	Note (Remark 1)	tensile stress at each temperature (N/㎟)																											
		125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
STPT370	(13)	92	92	92	92	92	92	92	92	92	92	89	80	70	56														
	(14)	79	79	79	79	79	79	79	79	79	79	76	69	59	47														
STPT410	(13)	102	102	102	102	102	102	102	102	102	102	97	88	76	57														
	(14)	87	87	87	87	87	87	87	87	87	87	82	75	64	48														
STPT480		120	120	120	120	120	120	120	120	120	120	113	101	84	58														
STPY400	(9)(10)	65	65	65	65	65	65	65	65	65	65																		
STPA12		95	95	95	95	95	95	95	95	95	95	95	95	93	90	88	68												
STPA20		102	102	102	102	102	102	102	102	101	99	98	96	93	91	89	73	51											
STPA22		102	102	102	102	102	102	102	102	102	102	102	102	102	99	92	81	60	36										
STPA23		102	102	102	102	102	102	102	102	102	102	102	102	102	100	92	81	60	36	25									
STPA24		102	102	102	102	102	102	102	102	101	102	102	102	102	100	92	81	64	48	36	27	20							
STPA25		102	102	102	102	102	101	99	97	96	94	92	90	88	83	75	60	45	34	26	20								
STPA26		102	102	102	102	102	101	99	97	96	94	92	90	88	86	83	77	66	49	32	21	15	10						

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable										
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100
Stainless steel pipes JIS G3459 (1997)	SUS304TP	18Cr, 8Ni	520	(3)(17)(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	109
				(3)(16)(17)(18)				128	128	128	128	128	128	128	128	128	119	114
	SUS304HTP	18Cr, 8Ni	520	(2)	○	○	○					128	128	128	128	128	117	109
				(2)(16)								128	128	128	128	128	119	114
	SUS304LTP	18Cr, 8Ni very low C	480	(17)	○	○	○	109	109	109	109	109	109	109	109	109	109	104
	SUS309TP	23Cr, 12Ni	520	(3)(17)(18)	○	○	○	128	128	128	128	128	128	128	128	128	121	116
				(3)(16)(17)(18)				128	128	128	128	128	128	128	128	128	123	118
	SUS310TP	25Cr, 20Ni	520	(3)(17)(18)	○	○	○	128	128	128	128	128	128	128	128	128	121	116
				(3)(17)(15)(18)				128	128	128	128	128	128	128	128	128	121	116
				(3)(16)(17)(18)				128	128	128	128	128	128	128	128	128	123	118
				(3)(16)(15)(17)(18)				128	128	128	128	128	128	128	128	128	123	118

Symbol	Note (Remark 1)	tensile stress at each temperature (N/㎟)																											
		125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
SUS304TP	(3)(17)(18)	102	94	90	85	82	79	77	76	75	74	73	72	71	70	69	68	66	64	60	55	46	37	30	25	20	16	13	10
	(3)(16)(17)(18)	111	107	105	103	102	101	100	99	99	98	98	97	96	95	94	93	89	82	71	57	46	37	30	25	20	16	13	10
SUS304HTP	(2)	102	94	90	85	82	79	77	76	75	74	73	72	71	70	69	68	66	64	60	55	46	37	30	25	20	16	13	10
	(2)(16)	111	107	105	103	102	101	100	99	99	98	98	97	96	95	94	93	89	82	71	57	46	37	30	25	20	16	13	10
SUS304LTP	(17)	97	90	83	76	73	69	66	63	62	60	59	57	56															
SUS309TP	(3)(17)(18)	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	78	74	65	54	42	33	25	21	17	13	10	8	6
	(3)(16)(17)(18)	116	113	112	110	109	107	107	106	105	105	104	103	103	101	97	89	78	67	54	42	33	25	21	17	13	10	8	6
SUS310TP	(3)(17)(18)	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	77	72	60	44	32	24	17	11	6	4	3	2	2
	(3)(17)(15)(18)	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	79	76	72	65	57	49	41	33	25	19	13	9	7
	(3)(16)(17)(18)	116	113	112	110	109	107	107	106	105	105	104	103	103	101	97	89	80	64	44	32	24	17	11	6	4	3	2	2
	(3)(16)(15)(17)(18)	116	113	112	110	109	107	107	106	105	105	104	103	103	101	97	89	80	72	65	57	49	41	33	25	19	13	9	7

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																						
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
(Continued)	SUS316TP	16Cr, 12Ni 2Mo	520	(3) (17)(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	110	105	100	97	94	91	88	85	83	81	79	77	76	75	74	72	71	69	67	66	64	58	47	37	29	21	16	12	9
				(3) (16)(17) (18)				128	128	128	128	128	128	128	128	128	124	121	119	117	115	113	112	111	110	110	110	110	110	109	107	106	103	101	98	94	88	78	63	47	37	29	21	16	12	9
	SUS316HTP	16Cr, 12Ni 2Mo	520	(2)	○	○	○					128	128	128	128	128	117	110	105	100	97	94	91	88	85	83	81	79	77	76	75	74	72	71	69	67	66	64	58	47	37	29	21	16	12	9
				(2)(16)								128	128	128	128	128	124	121	119	117	115	113	112	111	110	110	110	110	110	109	107	106	103	101	98	94	88	78	63	47	37	29	21	16	12	9
	SUS316LTP	16Cr, 12Ni 2Mo, very low C	480	(17)	○	○	○	109	109	109	109	109	109	109	109	109	109	109	105	98	91	84	80	77	74	72	69	67	65	63	61	59														
	SUS321TP	18Cr, 10Ni Ti	520	(3) (17)	○	○	○	128	128	128	128	128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	77	76											
				(3) (17)(16)				128	128	128	128	128	128	128	128	128	121	115	112	109	108	107	106	105	104	104	104	104	104	104	104	104	103	102	99											
	SUS321HTP	18Cr, 10Ni Ti	520	(2) (19)	○	○	○					128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	77	76	76	73	65	51	38	28	22	17	13	9	7
				(2)(16) (19)								128	128	128	128	128	121	115	112	109	108	107	106	105	104	104	104	104	104	104	104	104	103	102	101	97	87	68	51	38	28	22	17	13	9	7
	SUS347TP	18Cr, 10Ni Nb	520	(3) (17)(18)	○	○	○	128	128	128	128	128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	77	76	75	70	57	40	30	24	17	12	9	7	6
				(3) (16)(17) (18)				128	128	128	128	128	128	128	128	128	121	115	112	109	108	107	106	105	104	104	104	104	104	104	104	104	103	102	99	91	76	58	40	30	24	17	12	9	7	6
	SUS347HTP	18Cr, 10Ni Nb	520	(2)(17)	○	○	○					128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	77	76	76	74	68	56	41	31	25	19	14	11	9
				(2)(16) (17)								128	128	128	128	128	121	115	112	109	108	107	106	105	104	104	104	104	104	104	104	104	103	102	101	98	91	76	56	41	31	25	19	14	11	9
Alloy steel pipes for power plant (Remark 12)	KA-STPA21	1Cr, 0.3Mo	410		○	○							102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	98	92	74	51	28										
	KA-STPA24J1	2.25Cr, 1.6W	510		○	○						128	128	128	128	128	128	128	128	128	127	127	126	123	123	123	123	123	123	122	120	116	113	110	101	85	70	54	35							
	KA-STPA27	9Cr, 2Mo	510		○	○							128	128	128	128	128	125	124	122	121	119	117	115	115	114	112	110	110	110	108	105	102	99	93	84	61	41	27	17						
	KA-STPA28	9Cr,1Mo,Nb,V	590		○	○							148	148	148	148	148	148	148	146	146	146	146	145	145	144	142	140	137	133	128	124	117	110	102	94	83	66	45	29						
	KA-STPA29	9Cr, 1.8W	620		○	○							155	155	155	155	155	155	155	153	151	148	146	145	143	141	139	137	134	132	129	126	122	118	113	107	101	86	65	47	30					
Stainless steel pipes for power plant (Remark 13)	KA-SUS410J3 TP	11Cr,2W,0.4Mo	620		○	○						155	155	155	155	155	155	155	155	153	150	147	146	144	142	140	138	136	134	132	129	125	122	118	112	106	100	85	65	45	30					
Carbon steel castings JIS G5101 (1991)	SC360		360		○	○	○						60	60	60	60	60	60	60	60	60	60	60	60	60	60	60																			
	SC410		410		○	○	○						68	68	68	68	68	68	68	68	68	68	68	68	68	68	68																			
	SC450		450		○	○	○						75	75	75	75	75	75	75	75	75	75	75	75	75	75	75																			
	SC480		480		○	○	○						80	80	80	80	80	80	80	80	80	80	80	80	80	80	80																			
Steel castings for high temperature and high pressure service JIS G5151 (1991)	SCPH1		410		○	○	○						82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	81	77	71	60	45														
	SCPH2		480		○	○	○						96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	90	80	67	48														
	SCPH11	0.5Mo	450		○	○	○						88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	86	80	72	55												
	SCPH21	1Cr, 0.5Mo	480		○	○	○						96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	94	88	79	67	47	29	21									
	SCPH32	2.5Cr, 1Mo	480		○	○	○						96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	94	88	79	67	51	38	27	15								
	SCPH61	5Cr, 0.5Mo	620		○	○	○						118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	1125	105	95	79	62	47	35	25	16								

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																						
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
Alloy steel casting for power plant (Remark 14)	KA-SCPH91	9Cr,1Mo,Nb,V	590		○	○	○								148	148	147	146	146	146	146	146	146	146	146	145	144	142	140	133	128	124	117	110	103	94	83	72	48	30						
Carbon steel forgings for general use JIS G3201 (1988)	SF340A		340	(4)	○	○	○						85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	79	75	64	51														
	SF390A		390	(4)	○	○	○						98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	93	84	73	56														
	SF440A		440	(4)	○	○	○						110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	98	94	81	57														
	SF490A		490	(4)	○	○	○						122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	115	102	84	58														
Carbon steel forging for pressure vessels JIS G3202 (1988)	SFVC1		410		○	○	○						102	102	102	102	102	102	102	102	102	102	102	102	102	102																				
	SFVC2A		490		○	○	○						122	122	122	122	122	122	122	122	122	122	122	122	122	122																				
	SFVC2B		490		○	○	○						122	122	122	122	122	122	122	122	122	122	122	122	122	122																				
Alloy steel forgings for pressure vessels for high-temperature service JIS G3203 (1988)	SFVAF1	0.5Mo	480		○	○	○						120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	119														
	SFVAF2	0.5Cr, 0.5Mo	480		○	○	○						120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	119	107	77	51											
	SFVAF12	1Cr, 0.5Mo	480		○	○	○						120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	119	112	88	60	38										
	SFVAF11A	1.25Cr, 0.5Mo	480		○	○	○						120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	119	112	88	61	40	25									
	SFVAF22A	2.25Cr, 1Mo	410		○	○	○						102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	100	92	81	64	48	36	25								
	SFVAF22B	2.25Cr, 1Mo	520		○	○	○						130	130	130	130	130	128	127	127	126	125	124	124	124	123	123	122	121	119	117	114	110	87	63	47	36	26								
	SFVAF5B	5Cr, 0.5Mo	480		○	○	○						120	120	120	120	120	120	118	117	116	116	116	116	115	115	113	112	110	106	103	98	80	62	47	35	25	19	13							
	SFVAF9	9Cr, 1Mo	590		○	○	○						148	148	148	148	146	145	144	142	140	140	140	140	140	139	138	136	133	128	125	119	113	88	63	43	30	21	15							
Alloy steel forging for pressure vessels JIS G3204 (1988)	SFVQ1A	0.7Ni, 0.5Mo	550		○	○	○								138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	132															
	SFVQ1B	0.7Ni, 0.5Mo	620		○	○	○								155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	144															
	SFVQ2A	0.75Ni, 0.33Cr 0.6Mo	550		○	○	○								138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	132															
	SFVQ2B	0.75Ni, 0.33Cr	620		○	○	○								155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	144															
Alloy steel forging for power plant (Remark 15)	KA-SFVAF22A J1	2.25Cr, 1.6W	510		○	○						128	128	128	128	128	128	128	128	128	127	127	126	123	123	123	123	123	123	122	120	116	113	110	101	85	70	54	35							
	KA-SFVAF27	9Cr, 2Mo	510		○	○							128	128	128	128	128	128	125	122	121	119	117	115	115	114	112	110	110	110	108	105	102	99	93	84	61	41	27	17						
	KA-SFVAF28	9Cr,1Mo,Nb,V	590		○	○							148	148	148	148	148	148	148	146	146	146	146	145	145	144	142	140	137	133	128	124	117	110	102	94	83	66	45	29						
	KA-SFVAF29	9Cr, 1.8W	620		○	○							155	155	155	155	155	155	155	153	151	148	146	145	143	141	139	137	134	132	129	126	122	118	113	107	101	86	65	47	30					
Stainless steel forging for power plant (Remark 16)	KA-SUSF410 J3	11Cr,2W,0.4Mo	620		○	○						155	155	155	155	155	155	155	155	153	150	147	146	144	142	140	138	136	134	132	129	125	122	118	112	106	100	85	65	45	30					
Carbon steel for machine structural use JIS G4051 (1979)	S10C		310	(5)	○	○	○						78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	76	71	61	50														
	S12C,S15C		370	(5)	○	○	○						92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	89	80	70	56														
	S17C,S20C		400	(5)	○	○	○						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	95	86	75	57														

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																								
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
(Continued)	S22C,S25C		440	(5)	○	○	○						110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	104	94	79	57														
	S28C,S30C		470	(5)(24)	○	○	○						118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	110	99	82	58														
			440	(5)(25)									110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	104	94	79	57														
	S33C,S35C		510	(5)(24)	○	○	○						128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128																				
			470	(5)(25)									118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118																				
Blackheart malleable iron castings JIS G5702 (1988)	FCMB270		270	(8)	○	○	○						43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43																				
	FCMB310		310	(8)	○	○	○						50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50																				
	FCMB340		340	(8)	○	○	○						54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54																				
	FCMB360		360	(8)	○	○	○						58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58																				
White heart malleable iron castings JIS G5703 (1988)	FCMW330		310	(8)	○	○	○						31	31	31	31	31	31	31	31	31	31	31	31																						
			330										33	33	33	33	33	33	33	33	33	33	33	33																						
			350										35	35	35	35	35	35	35	35	35	35	35	35																						
	FCMW370		350	(8)	○	○	○						35	35	35	35	35	35	35	35	35	35	35	35																						
			370										37	37	37	37	37	37	37	37	37	37	37	37																						
			390										39	39	39	39	39	39	39	39	39	39	39	39																						
	FCMWP440		440	(8)	○	○	○						40	40	40	40	40	40	40	40	40	40	40	40																						
	FCMWP490		490	(8)	○	○	○						49	49	49	49	49	49	49	49	49	49	49	49																						
	FCMWP540		540	(8)	○	○	○						54	54	54	54	54	54	54	54	54	54	54	54																						
Pearlitic malleable iron castings JIS G5704 (1988)	FCMP440		440	(8)	○	○	○						44	44	44	44	44	44	44	44	44	44	44	44																						
	FCMP490		490	(8)	○	○	○						49	49	49	49	49	49	49	49	49	49	49	49																						
	FCMP540		540	(8)	○	○	○						54	54	54	54	54	54	54	54	54	54	54	54																						
	FCMP590		590	(8)	○	○	○						59	59	59	59	59	59	59	59	59	59	59	59																						
Rat cast iron JIS G5501 (1995)	FC150		150	(8)	○	○	○						15	15	15	15	15	15	15	15	15	15	15	15																						
	FC200		200	(8)	○	○	○						20	20	20	20	20	20	20	20	20	20	20	20																						
	FC250		250	(8)	○	○	○						25	25	25	25	25	25	25	25	25	25	25	25																						
	FC350		350	(8)	○	○	○						35	35	35	35	35	35	35	35	35	35	35	35																						
Alloy steel bolt materials for high-temperature service JIS G4107 (1994)	SNB5	5Cr, 0.5Mo	690		○	○						138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	119	105	78	58	44	33	26	19	13	9						
	SNB7	1Cr, 0.2Mo	860		○	○			172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	163	146	122	94	69	44	31										
			800		○	○			160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	158	142	139	116	92	69	44	31										
			690		○	○			130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	128	125	114	92	69	44	31										
	SNB16	1Cr, 0.5Mo, V	860		○	○						172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	165	148	124	92	63	34	19								
			760		○	○						152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	152	147	133	115	90	63	34	19								
			690		○	○						138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	130	119	105	87	63	34	19								
Stainless steel bars JIS G4303 (1991)	SUS304	18Cr, 8Ni	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	109	102	94	90	85	82	79	77	76	75	74	73	72	71	70	69	68	66	64	60	55	46	37	30	25	20	16	13	10
	SUS304L	18Cr, 8Ni very low C	480	(18)	○	○	○	109	109	109	109	109	109	109	109	109	109	104	97	90	83	76	73	69	66	63	62	60	59	57	56															

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																								
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
(Continued)	SUS309S	23Cr, 12Ni	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	121	116	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	78	74	65	54	42	33	25	21	17	13	10	8	6
	SUS310S	25Cr, 20Ni	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	121	116	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	77	72	60	44	32	24	17	11	6	4	3	2	2
				(15)				128	128	128	128	128	128	128	128	128	121	116	113	109	106	103	101	98	96	93	91	89	87	86	84	82	80	79	76	72	65	57	49	41	33	25	19	13	9	7
	SUS316	16Cr,12Ni,2Mo	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	110	105	100	97	94	91	88	85	83	81	79	77	76	75	74	72	71	69	67	66	64	58	47	37	29	21	16	12	9
	SUS316L	16Cr, 12Ni 2Mo, very low C	480	(18)	○	○	○	109	109	109	109	109	109	109	109	109	109	109	105	98	91	84	80	77	74	72	69	67	65	63	61	59														
	SUS317	18Cr, 13Ni 3Mo	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	117	110	105	100	97	94	91	88	85	83	81	79	77	76	75	74	72	71	69	67	66	64	58	47	37	29	21	16	12	9
	SUS317L	18Cr, 13Ni 3Mo, very low C	480	(18)	○	○	○	109	109	109	109	109	109	109	109	109	109	109	105	98	91	84	80	77	74	72	69	67	65	63	61	59														
	SUS321	18Cr, 10Ni Ti	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	76	76	75	70	58	40	30	24	17	12	9	7	6
	SUS347	18Cr, 10Ni Nb	520	(18)	○	○	○	128	128	128	128	128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85	84	83	82	80	78	76	76	75	70	58	40	30	24	17	12	9	7	6
Nickel steel plates for pressure vessels for low temperature service JIS G3127 (1990)	SL2N255	2.5Ni	450	(22)			○			112	112	112	112	112	112	112	112	112																												
	SL3N255	3.5Ni	450				○		112	112	112	112	112	112	112	112	111	112																												
	SL3N275	3.5Ni	480				○		120	120	120	120	120	120	120	120	120	120																												
	SL3N440	3.5Ni	540	(23)			○		135	135	135	135	135	135	135	135	135	135																												
				(35)					173	173	173	173	173	173	173	173	169	164																												
	SL9N520	9Ni	690	(26)			○	172	172	172	172	172	172	172	172	172	172	172																												
				(35)				219	219	219	219	219	219	219	219	219	213	208																												
	SL9N590	9Ni	690	(26)			○	172	172	172	172	172	172	172	172	172	172	172																												
				(35)				219	219	219	219	219	219	219	219	219	213	208																												
Steel pipes for low temperature service JIS G3460 (1988)	STPL380		380	(13)			○				95	95	95	95	95	95	95	95	95	95	95	95																								
				(14)							81	81	81	81	81	81	81	81	81	81	81	81																								
	STPL450	3.5Ni	450				○		112	112	112	112	112	112	112	112	112	112	112	112	112	112																								
	STPL690	9Ni	690	(26)			○	172	172	172	172	172	172	172	172	172	172	172																												
Steel heat exchanger tubes for low temperature service JIS G3464 (1988)	STBL380		380	(13)			○				95	95	95	95	95	95	95	95	95	95	95	95																								
				(14)							81	81	81	81	81	81	81	81	81	81	81	81																								
	STBL450	3.5Ni	450				○		112	112	112	112	112	112	112	112	112	112	112	112	112	112																								
	STBL690	9Ni	690	(26)			○	172	172	172	172	172	172	172	172	172	172	172																												
Arc welded large diameter stainless steel pipes JIS G3468 (1994)	SUS304TPY	18Cr, 8Ni	520	(18)(21)	○	○	○	90	90	90	90	90	90	90	90	90	81	76	72	66	63	60	58	56	56	53	52	51	51	50	49	49	48	47	46	45	42	38	32	26	22	18	14	11	9	7
	SUS304LTPY	18Cr, 8Ni very low C	480	(21)	○	○	○	77	77	77	77	77	77	77	77	77	77	73	68	63	59	54	51	48	46	44	43	42	41	40	39															
	SUS309STPY	23Cr, 12Ni	520	(18)(21)	○	○	○	90	90	90	90	90	90	90	90	90	84	81	78	76	75	73	71	69	68	65	64	63	61	61	59	58	56	55	51	45	37	29	24	18	15	12	9	7	6	4
	SUS310STPY	25Cr, 20Ni	520	(18)(21)	○	○	○	90	90	90	90	90	90	90	90	90	84	81	78	76	75	73	71	69	68	65	64	63	61	61	59	58	56	54	50	42	31	23	17	12	8	4	3	2	1	1
				(15)(18)(21)				90	90	90	90	90	90	90	90	90	84	81	78	76	75	73	71	69	68	65	64	63	61	61	59	58	56	56	54	50	45	40	34	28	24	18	13	9	6	5
	SUS316TPY	16Cr,12Ni,2Mo	520	(18)(21)	○	○	○	90	90	90	90	90	90	90	90	90	81	78	74	70	68	66	64	62	60	59	57	56	54	53	52	51	50	49	48	47	46	45	40	33	26	21	15	11	8	6
	SUS316LTPY	16Cr, 12Ni 2Mo, very low C	480	(21)	○	○	○	77	77	77	77	77	77	77	77	77	77	77	74	69	64	59	56	54	51	50	48	47	45	44	42	41														

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																						
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
(Continued)	SUS321TPY	18Cr, 10Ni Ti	520	(18)(21)	○	○	○	90	90	90	90	90	90	90	90	90	83	78	76	74	73	70	68	66	65	63	61	60	59	59	58	56	55	54	53	52	49	40	28	22	17	12	8	6	5	4
	SUS347TPY	18Cr, 10Ni Nb	520	(18)(21)	○	○	○	90	90	90	90	90	90	90	90	90	83	78	76	74	73	70	68	66	65	63	61	60	59	59	58	56	55	54	53	52	49	40	28	22	17	12	8	6	5	4
Nickel steel forging for pressure vessels for low temperature service of power plant (Remark 17)	KA−SFL9N690	9Ni	690	(26)			○	172	172	172	172	172	172	172	172	172	160	152																												
Stainless steel forgings for pressure vessels JIS G3214 (1991)	SUSF304	18Cr, 8Ni	520 480	(18) (18)(20)	○	○	○	128 120	128 120	128 120	128 120	128 120	128 120	128 120	128 120	128 120	117 112	109 105	102 100	94 94	90 90	85 85	82 82	79 79	77 77	76 76	75 75	74 74	73 73	72 72	71 71	70 70	69 69	68 68	66 66	64 64	60 60	55 55	46 46	37 37	30 30	25 25	20 20	16 16	13 13	10 10
	SUSF304H	18Cr, 8Ni	520 480	(20)	○	○	○					128 120	128 120	128 120	128 120	128 120	117 112	109 105	102 100	94 94	90 90	85 85	82 82	79 79	77 77	76 76	75 75	74 74	73 73	72 72	71 71	70 70	69 69	68 68	66 66	64 64	60 60	55 55	46 46	37 37	30 30	25 25	20 20	16 10	13 13	10 10
	SUSF304L	18Cr, 8Ni very low C	450		○	○	○	109	109	109	109	109	109	109	109	109	104	99	93	88	82	76	73	69	66	63	62	60	59	57	56															
	SUSF310	25Cr, 20Ni	520	(18) (15)(18) (20)	○	○	○	128 128	128 128	128 128	128 128	128 128	128 128	128 128	128 128	128 128	121 121	116 116	113 113	109 109	106 106	103 103	101 101	98 98	96 96	93 93	91 91	89 89	87 87	86 86	84 84	82 82	80 80	77 79	72 76	60 72	44 65	32 57	24 49	17 41	11 33	6 25	4 19	3 13	2 9	2 7
	SUSF316	16Cr,12Ni,2Mo	520 480	(18) (18)(20)	○	○	○	128 120	128 120	128 120	128 120	128 120	128 120	128 120	128 120	128 120	117 115	110 110	105 105	100 100	97 96	94 92	91 89	88 86	85 84	83 82	81 80	79 79	77 77	76 76	75 75	74 74	72 72	71 71	69 69	67 67	66 66	64 64	58 58	47 47	37 37	29 29	21 21	16 16	12 12	9 9
	SUSF316H	16Cr,12Ni,2Mo	520 480	(20)	○	○	○					128 120	128 120	128 120	128 120	128 120	117 115	110 110	105 105	100 100	97 97	94 94	91 91	88 88	85 85	83 83	81 81	79 79	77 77	76 76	75 75	74 74	72 72	71 71	69 69	67 67	66 66	64 64	58 58	47 47	37 37	29 29	21 21	16 16	12 12	9 9
	SUSF316L	16Cr, 12Ni 2Mo, very low C	450		○	○	○	109	109	109	109	109	109	109	109	109	109	109	105	98	91	84	80	77	74	72	69	67	65	63	61	59														
	SUSF321	18Cr, 10Ni Ti	520 480	(18) (18)(20)	○	○	○	128 120	128 120	128 120	128 120	128 120	128 120	128 120	128 120	128 120	119 114	113 108	109 105	106 102	103 101	100 99	97 97	94 94	92 92	89 89	87 87	85 85	84 84	83 83	82 82	80 80	78 78	77 77	76 76	75 75	70 70	58 58	40 40	30 30	24 24	17 17	12 12	9 9	7 7	6 6
	SUSF321H	18Cr, 10Ni Ti	520 480	(20)	○	○	○					128 120	128 120	128 120	128 120	128 120	119 113	113 108	109 105	105 102	103 101	100 99	97 97	94 94	92 92	89 89	87 87	85 85	84 84	83 83	82 82	80 80	78 78	77 77	76 76	76 76	73 73	65 65	51 51	38 38	28 28	22 22	17 17	13 13	9 9	7 7
	SUSF347	18Cr, 10Ni Nb	520 480	(18) (18)(20)	○	○	○	128 120	128 120	128 120	128 120	128 120	128 120	128 120	128 120	128 120	119 113	113 108	109 105	105 102	103 101	100 99	97 97	94 94	92 92	89 89	87 87	85 85	84 84	83 83	82 82	80 80	78 78	77 77	76 76	75 75	70 70	58 58	40 40	30 30	24 24	17 17	12 12	9 9	7 7	6 6
	SUSF347H	18Cr, 10Ni Nb	520 480	(20)	○	○	○					128 120	128 120	128 120	128 120	128 120	119 113	113 108	109 105	105 102	103 101	100 99	97 97	94 94	92 92	89 89	87 87	85 85	84 84	83 83	82 82	80 80	78 78	77 77	76 76	76 75	74 70	68 58	56 40	41 30	31 24	25 17	19 12	14 9	11 7	9 6
Heat-resisting steel plates and sheets JIS G4312 (1991)	SUS304	18Cr, 8Ni	520				○	128	128	128	128	128	128	128	128	128	117	109	102	94	90	85	82	79	77	76	75	74																		
	SUS316	16Cr,12Ni,2Mo	520				○	128	128	128	128	128	128	128	128	128	117	110	105	100	97	94	91	88	85	83	81	79																		
	SUS317	18Cr,13Ni,3Mo	520				○	128	128	128	128	128	128	128	128	128	117	110	105	100	97	94	91	88	85	83	81	79																		
	SUS321	18Cr,10Ni,Ti	520				○	128	128	128	128	128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85																		
	SUS347	18Cr,10Ni,Nb	520				○	128	128	128	128	128	128	128	128	128	119	113	109	105	103	100	97	94	92	89	87	85																		
Seamless nickel-chromium-iron alloy pipes JIS G4903 (1991)	NCF600TP	72Ni,15Cr,8Fe	550 520 550 550	(27) (28) (29) (30)			○	128 109 138 128	128 109 138 128	128 109 138 128	128 109 138 128	128 109 138 128	128 109 138 128	128 109 138 128	128 109 138 128	128 109 138 128	128 109 138 128	128 105 138 128	128 102 138 128	126 100 138 126	124 98 138 124	121 97 138 121	119 95 138 118	118 94 138 118	115 93 138 115	113 92 138 113	111 91 138 111	110 90 136 110	108 89 135 108	107 89 133 107	106 87 131 106	104 85 131 104	103 82 115 103	83 76 86 83	60 60 60 60	40 40 40 40	27 27 27 27	19 19 19 19	15 15 15 15							
	NCF800TP	33Ni, 21Cr	450 520	(31) (32)			○	109 128	109 128	109 128	109 128	109 128	109 128	109 128	109 128	109 128	104 128	98 128	93 126	89 124	85 122	82 119	80 117	76 116	76 115	74 113	74 112	72 111	71 110	70 108	69 107	68 106	67 105	67 103	66 102	65 101	65 96	65 84	63 65	54 45	42 29	40 16	26 12	22 9	17 7	13 6

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable											tensile stress at each temperature (N/㎟)																											
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
Seamless nickel-chromium-iron alloy heat exchanger tubes JIS G4904 (1991)	NCF600TB	72Ni, 15Cr, 8Fe	500	(34)			○	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	138	136	135	133	131	131	115	86	60	40	27	19	15	14						
	NCF800TB	33Ni, 21Cr	450 520	(33) (34)			○	109 128	109 128	109 128	109 128	109 128	109 128	109 128	109 128	109 128	104 128	98 128	93 126	89 124	85 122	82 119	80 117	76 116	76 115	74 113	74 112	72 111	71 110	70 108	69 107	68 106	67 105	67 103	66 102	65 101	65 96	65 84	63 65	54 45	42 29	40 16	26 12	22 9	17 7	13 6

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable											tensile stress at each temperature (N/㎟)																											
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
Stainless steel casting JIS G5121 (1991)	SCS1	13Cr	540		○	○	○						108	108	108	108	108	108	108	108	108	108	108	107	105	104	102	100																		
	SCS13	18Cr, 8Ni	440		○	○	○	88	88	88	88	88	88	88	88	88	88	84	80	76	73	69	66	64	62	61	59	58																		
	SCS14	18Cr, 9Ni,2Mo	440		○	○	○	88	88	88	88	88	88	88	88	88	88	86	82	78	76	75	74	73	73	73	72	71																		
	SCS16	18Cr, 12Ni 2Mo, very low C	390		○	○	○	78	78	78	78	78	78	78	78	78	78	78	78	78	76	75	74	73	73	73	72	71																		
	SCS17	25Cr, 12Ni	480		○	○	○	88	88	88	88	88	88	88	88	88	88	88	84	84	83	81	80	78	76	75	73	72																		
	SCS18	25Cr, 12Ni	450		○	○	○	88	88	88	88	88	88	88	88	88	84	80	79	78	77	76	75	73	72	70	69	67																		
	SCS19	18Cr, 8Ni very low C	390		○	○	○	78	78	78	78	78	78	78	78	78	78	78	77	76	73	69	66	64	62	61	59	58																		
	SCS21	18Cr, 10Ni Nb	480		○	○	○	88	88	88	88	88	88	88	88	88	88	86	84	81	80	79	76	75	73	72	70	69																		
Steel castings for low temperature and high pressure service JIS G5152 (1991)	SCPL1		450				○				90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90																		
	SCPL11	0.5Mo	450				○			90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90																		
	SCPL21	2.5Ni	480				○			96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96																		
	SCPL31	3.5Ni	480				○		96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96																		
Alloy steel for low temperature pressure vessels JIS G3205 (1988)	SFL2		490				○				122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122																		
	SFL3	3.5Ni	490				○		122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122																		
Carbon steel plates for pressure vessels for low temperature service JIS G3126 (1990)	SLA235A		400				○					100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100																		
	SLA235B		400				○				100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100																		
	SLA325A		400	(35)			○				110 140	110 140	110 140	110 140	110 140	110 140	110 136	110 133	110 129	110 125	110 125	110 125	110 125	110 125	110 125	110 125	110 125	110 125																		
	SLA325B		400	(35)			○			110 140	110 140	110 140	110 140	110 140	110 140	110 140	110 136	110 133	110 129	110 125	110 125	110 125	110 125	110 125	110 125	110 125	110 125	110 125																		
	SLA365		490	(35)			○			122 156	122 156	122 156	122 156	122 156	122 156	122 156	122 156	122 151	122 148	122 144	122 140	122 140	122 140	122 140	122 140	122 140	122 140	122 140																		
Carbon steel plates for pressure vessels for low temperature service of power plant (Remark 18)	KA-SLA325B		440				○			110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110																		

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable										
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100
Nickel chromium steels JIS G4102 (1979)	SNC236	1.25Ni, 0.7Cr	740				○					185	185	185	185	185	185	185
	SNC631	2.75Ni, 0.8Cr	830				○					208	208	208	208	208	208	208
	SNC836	3.25Ni, 0.8Cr	930				○					232	232	232	232	232	232	232
Nickel chromium molybdenum steels JIS G4103 (1979)	SNCM240	0.55Ni, 0.55Cr 0.23Mo	880				○					220	220	220	220	220	220	220
	SNCM431	1.8Ni, 0.8Cr 0.23Mo	830				○					208	208	208	208	208	208	208
	SNCM439	1.8Ni, 0.8Cr 0.23Mo	980				○					245	245	245	245	245	245	245
	SNCM447	1.8Ni, 0.8Cr 0.23Mo	1030				○					258	258	258	258	258	258	258
	SNCM625	3.25Ni, 1.25Cr 0.23Mo	930				○					232	232	232	232	232	232	232
	SNCM630	3.0Ni, 3.0Cr 0.6Mo	1080				○					270	270	270	270	270	270	270
Chromium steels JIS G4104 (1979)	SCr430	0.3C, 1Cr	780				○					195	195	195	195	195	195	195
	SCr435	0.35C, 1Cr	880				○					220	220	220	220	220	220	220
	SCr440	0.40C, 1Cr	930				○					232	232	232	232	232	232	232
	SCr445	0.45C, 1Cr	980				○					245	245	245	245	245	245	245
Chromium molybdenum steels JIS G4105 (1979)	SCM430	1.1Cr, 0.23Mo	830				○					208	208	208	208	208	208	208
	SCM432	1.25Cr, 0.23Mo	880				○					220	220	220	220	220	220	220
	SCM435	1.1Cr, 0.23Mo	930				○					232	232	232	232	232	232	232
	SCM440	1.1Cr, 0.23Mo	980				○					245	245	245	245	245	245	245
	SCM445	1.1Cr, 0.23Mo	1030				○					258	258	258	258	258	258	258
Aluminium chromium molybdenum steels JIS G4202 (1979)	SACM645	1.5Cr, 0.23Mo 1Al	830				○					208	208	208	208	208	208	208
Hot-rolled atmospheric corrosion resisting steels for welded structure JIS G3114 (1988)	SMA400A	0.4Cu, 0.4Cr	400				○						100	100	100	100	100	100
	SMA400B	0.4Cu, 0.4Cr	400				○						100	100	100	100	100	100
	SMA400C	0.4Cu, 0.4Cr	400				○						100	100	100	100	100	100
Hot-rolled mild steel plates, sheets and strip JIS G3131 (1990)	SPHC		270				○						68	68	68	68	68	68
	SPHD		270				○						68	68	68	68	68	68
	SPHE		270				○						68	68	68	68	68	68
Spheroidal graphite iron castings JIS G5502 (1995)	FCD400		400				○						64	64	64	64	64	64
	FCD450		450				○						72	72	72	72	72	72
	FCD500		500				○						72	72	72	72	72	72
	FCD600		600				○						84	84	84	84	84	84

Symbol	tensile stress at each temperature (N/㎟)																											
	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
SNC236	185	185	185	185	185	185	185	185	185	185																		
SNC631	208	208	208	208	208	208	208	208	208	208																		
SNC836	232	232	232	232	232	232	232	232	232	232																		
SNCM240	220	220	220	220	220	220	220	220	220	220																		
SNCM431	208	208	208	208	208	208	208	208	208	208																		
SNCM439	245	245	245	245	245	245	245	245	245	245																		
SNCM447	258	258	258	258	258	258	258	258	258	258																		
SNCM625	232	232	232	232	232	232	232	232	232	232																		
SNCM630	270	270	270	270	270	270	270	270	270	270																		
SCr430	195	195	195	195	195	195	195	195	195	195	195	195																
SCr435	220	220	220	220	220	220	220	220	220	220	220	220																
SCr440	232	232	232	232	232	232	232	232	232	232	232	232																
SCr445	245	245	245	245	245	245	245	245	235	235	235	235																
SCM430	208	208	208	208	208	208	208	208	208	208	208	208																
SCM432	220	220	220	220	220	220	220	220	220	220	220	220																
SCM435	232	232	232	232	232	232	232	232	232	232	232	232																
SCM440	245	245	245	245	245	245	245	245	245	245	245	245																
SCM445	258	258	258	258	258	258	258	258	258	258	258	258																
SACM645	208	208	208	208	208	208	208	208	208	208																		
SMA400A	100	100	100	100	100	100	100	100	100	100																		
SMA400B	100	100	100	100	100	100	100	100	100	100																		
SMA400C	100	100	100	100	100	100	100	100	100	100																		
SPHC																												
SPHD																												
SPHE																												
FCD400	64	64	64	64	64	64	64	64	64	64																		
FCD450	72	72	72	72	72	72	72	72	72	72																		
FCD500	72	72	72	72	72	72	72	72	72	72																		
FCD600	84	84	84	84	84	84	84	84	84	84																		

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																																						
					2~5 Chapter	6 Chapter	7 Chapter	Temperature -196	-100	-60	-45	-30	-10	-5	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
Steel pipes for pipe lines of power plant APL 5L (1995)	X42		413	(38)			○						103 130	103 130	103 130	103 130																														
	X46		434	(38)			○						108 139	108 139	108 139	108 139																														
	X52		455	(38)			○						114 146	114 146	114 146	114 146																														
	X56		489	(38)			○						122 157	122 157	122 157	122 157																														
	X60		517	(38)			○						129 165	129 165	129 165	129 165																														
	X65		530	(38)			○						132 170	132 170	132 170	132 170																														

Name and standard number	Symbol	Nominal composition (%)	Min. Tensile strength (N/㎟)	Note (Remark 1)	Applicable ordinance			Allowable tensile stress at each temperature (N/㎟)																															
					2~5 Chapter	6 Chapter	7 Chapter	Temperature 400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800	825	850	875	900	925	950	975	980	985	1000	1010	1025	1050	1075	1100
Corrosion-resisting and heat-resisting superalloy bars JIS 4901 (1991)	NCF800H	33Ni, 21Cr	450			○		78	76	76	75	73	72	71	70	69	67	58	48	39	32	27	23	20	15	12	10	8	7	6	5	4	4						
Corrosion-resisting and heat-resisting superalloy plates and sheets JIS G4902 (1991)	NCF800H	33Ni, 21Cr	450			○		78	76	76	75	73	72	71	70	69	67	58	48	39	32	27	23	20	15	12	10	8	7	6	5	4	4						
Seamless nickel-chromium-iron alloy pipes JIS G4903 (1991)	NCF800HTP	33Ni, 21Cr	450			○		78	76	76	75	73	72	71	70	69	67	58	48	39	32	27	23	20	15	12	10	8	7	6	5	4	4						
Seamless nickel-chromium-iron alloy heat exchanger tubes JIS G4904 (1991)	NCF800HTB	33Ni, 21Cr	450			○		78	76	76	75	73	72	71	70	69	67	58	48	39	32	27	23	20	15	12	10	8	7	6	5	4	4						
Heat resisting steel castings superalloy plates and sheets JIS G5122 (1991)	SCH22	21Ni, 25Cr	440	(11)		○																37	31	25	21	17	14	11	9	7	7	6	5	4	4				
	SCH22CF	21Ni, 25Cr	440	(11)		○																37	31	25	21	17	14	11	9	7	7	6	5	4	4				

Remark 1. (1) to (38) shown in the note column of this table are as follows;

(1) For the portion which temperature exceeds 350 ℃, silicon contents should be 0.35% or less and 0.1% or more.

(2) Limited to those manufactured without the seam.

(3) For the portion which temperature becomes 540 ℃ or more, carbon contents should be 0.04% or more.

(4) For the portion which temperature exceeds 350 ℃, the chemical contents shall be within the range of the percentage shown on the next table.

Carbon	Silicon	Manganese
Max. 0.35	Max. 0.35	Max. 0.90

(5) According to the type of steel materials of the left column of the next table, it shall be annealed in the temperature range specified in the right column of the same table.

Type of steel materials	Annealing temperature
S 10C	900℃ or over, up to and including 950℃
S 12C and S 15C	880℃ or over, up to and including 930℃
S 17C and S 20C	870℃ or over, up to and including 920℃
S 22C and S 25C	860℃ or over, up to and including 910℃
S 28C and S 30C	850℃ or over, up to and including 900℃
S 33C and S 35C	840℃ or over, up to and including 890℃

(6) It shall not be used except for pressure parts of air, gas, oil and water at the temperature of lower than 100 ℃. But, those satisfies the requirements of SS330 or SS400 of the steel plate of Japanese Industrial Standards, JIS G3101 (1995), "Rolled steels for general structure" can be used as substitutive for Japanese Industrial Standards, JIS G3103 (1987), "Carbon steel and molybdenum alloy steel plates for boilers and other pressure vessels" for pressure parts lower than the maximum allowable pressure of 1MPa. This cannot be applied to boilers, independent superheaters, independent economizers and steam storage vessels, (hereafter, called "boiler, etc."), which have the longitudinal weld. In this case, the allowable tensile stress, when exceeding 96 N/㎟, shall be 96 N/㎟, regardless of Article 4, Paragraph 1-1.

(7) It shall not be used except for pressure parts of air, gas, oil and water at the temperature of lower than 100 ℃. However, this apply to the case what satisfies the requirements of SM400A, SM400B, SM400C, SM490A, SM490B, and SM490C of the steel plate of Japanese Industrial Standards, JIS G3106 (1995), "Rolled steels for welded structure" can be used as substitutive for Japanese Industrial Standards, JIS G3103 (1987), "Carbon steel and molybdenum alloy steel plates for boilers and other pressure vessels" for pressure parts lower than the maximum allowable pressure of 1MPa. In this case, the allowable tensile stress, when exceeding 96 N/㎟, shall be 96 N/㎟, regardless of Article 4, Paragraph 1-1.

(8) It shall not be used for what is listed as follows; But this requirement does not apply to the economizer.

1 Those exposed to flame.

2 Inner section perpendicular to longitudinal axis of a box type casting surrounded by planes is more than 200 ㎜ square (except accessories of the maximum allowable pressure of 1MPa or less).

3 Those of the operating pressure exceeding 1.6MPa (2.4MPa for those conform to Japanese Industrial Standards, JIS G5702 (1988), "Blackheart Malleable Iron Castings").

4 Those of the operating temperature higher than 230 ℃. (350 ℃ for those conform to Japanese Industrial Standards, JIS G5702 (1988), "Blackheart Malleable Iron Castings").

(9) It shall not be used for other than listed as follows;

1 Steam pipe with the maximum allowable pressure of 1MPa or less.

2 Feed water pipe listed as follows;

(1) Feed water pipes from a boiler to a reverse stop valve, of the maximum allowable pressure of 0.7MPa or less

(2) Feed water pipes other than mentioned in (1), of the maximum allowable pressure of 1MPa or less

3 Blow off pipes listed as follows;

(1) Blow off pipes from a boiler to a blow off valve (For two or more valves, farthest valve from a boiler), of the maximum allowable pressure of 0.7MPa or less

(2) Other blow off pipes than mentioned in (1), of the maximum allowable pressure of 1MPa or less

4 Pipes for air, gas or oil of the maximum allowable pressure of 1MPa or less

(10) This shall not be used for the pipe of liquefied gas, or with the maximum allowable pressure of 1MPa or more.

(11) This shall not be used for other than the reformer, the panel of reformer, the lid board reformer and the plate of reformer.

(12) The following electrical-resistance welding tube shall meet the value of the upper column. The tubes for water tube inside boiler casing or brick wall, the superheated tube, the reheater tube or the economizer tube, which are annealed and passed the ultrasonic inspection by the working sensitivity section UC of Japanese Industrial Standards, JIS G 0582 (1990), "Ultrasonic examination for steel pipes and tubes".

(13) Applicable to seamless steel tubes.

(14) Applicable to electric resistance welding tubes.

(15) Applicable to the crystal particle size number 6 of "2 (2), particle size number" or coarser of Japanese Industrial Standards, JIS G 0551(1977), "Methods of austenite grain size determination of steel".

(16) Applicable to a water tube, a superheated tube, a reheater tube, an economizer tube, a heat exchanger, or those similar to these.

(17) The value of 0.85 times of numbers of this column shall be applied for those manufactured by automatic arc welding without using filler metal, and with the last solution treatment for the perfect corrosion resistance of the base metal and welding parts after the cold work.

(18) The allowable tensile stress of those with the temperature higher than or equal to 540 ℃ is applied to a material with carbon content 0.04% or more. The value of the column where temperature exceeds 525 ℃ is applied to the materials of solution treatment with the quenching from 1040 ℃ or higher.

(19) The value of the column where temperature exceeds 525 ℃ is applied to the materials of solution treatment with the quick chilling from 1120 ℃ or more.

(20) Applicable to the forged steel parts of diameter, the opposite distance, or the thickness of a main part is 130 ㎜ or more.

(21) The value of allowable tensile stress shall be that of the allowable tensile stress of the base metal multiplied by the welding efficiency 0.7: the welding efficiency in other case in [Both side butt welding or one side butt welding considered to be equivalent] on the attached table No.4. The value of allowable tensile stress of the material, manufactured according to "The kind of joint" and "The classification of radiography test" on the attached table №4 of JIS G4304 (1991), "Hot rolled stainless steel plates, sheets and strip" and JIS G4305 (1991), "Cold rolled stainless steel plates, sheets and strip", shall be that of the value of the allowable tensile stress of the base metal multiplied by the corresponding "welding factors".

(22) The value of −60 ℃ column is applied to −70 ℃.

(23) The value of −100 ℃ column is applied to −110 ℃.

(24) Applicable to those steel parts with the diameter, the opposite distance, or the thickness of main parts of 100 ㎜ or less.

(25) Applicable to those steel parts with the diameter, the opposite distance or the thickness of main parts exceeds 100 ㎜ and to 200 ㎜ or less.

(26) Applicable when use welding material of the tensile strength of tensile test is 650 N/㎟ or more and the yield strength is 365 N/㎟ or more. In this case, the tensile strength of the tensile test of the joint shall be greater than or equal to 650 N/㎟.

(27) Applicable to annealed materials after the hot work of the outer diameters 127㎜ or less.

(28) Applicable to annealed materials after the hot work of the outer diameters exceeding 127㎜.

(29) Applicable to annealed materials after the cold work of the outer diameters 127㎜ or less.

(30) Applicable to annealed materials after the cold work of the outer diameters exceeding 127 ㎜.

(31) Applicable to hot worked materials.

(32) Applicable to cold worked materials.

(33) Applicable to materials treated solution treatment.

(34) Applicable to annealed materials.

(35) Applicable for pressure parts of liquefied gas facility when the non-destructive inspection by the article 58, №4 is carried out.

(36) It is suited for the using of a boiler casing or the water tube of a brick wall inner side, the superheated tube, the reheater tube or the economizer tube for the having passed the ultrasonic inspection by the working sensitivity section UC of Japanese Industrial Standards JIS G 0582 (1990) "Ultrasonic examination for steel pipes and tubes"

(37) Applicable to the forged welding pipe.

(38) The value of the upper column shows the allowable stress on the basis of the minimum tensile strength, and the value of the lower column shows the allowable stress on the basis of 0.5% yield strength. The value of the 40 ℃ column of the upper column is applied up to 60 ℃. The value of the lower column is applicable to those passed ultrasonic examination or radioactive examination on the whole line of the weld.

2. On this table, the value of the allowable tensile stress at the middle temperature between the indicated temperatures can be calculated by the proportional method.

3. Rimmed steel shall not be used at a temperature above 350 ℃.

4. Carbon steel plates other than those conform to the following standards shall not be used for the following vessels; Japanese Industrial Standards, JIS G3103 (1987), "Carbon steel and molybdenum alloy steel plates for boilers and other pressure vessels", Japanese Industrial Standards, JIS G3115 (1990), "Steel plates for pressure vessels for intermediate temperature service", Japanese Industrial Standards, JIS G3126 (1990) "Carbon steel plates for pressure vessels for low temperature service", or Carbon steel plates for low temperature pressure vessels of power plant". However, Japanese Industrial Standards, JIS G3106 (1995), "Rolled steels for welded structure" can be applied for the vessel listed in (1) and (2).

  1) For those of the maximum allowable pressure higher than 1.6MPa.
  2) For those of the maximum allowable temperature above 350 ℃.
  3) For those of the maximum allowable pressure of 1.0MPa or more and with the longitudinal joint.

5. Stainless steel other than austenite stainless steel with carbon content less than 0.10%, with the minimum allowable temperature of −30 ℃ or less, shall satisfy the impact test mentioned as follows;

  1) The number of test pieces, sampling position and test method shall meet the following JIS standards; for rolling steel materials: Japanese Industrial Standards, JIS G3126 (1990), "Carbon steel plates for pressure vessels for low temperature service", for pipes: Japanese Industrial Standards, JIS G3460 (1988), "Steel pipes for low temperature service", for forgings: Japanese Industrial Standards, JIS G3205 (1988) "Carbon and alloy steel forgings for pressure vessels for low-temperature service", and for castings: Japanese Industrial Standards, JIS G5152 (1991) "Steel castings for low temperature and high pressure service"
  2) The form and the dimension of the test piece shall be №4 of Japanese Industrial Standards, JIS Z2202 (1980), "Test pieces for impact test for metallic materials"
  3) In performing the impact test, absorption energy shall meet the value listed in the right column of the table according to the dimension classification of the test piece listed in the left column of the table.

Dimension of test piece (㎜)	Absorption energy (J)	
	Average value, two pieces	Value of one piece
10 × 10	Min. 21	Min. 14
10 × 7.5	Min. 17	Min. 12
10 × 5	Min. 14	Min. 10
10 × 2.5	Min. 7	Min. 5

  4) When 3) cannot be met, twice of the number of groups of test pieces specified in 1) shall satisfy 3).

6 −18. Material standards of materials used for power plant (omitted)

27-3 Technical Standards on the Welding of Electrical Facilities

(Ordinance №123 of Ministry of International Trade and Industry, June 30 2000.)

(Weld Joint Geometries)

Article 1 Welds of the equipment or components defined in article 79 of the Rules for the Enforcement of the Electric Utilities Industry Law (Order №77 of Ministry of International Trade and Industry, 1995), and of the parts retaining pressure higher than that defined in article 80 of the Rules, and the welds of the equipment or components defined in article 81 of the Rules, shall have safety joint geometries.

(Cracks in the welds)

Article 2 The weld shall not have any crack formed by welding or any appearance to cause cracks.

(Flaws in the welds)

Article 3 The weld shall have enough depth of fusion, and shall not have defects such as undercut, overlap, crater, slag inclusion, blowhole, or other similar flaws that harm sound welds.

(Strength of the welds)

Article 4 The weld shall have enough strength to keep sound welded connections.

Interpretations for the Technical Standards on the Welding of Electrical Facilities

(Official notice of Electric Power Unit Manager 12APED No.20, June 30 2,000. APED: Agency of Natural Resources and Energy, Public Utilities Department)

Section 1 General Requirements

Item	Article Number in the Standards	Summary
1. Definitions of Terms	Article 1	Definitions of the terms used in this interpretations (1) Boilers (2) Heat Exchangers (3) Equipment of Liquefied Gases (4) Class 1 Vessels, Class 1 Piping (5) Class 2 Vessels (6) Class 3 Vessels, Class 3 Piping (7) Class 4 Vessels, Class 4 Piping (8) Class 5 Piping (9) Class 1 Joints (10) Class 2 Joints (11) Class 3 Joints (12) Class 4 Joints

Section 2 Welding Procedure Qualifications

Item	Article Number in the Standards	Summary
1. Welding Procedures	Article 2	(1) Classification of welding processes → Attached table 1 (2) Variable terms to be confirmed on each welding process → Attached table 2 (3) Classification of the essential variables → Attached table 4 (4) Testing methods for welding procedure qualifications → Attached table 5 (5) Temperature at the impact testing → Attached table 6 (6) Requirements for the tests
2. Acceptance Criteria	Article 3	Acceptance criteria for the tests → Attached table 5

(Continued)

Item	Article Number in the Standards	Summary
3. Welding Equipment	Article 4	The types of welding equipment, and the types of post-weld heat treatment and its capacity means to meet the requirements of welding procedures.
4. Welders	Article 5	(1) Items for manual welder performance qualification tests → Attached table 7 (Classification of welding methods, test materials, welding positions, welding rods, filler metals, and core wires.) (2) Methods of welder performance qualification tests → Attached table 8 (3) Relation to the qualifications of other laws and regulations (4) Relation to the qualifications of JIS → Attached table 10 (5) Requirements for automatic welding operators (6) Requirements for the tests
5. Acceptance Criteria	Article 6	Acceptance criteria for tests → Attached table 8
6. Personnel Performance Qualifications	Article 7	Requirements for the renewal of performance qualifications
7. Welding Range	Article 8	Classification of testing materials and welding positions, and welding range → Attached table 11

Section 3 Equipment for Thermal Power Plants

Item	Article Number in the Standards			Summary
	Boilers	Heat Exchangers	Equipment of Liquefied Gases	
1. Geometries of Welding Joints	Article 9	Article 27	Article 45	"Safety joint geometry" defined in article 2 of the Ministerial Order means to meet the requirements of the article 13, 17, and 18 (these article numbers are those of the case of Boilers).
2. Cracks in the Welds	Article 10	Article 28	Article 46	"No crack in the weld" defined in article 3 of the Ministerial Order means to meet the requirements of section 2, Welding Procedural Methods, and article 19, 20, and 22. "No fear of forming crack in the weld" means to meet the requirements of section 2, Welding Procedural Methods, and article 14, 15, and 21. (These article numbers are those of the case of Boilers)

(Continued)

Item	Article Number in the Standards			Summary
	Boilers	Heat Exchangers	Equipment of Liquefied Gases	
3. Flaws in the Welds	Article 11	Article 29	Article 47	"Enough penetration" defined in article 3 of the Ministerial Order means to meet the requirements of section 2, Welding Procedural Method, and article 13, 15. "Not having defects such as undercut, overlap, crater, slag inclusion, blowhole, or any other similar flaws that harm sound welds" means to meet the requirements of section 2, Welding Procedural Methods, and article 15, 19, 20, and 22. (These article numbers are those of the case of Boilers)
4. Strength of the Welds	Article 12	Article 30	Article 48	"Enough strength" defined in article 4 of the Ministerial Order means to meet the requirement of section 2 Welding Procedural Method, and article 16, 23 to 25. (These article numbers are those of the case of Boilers)
5. Design of Welding Connections	Article 13	Article 31	Article 49	(1) Longitudinal joints, circumferential joints →As a general rule, double groove butt weld, single groove butt weld using backing strip, or first layer inert gas arc welding shall be adopted. (2) Other joints →Designs in accordance with the attached figures, etc.
6. Restriction on Welding	Article 14	Article 32	Article 50	The welding of the base metal of over 0.35% carbon content shall be restricted.
7. Groove Face	Article 15	Article 33	Article 51	(1) Before welding, the groove faces and the nearby areas shall be cleaned to remove the water, paint, oils, dust, harmful rust, slag, and other foreign materials. (2) The insufficient penetration part in the back chipping portion shall be removed completely.
8. Strength of Weld	Article 16	Article 34	Article 52	(1) The strength at the welds shall not be less than that of base metals.
9. Offsets at Butt Weld Surfaces	Article 17	Article 35	Article 53	(1) The maximum allowable offset at every thickness of the base metal for each longitudinal and circumferential weld joints is defined. (2) Longitudinal joints - the maximum allowable offset is about 5% of the thickness of base metal. (3) Circumferential joints - the maximum allowable offset is about 10% of the thickness of base metal
10. Butt Joints of Unequal Thickness	Article 18	Article 36	Article 54	The maximum transitional sloping shall be 1/3.
11. Flaws in the Welds	Article 19	Article 37	Article 55	The weld shall have enough depth of fusion, and not have any harmful flaws such as crack, undercut, overlap, crater, slag inclusion, blowhole, etc. by welding.

(Continued)

Item	Article Number in the Standards			Summary
	Boilers	Heat Exchangers	Equipment of Liquefied Gases	
12. Finishing of Welds	Article 20	Article 38	Article 56	(1) Before applying nondestructive testing, the surfaces of the welds shall be finished to be smooth, and not to form sinks or irregularities from the surface of the base metal. (2) For performing radiographic testing, the height of weld reinforcement is restricted at every thickness of the base metal.
13. Post Weld Heat Treatments	Article 21	Article 21	Article 57	(1) Range of the heat treatment is not required to apply → Attached table 17 Variables: material (P classification), thickness of weld joint, type of weld joint, carbon content of base metal, preheat temperature. (2) Method of heat treatment → Attached table 16 (3) Range of the temperature and time in the heat treatment → Attached table 15
14. Nondestructive Testing	Article 22	Article 40	Article 58	(1) Classification for applying nondestructive testing → Attached table 18 Variables: Material (P classification), outer diameter, thickness of base metal, inner fluid, contact to burning gas. (2) Testing methods and acceptance criteria : Radiographic testing → Attached table 19 : Ultrasonic testing → Attached table 20 : Magnetic particle testing → Attached table 21 : Liquid penetrant testing → Attached table 22 (3) Requirements for personnel qualifications of nondestructive testing
15. Mechanical Testing	Article 23	Article 41	Article 59	(1) Classification for applying mechanical testing → Attached table 23 Variables: Type of component (vessel, header, piping), inner diameter of shell, type of welding joint (2) Types of Mechanical Testing → Attached table 24 (3) Types of tests, testing methods, and acceptance criteria → Attached table 25
16. Retests	Article 24	Article 42	Article 60	Retests for mechanical testing → Attached table 27
17. Pressure Testing	Article 25	Article 43	Article 61	(1) The soundness of the structure and non-leakage shall be confirmed at the defined test pressure. (2) The methods and pressures at the testing → Attached table 28 (3) Alternative to pressure testing → RT, UT, MT, PT
18. Others (Compliance with other article)	Article 26	Article 44	—	The vessels or pipes of boilers or heat exchangers in which gas or liquefied gas passes shall be complied with the articles for the equipment of liquefied gases.

Section 3 Equipment for Nuclear Power Plants (Vessels)

Item	Article Number in the Standards				Summary
	1V	2V	3V	4V	
1. Geometries of Welding Joints	Article 62	Article 79	Article 97	Article 115	"Safety joint geometry" defined in article 1 of the Ministerial Order means to meet the requirements of the article 66, 70, and 71 (These article numbers are those of the case of class 1 vessels).
2. Cracks in the Welds	Article 63	Article 80	Article 98	Article 116	"No crack in the weld" defined in article 2 of the Ministerial Order means to meet the requirements of section 2, Welding Procedural Methods, and article 72, 73, and 75. "No fear of forming crack in the weld" means to meet the requirements of section 2, Welding Procedural Methods, and article 67, 68, and 74. (These article numbers are those of the case of class 1 vessels.)
3. Flaws in the Welds	Article 64	Article 81	Article 99	Article 117	"Enough penetration" defined in article 3 of the Ministerial Order means to meet the requirements of section 2, Welding Procedural Method, and article 66, 68. "Not having defects such as undercut, overlap, crater, slag inclusion, blowhole, or any other similar flaws that harm sound welds" means to meet the requirements of section 2, Welding Procedural Methods, and article 68, 72, 73, and 75. (Thesearticle numbers are for class 1 vessels)
4. Strength of the Welds	Article 65	Article 82	Article 100	Article 118	"Enough strength" defined in article 4 of the Ministerial Order means to meet the requirement of section 2, Welding Procedural Method, and article 69, 76 to 78. (These article numbers are for class 1 vessels)
5. Design of Welds	Article 66	Article 83	Article 101	Article 119	(1) Longitudinal joints, circumferential joints → As a general rule, double groove butt weld, single groove butt weld using backing strip, or first layer inert gas arc welding shall be adopted. (2) Other joints → Designs in accordance with the attached figures or others.
6. Restriction on Welding	Article 67	Article 84	Article 102	Article 120	The welding of the base metal of over 0.35% carbon content shall be restricted.
7. Groove Face	Article 68	Article 85	Article 103	Article 121	(1) Before welding, the groove faces and the nearby areas shall be cleaned to remove the water, paint, oils, dust, harmful rust, slag, and other foreign materials. (2) The insufficient penetration part in the back chipping portion shall be removed completely. (3) MT, PT shall be performed on 1V, 2V and 3V vessels except for materials with thickness of 50 mm or less made by rolling or forging.

(Continued)

Item	Article Number in the Standards				Summary
	1V	2V	3V	4V	
8. Strength of Weld	Article 69	Article 86	Article 104	Article 122	(1) The strength at the welds shall not be less than that of base metals.
9. Offsets at Butt Weld Surfaces	Article 70	Article 87	Article 105	Article 123	(1) The maximum allowable offset at every thickness of the base metal for each class 1 to 4 joints is defined. (2) Class 1 joints - the maximum allowable offset is about 5% of the thickness of the base metal. (3) Class 2 to 4 joints - the maximum allowable offset is about 10% of the thickness of the base metal
10. Butt Joints of Unequal Thickness	Article 71	Article 88	Article 106	Article 124	The maximum transitional sloping shall be 1/3 except for that of Class 3 and 4 joints.
11. Flaws in the Welds	Article 72	Article 89	Article 107	Article 125	The weld shall have enough depth of fusion, and shall not have any harmful flaws such as crack, undercut, overlap, crater, slag inclusion, blowhole, etc.
12. Finishing of Welds	Article 73	Article 90	Article 108	Article 126	(1) Before applying nondestructive testing, the surfaces of the welds shall be finished to be smooth, and not to form sinks or irregularities from the surface of the base metal. (2) For performing radiographic testing, the height of weld reinforcement is restricted at the every thickness of the base metal.
13. Post Weld Heat Treatments	Article 74	Article 91	Article 109	Article 127	(1) Range of the heat treatment is not required to apply → Attached table 17 Variables: Material (P classification), thickness of weld joint, type of weld joint, carbon content of base metal, preheat temperature. (2) Method of heat treatment → Attached table 16 (3) Range of the temperature and time of the heat treatment → Attached table 15
14. Nondestructive Testing	Article 75	Article 92	Article 110	Article 128	(1) Classification for applying nondestructive testing → Attached table 18 Variables: Type of welding joint, material (P classification), outer diameter, thickness of base metal, inner fluid, pressure. (2) Testing methods and acceptance criteria : Radiographic testing → Attached table 19 : Ultrasonic testing → Attached table 20 : Magnetic particle testing → Attached table 21 : Liquid penetrant testing → Attached table 22 (3) Requirements for personnel qualifications of nondestructive testing

(Continued)

Item	Article Number in the Standards				Summary
	1V	2V	3V	4V	
15. Mechanical Testing	Article 76	Article 93	Article 111	Article 129	(1) Classification for applying mechanical testing → Attached table 23 (except for open vessels that do not include safety related equipments.) Variables: Inner diameter of shell, type of welding joint (2) Types of Mechanical Testing → Attached table 24 (3) Types of tests, testing methods, and acceptance criteria → Attached table 25 (4) Fracture Toughness Testing → Attached table 26
16. Retests	Article 77	Article 94	Article 112	Article 130	Retests for mechanical testing → Attached table 27
17. Pressure Testing	Article 78	Article 95	Article 113	Article 131	(1) Under the required test pressure, soundness of the structure and non- leakage shall be confirmed. (2) The methods and pressures at the testing → Attached table 28 (3) Alternative to pressure testing → RT, UT, MT, PT
18. Others (Special Application)	–	Article 96	Article 114	–	The rules for welding of 1V shall be applied to the 2V or 3V vessels to which the rules for materials and structures of 1V are applied.

1V: Class 1 Vessels, 2V: Class 2 Vessels, 3V: Class 3 Vessels, 4V: Class 4 Vessels

Section 3 Equipment for Nuclear Power Plants (Piping, Auxiliary Boilers and the Attached equipments)

Item	Article Number in the Standards					Summary
	1P	3P	4P	5P	A/B	
1. Geometries of Welding Joints	Article 132	Article 150	Article 168	Article 185	Article 196 (Comply with the articles of Boilers or Heat Exchangers)	"Safety joint geometry" defined in article 1 of the Ministerial Order means to meet the requirements of the article 136, 140, and 141 (These article numbers are those of the case of Class 1 Piping).
2. Cracks in the Welds	Article 133	Article 151	Article 169	Article 186		"No crack in the weld" defined in article 2 of the Ministerial Order means to meet the requirements of section 2 Welding Procedural Methods, and article 142, 143, and 145. "No fear of forming crack in the weld" means to meet the requirements of section 2 Welding Procedural Methods, and article 137, 138, and 144. (These article numbers are those of the case of Class 1 Piping.)

(Continued)

Item	Article Number in the Standards					Summary
	1P	3P	4P	5P	A/B	
3. Flaws in the Welds	Article 134	Article 152	Article 170	Article 187	Article 196 (Comply with the articles of Boilers or Heat Exchangers)	"Enough penetration" defined in article 3 of the Ministerial Order means to meet the requirements of section 2 Welding Procedural Method, and article 136, 138. "Not having defects such as undercut, overlap, crater, slag inclusion, blowhole, or any other similar flaws that harm sound welds" means to meet the requirements of section 2 Welding Procedural Methods, and article 138, 142, 143, and 145. (These article numbers are those of the case of Class 1 Piping.)
4. Strength Requirements of the Welds	Article 135	Article 153	Article 171	Article 188		"Enough strength" defined in article 4 of the Ministerial Order means to meet the requirement of section 2 Welding Procedural Method, and article 139, 146 to 148. (These article numbers are those of the case of Class 1 Piping.)
5. Design of Welding Connections	Article 136	Article 154	Article 172	Article 189		(1) Class 1 Joints, Class 2 Joints → As a general rule, double groove butt weld, single groove butt weld using backing strip, or first layer inert gas arc welding shall be adopted. (2) Other joints → Designs in accordance with the attached figures, etc.
6. Restriction on Welding	Article 137	Article 155	Article 173	Article 190		The welding of the base metal of over 0.35% carbon content shall be restricted.
7. Groove Face	Article 138	Article 156	Article 174	Article 191		(1) Before welding, the groove faces and the nearby areas shall be cleaned to remove the water, paint, oils, dust, harmful rust, slag, and other foreign materials. (2) The insufficient penetration part in the back chipping portion shall be removed completely. (3) MT, PT shall be performed on 1P and 3P except for that of the thickness of 50 mm or less which is made by rolling mill or forging.
8. Strength of Weld	Article 139	Article 157	Article 175	Article 192		(1) The strength at the welds shall not be less than that of base metals.
9. Offsets at Butt Weld Surfaces	Article 140	Article 158	Article 176	–		(1) the maximum allowable offset at every thickness of the base metal for each Class 1 to 4 Joints is defined. (2) Class 1 Joints - the maximum allowable offset is about 5% of the thickness of base metal. (3) Class 2 to 4 Joints - the maximum allowable offset is about 10% of the thickness of base metal
10. Butt Joints of Unequal Thickness	Article 141	Article 159	Article 177	–		The maximum transitional sloping shall be 1/3 except for that of Class 3 and 4 joints.

(Continued)

Item	Article Number in the Standards					Summary
	1P	3P	4P	5P	A/B	
11. Flaws in the Welds	Article 142	Article 160	Article 178	Article 193	Article 196 (Comply with the articles of Boilers or Heat Exchangers)	The weld shall have enough depth of fusion, and not have any harmful flaws such as crack, undercut, overlap, crater, slag inclusion, blowhole, etc by welding.
12. Finishing of Welds	Article 143	Article 161	Article 179	—		(1) Before applying nondestructive testing, the surfaces of the welds shall be finished to be smooth, and not to form sinks or irregularities from the surface of the base metal. (2) For performing radiographic testing, the height of weld reinforcement is restricted at the every thickness of the base metal.
13. Post Weld Heat Treatment	Article 144	Article 162	Article 180	—		(1) Range of the heat treatment is not required to apply → Attached table 17 Variables: material (P classification), thickness of weld joint, type of weld joint, carbon content of base metal, preheat temperature. (2) Method of heat treatment → Attached table 16 (3) Range of the temperature and time in the heat treatment → Attached table 15
14. Nondestructive Testing	Article 145	Article 163	Article 181	Article 194		(1) Classification for applying nondestructive testing → Attached table 18 Variables: Type of welding joint, material (P classification), outer diameter, thickness of base metal, inner fluid, pressure. (2) Testing methods and acceptance criteria : Radiographic testing → Attached table 19 : Ultrasonic testing → Attached table 20 : Magnetic particle testing → Attached table 21 : Liquid penetrant testing → Attached table 22 (3) Requirements for personnel qualifications of nondestructive testing
15. Mechanical Testing	Article 146	Article 164	Article 182	—		(1) Classification for applying mechanical testing → Attached table 23 (except for the piping from open vessel to the nearest stop valve that does not include safety related equipment.) Variables: Inner diameter of shell, type of welding joint (2) Types of Mechanical Testing → Attached table 24 (3) Types of tests, testing methods, and acceptance criteria → Attached table 25 (4) Fracture Toughness Testing → Attached table 26
16. Retests	Article 147	Article 165	Article 183	—		Retests for mechanical testing → Attached table 27

(Continued)

Item	Article Number in the Standards					Summary
	1P	3P	4P	5P	A/B	
17. Pressure Testing	Article 148	Article 166	Article 184	Article 195	Article 196 (Comply with the articles of Boilers or Heat Exchangers)	(1) Under the required test pressure, soundness of the structure and non-leakage shall be confirmed. (2) The methods and pressures at the testing → Attached table 28 (3) Alternative to pressure testing → RT, UT, MT, PT
18. Others (Special Application)	Article 149	Article 167	—	—		The rules for welding of 1V shall be applied to the 1P or 3P pipes to which the rules for materials and structures of 1V are applied.

1P: Class 1 piping, 3P: Class 3 piping, 4P: Class 4 piping, 5P: Class 5 piping, A/B: Auxiliary boilers and the attached equipment

27-4 Regulation for the Boiler used for both Power Generation and Factory at the Industrial Steam Power Plant (Summary) (July 1, 1965, No. 40 of the Bureau No. 566)

The above has been applied based on "Regulation for the Turbine and the Boiler for Power Generation", No. 2779 of the Work, as of August 14, 1935, Electric Bureau Chief notification in order to adjust with the conventional Ministry of Labor on management, but in connection with publication of Electric Utility Law, it was decided and notified to handle as follows:

1 When exhaust steam of the steam turbine used for drive such as a pump, blower, etc. which are other than for power generation, is used to generate electricity with an exhaust turbine or a reciprocating engine, the boiler which supplies steam to the steam turbine shall not be dealt with as an electric structure.
2 When the steam produced from two or more boilers is used for the steam turbine or the reciprocating engine for power generation, and used other than for power generation, the boiler (a spare boiler is included) of the range required for generating the output of the plant shall be dealt with as an electric structure.
3 When one steam turbine or one reciprocating engine is used as a motor for power generation and factory power, and 1/2 or more of the output is used for power generation, the boiler shall be dealt with as an electric structure. When two or more boilers are used, it shall be as specified as the above correspondingly.
4 When the steam produced from one boiler is used for the steam turbine or the reciprocating engine for power generation and used other than for power generation, and 1/2 or more of the steam is used for power generation, the boiler shall be dealt with as an electric structure.

27-5 Safety Regulations for Boiler and Pressure Vessel

(Labour Ministerial Ordinance No. 33, September 30, 1972, Labour Ministerial Ordinance No. 2, January 31, 2000)

This ministerial ordinance is enacted by the Industrial Safety and Health Law (Law No. 57, 1972) and the Ordinance for its Enforcement (Cabinet Order No. 318, 1972). It is the general regulation on various regulations for the boiler and pressure vessel.

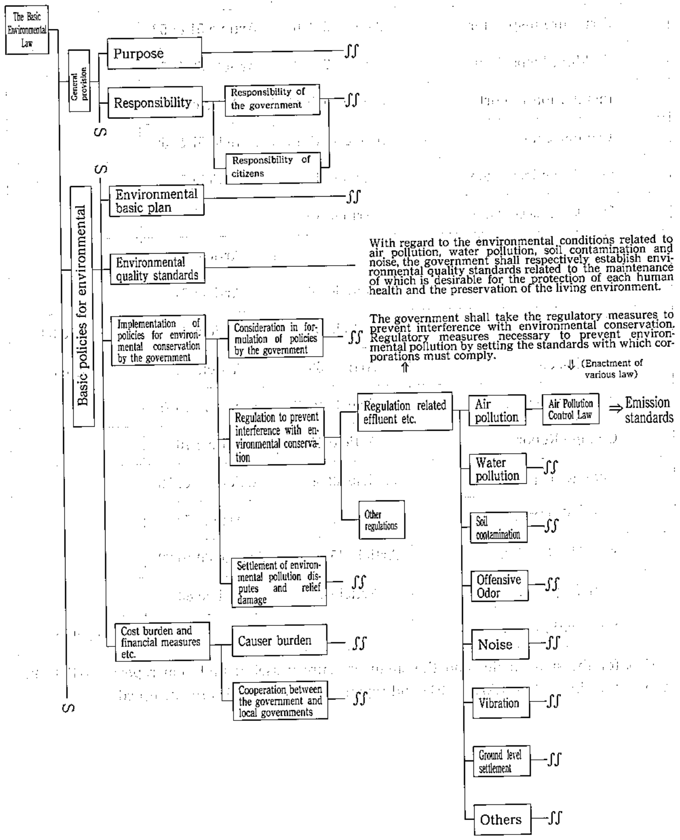
The article 125 of Safety Regulations for the Boiler and the Pressure Vessel exempts the boiler and the pressure vessel regulated by the Electric Utilities Industry Law. Following table shows the exempted regulations.

Contents of the regulations exempted from the Safety Regulations for Boiler and Pressure Vessel	Associated Regulations exempted by Article 125-1		
	Boiler	Class 1 Pressure Vessel	Class 2 Pressure Vessel
Manufacturing License	Article 3	Article 49	
Change Report	Article 4	Article 50	
Structure Inspection	Article 5 & 6	Article 51 & 52	
Welding Inspection	Article 7 & 8	Article 53 & 54	
Installation Report	Article 10 & 11	Article 56	
Use Inspection	Article 12 & 13	Article 57 & 58	
Completion Inspection	Article 14	Article 59	
Boiler Inspection Certificate	Article 15	–	
Class 1 Pressure Vessel Inspection Certificate	–	Article 60	
Use Restriction	Article 26	Article 64	
Periodical Autonomous Inspection	Article 32	Article 67	Article 88
Repairs, etc.	Article 33	Article 68	Article 89
Performance Inspection	Article 37 to 40	Article 72 to 75	
Change Report	Article 41	Article 76	
Change Inspection	Article 42 & 43	Article 77 & 78	
Change of Enterpriser etc.	Article 44	Article 79	
Stay and Use Renewal, etc.	Article 45 to 47	Article 80 to 82	
Return of Inspection Certificate	Article 48	Article 83	
Verification			Article 84

Also, for the small boiler and the small pressure vessel, installation report (Article 91), autonomous inspection (Article 94) and repairs, etc (Article 95) are exempted.

27-6 Law System Related to the Environment (Summary)

The Basic Environmental Law specified mainly for prevention of environmental pollution contains (1) fear of the pollution, (2) responsibility of corporations, the state and local government, (3) establishment of the environmental standards, (4) enactment of the effluent, and (5) decision of the pollution prevention plan.



With regard to the environmental conditions related to air pollution, water pollution, soil contamination and noise, the government shall respectively establish environmental quality standards related to the maintenance of which is desirable for the protection of each human health and the preservation of the living environment.

The government shall take the regulatory measures to prevent interference with environmental conservation. Regulatory measures necessary to prevent environmental pollution by setting the standards with which corporations must comply.

27-7 Environmental Quality Standards for Air Pollution (Summary)

Substance	Environmental condition	Measuring method
Sulfur dioxide	Daily average of hourly values shall not exceed 0.04ppm, and hourly values shall not exceed 0.1ppm (Notification on May 16, 1973).	Conduct metric method or ultraviolet fluorescence method
Carbon monoxide	Daily average of hourly values shall not exceed 10ppm, and average of hourly values in eight consecutive hours shall not exceed 20ppm (Notification on May 16, 1973).	Nondispersive infrared analyzer method
Suspended particulate substance	Daily average of hourly values shall not exceed 0.10mg/m³, and hourly values shall not exceed 0.20mg/m³ (Notification on May 8, 1973).	Weight concentration measuring methods based on filtration collection ,or light scattering method , or Piezoelectric microbalance method or β-ray attenuation method yielding values having a linear relation with the values of the above methods.
Nitrogen dioxide	Daily average of hourly values shall be within the range from 0.04 ppm to 0.06ppm or below (Notification on July 11, 1978)	Colorimetric employing Saltzman reagent or chemiluminescent method using ozone.
Photochemical oxidants	Hourly values shall not exceed 0.06 ppm (Notification on May 8, 1973)	Absorption spectrophotometer using neutral potassium iodide solution or coulometry or ultraviolet absorption spectrometry or chemiluminescent method using ethylene.
Benzene	Annual average shall not exceed 0.003mg/m³ (Notification on Feb. 4, 1997).	Preference method: gas chromatograph-mass spectrometer (Sample gas should be collected with canister or tube) or its equivalent method.
Trichloroethylene	Annual average shall not exceed 0.2 mg/m³ (Notification on Feb. 4, 1997).	
Tetrachloroethylene	Annual average shall not exceed 0.2 mg/m³ (Notification on Feb. 4, 1997).	
Dioxins	Annual average shall not exceed 0.6pg-TEQ/m3 (Notification on Dec. 27, 1999).	Using high-resolution gas chromatograph -high resolution mass spectrometry (HRGC-HRMS). (Sample should be collected by an air sampler equipped with an inlet filter followed by a cartridge filled with polyurethane form.)

Remark: 1. Environmental standards dose not apply about the area only for industry, driveway, and the area or a place where public are not living.
2. Suspended particulate matter is defined as airborne particles with diameter smaller than or equal to 10 μm.
3. About nitrogen dioxide, if it is in the area, which will have the daily average of hourly values in the zone from 0.04ppm to 0.06ppm, it shall try to maintain the level about the present condition in this zone in principle, or to far exceed this.
4. Photochemical oxidants are oxidizing substances such as ozone and peroxiacetyl nitrate produced by photochemical reactions (only those capable of isolating iodine from neutral potassium iodide, excluding nitrogen dioxide).
5. Standard value concerning dioxin is the value converted into the toxicity of 2,3,7,8-tetrachlorodibenzo-para-dioxin

27-8 Environmental Quality Standards for Water Pollution (Summary)

[Environmental Agency Notification No.59 on December 28, 1971.
Latest Amendment: Environmental Agency Notification No.15 on April 24, 1998.]

Environmental Quality Standards Related to the Protection of Human Health

Item	Standard values	Item	Standard values
Cadmium	0.01mg/ℓ or less.	1,1,1-trichloroethane	1mg/ℓ or less.
Total cyanogens	Not detectable	1,1,2-trichloroethane	0.006mg/ℓ or less.
Lead	0.01mg/ℓ or less.	Trichloroethylene	0.03mg/ℓ or less.
Sexivalent chrome	0.05mg/ℓ or less.	Tetrachloroethylene	0.01mg/ℓ or less.
Arsenic	0.01mg/ℓ or less.	1,3-dichloropropene	0.002mg/ℓ or less.
Total mercury	0.0005mg/ℓ or less.	Thiram	0.006mg/ℓ or less.
Alkyl mercury	Not detectable	Simazine	0.003mg/ℓ or less.
PCB	Not detectable	Thiobencarb	0.02mg/ℓ or less.
Dichlomethane	0.02mg/ℓ or less.	Benzene	0.01mg/ℓ or less.
Carbon tetrachloride	0.002mg/ℓ or less.	Selenium	0.01mg/ℓ or less.
1,2-dichloroethane	0.004mg/ℓ or less.	Nitrate-N and nitrite-N	10mg/ℓ or less.
1,1-dichloroethylene	0.02mg/ℓ or less.	Fluoride	0.8mg/ℓ or less.
Cis 1,2-dichloroethylene	0.04mg/ℓ or less.	Boron	1 mg/ℓ or less.

Remark 1. Standard values are the annual mean. However, the value for total CN is the maximum value.
2. "Not detectable" means that the result is less than the quantity limit of the concerned method when analyzed by the method described in column. Same as attached table 2.
3. Standard values for fluoride and boron are not applicable to coastal water.
4. Concentration for nitrate-N and nitrite-N shall be summed the concentration of nitric acid ion measure by standard 43.2.1, 43.2.3 or 43.2.5 multiplied conversion factor 0.2259 and the concentration of nitrous acid ion measured by standard 43.1 multiplied conversion factor 0.3045.

Environmental Quality Standards Related to the Preservation of the Living Environment (Coastal Waters)

	Class	A	B	C
	Water use	Fishery class 1, bathing, conservation of the natural environment, and uses listed in B, C	Fishery class 2, industrial water and the uses listed in C	Conservation of the environment
Standard values	Hydrogen ion exponent (PH)	7.8 or more and 8.3 or less	7.8 or more and 8.3 or less	7.8 or more and 8.3 or less
	Chemical Oxygen Demand (COD)	2mg/ℓ or less	3mg/ℓ or less	8mg/ℓ or less
	Dissolved Oxygen (DO)	7.5mg/ℓ or less	5mg/ℓ or less	2mg/ℓ or less
	Total coliform	1,000MPN/100ml or less	—	—
	N-hexane Extracts (oil content etc.)	Not detectable	Not detectable	
	Object area	Specified area for each class		

27-9 Environmental Quality Standards for Noise (Summary)

〔About the environmental quality standards for noise. (Designated by Cabinet Council on May 25, 1971)〕

Type of area		AA	A			B		
			Areas other than an area facing a road	Areas facing road		Areas other than an area facing a road	Areas facing road	
				Areas facing road with two lanes	Areas facing road with two or more lanes		Areas facing road with two lanes	Areas facing road with two or more lanes
Standard value	Daytime	45dB or less	50dB or less	55dB or less	60dB or less	60dB or less	65dB or less	65dB or less
	Morning and evening	40dB or less	45dB or less	50dB or less	55dB or less	55dB or less	60dB or less	65dB or less
	Night-time	35dB or less	40dB or less	45dB or less	50dB or less	50dB or less	55dB or less	60dB or less
Object area		Areas specified by prefecture governors for each category 〔on the basis of the ordinances concerning the delegation of authority to specify the areas including those of the sea related to the environmental standards (Ordinance No. 159 issued in 1971)〕						
		1. Area category AA shall be the area where quiet is specially required, such as those in which convalescent facilities and welfare institutions are concentrated. 2. Area category A shall be applied to the area that is used mainly for residences. 3. Area category B shall be applied to the area that is used for commerce and industry as well as for significant number of residence.						

27-10 Flue Gas Standards (Summary)

[Air Pollution Control Law Enforcement: Ordinance No.329 on November 30, 1968.
Latest Amendment: Ordinance No.306 on October 1, 1997.
Air Pollution control Law Enforcement: the Ministry of Welfare, the Ministry of International Trade and Industry, Ministerial Ordinance No.1 on June 22, 1971.
Latest Amendment: Order of the Prime Minister's Office No.27 on April 10, 1998.]

Sulfur Oxides Emission Standard

$$q = K \times 10^{-3}\ He^2$$

q : Permissible emission volume of sulfur oxides (m_N^3 /h)
K : Each region value shown in Table below
He : Effective stack height calculated by the following method (m)

$$He = Ho + 0.65(Hm + Ht)$$

$$Hm = \frac{0.795\sqrt{Q \cdot V}}{1 + \frac{2.58}{V}}$$

He : Effective stack height (m)
Ho : Actual height of the outlet (m)
Q : Amount of exhaust gas at 15℃ (m^3/s)
V : Exhaust gas velocity (m/s)
T : Exhaust gas temperature (K)

$$Ht = 2.01\times10^{-3}\cdot Q\cdot(T-288)\cdot(2.30\log J+\frac{1}{J}-1)$$

$$J=\frac{1}{\sqrt{Q\cdot V}}(1.460-296\times\frac{V}{T-288})+1$$

K Values

Category	Rank	Region Name	K Values
General Exhaust Standard	1	Special wards, etc., in Tokyo, Yokohama/Kawasaki City, etc., Nagoya City, etc., Yokkaichi City, etc., Osaka/Sakai, etc., Kobe/Amagasaki, etc.	3.0
	2	Kawaguchi/Soka/Chiba/Ichihara, etc., Shimizu, etc., Fujinomiya/Fuji, etc., Handa/Hekinan, etc., Kyoto, etc., kishiwada, etc., Himeji, etc., Wakayama, etc., Kurashiki (Mizushima), Kurashiki (except for Mizushima), Bizen, Fukuyama, Otake, Ube, etc., Tokuyama, etc., Iwakuni, etc., Niihama, etc., Kita-Kyushu, etc., Omuta, Oita, etc., Kawaguchi/Soka, etc., Wakayama/Kainan, etc.	3.5
	3	Sapporo	4.0
	4	Muroran, Hitachi, Kashima, etc., and Boufu	4.5
	5	Toyama/Takaoka, etc., Kure, Toyo, Komatsu	5.0
	6	Hachinohe, Iwaki, Annaka, etc., Niigata, etc., Okayama, Shimonoseki, Marugame, Sakaide, etc., Kawanoe, etc., Arao	6.0
	7	Tomakomai, etc., Hachioji, etc., Kasaoka	6.42
	8	Sendai, etc., Ashikaga, etc., Tochigi, etc., Fukui, etc., Hamamatsu, etc., Hiroshima, etc.	7.0
	9	Otaru, Asahikawa, Sakata, Utsunomiya, etc., Turuga, Takehara, etc., Mihara /Onomichi, etc., Tokushima/Anan, etc.	8.0
	10	Akita, etc., Kanazawa, etc., Toyohashi, etc., Otsu, etc., Aioi, etc., Fukuoka, Nagasaki, etc., Nobeoka	8.76
	11	Takasaki (except for Yawata-Machi, etc.), Kawagoe/Urawa, etc., Noda/Narita, etc., Ichinomiya/Inuyama, etc., Seto, etc., Naha, etc.	9.0
	12	Kushiro, Takefu/Sabae, etc., Shizuoka, Sasebo	10.0
	13	Hakodate, etc., Ishinomaki, etc., Natori, etc., Koriyama, Katsuta, Hiratsuka/Kamakura, etc., Joetsu, etc., Gifu/Ogaki, etc., TAjimi, etc., Fukuchiyama, etc., Takamatsu, Matsuyama, etc., Yatsushiro, etc., Minamata, Sendai (Kyusyu)	11.5
	14	Shibukawa, Numazu/Mishima, etc., Tamano, Naruto, etc., Kurume, Itoman, etc.	13.0
	15	Aomori, Morioka, Miyako, Kamaishi, Yamagata, Tsuchiura, etc., Koga, etc., Chichibu, etc., Choshi, Mobara, Nagaoka, Nagano, Matsumoto, etc., Kuwana /Suzuka, Hikone/Nagahama, etc., Nishiwaki/Miki, etc., Imabari, Kumamoto, Hyuga, Kagoshima	14.5
	16	Other	17.5
Special Exhaust Standard	1	Special Wards in Tokyo, etc., Yokohama/Kawasaki, etc., Nagoya, etc., Yokkaichi, etc., Osaka/Sakai, etc., Kobe/Amagasaki, etc.	1.17
	2	Chiba/Ichihara, Fuji, Handa/Hekinan, etc., Kishiwada/Ikeda, etc., Himeji, etc.,Wakayama/Kainan, etc., Kurashiki (Mizushima), Kita-Kyushu, etc.	1.75
	3	Kashima, etc., Kawaguchi/Soka, etc., Toyama/Takaoka, etc., Shimizu, Kyoto, etc., Fukuyama, Otake, Ube, etc., Tokuyama, etc., Iwakuni, etc., Marugame/Sakaide, etc., Niihama, etc., Omuta, Oita, etc.	2.34

Total Mass Emission Regulation for Sulfur Oxides

Area (Ordinance, Attached Table No2 of 3)	Existing Specific Factories, etc.				New/enlarged Specific Factories, etc.	
	Total Mass Emission Control Standards $Q = aW^b$ Q : SO_x emissions (m_N^3/h) W : Fuel consumption (kℓ/h)				Special Total Mass Emission Control Standard $Q = aW^b + r\cdot a\{(W+Wi)^b - W^b\}$ Wi : New/enlarged facilities fuel consumption (kℓ/h)	
	Coefficient a	Coefficient b	Scale of specific factory, etc. W	Applied Date	Coefficient r	Applied Date
Kawaguchi/Soka, etc.	2.11	0.86	0.3	53. 5. 31	0.5	53. 2. 28
Chiba/Ichikawa, etc.	3.3	0.90 (northern part) 0.88 (southern part)	0.5	52. 1. 1	0.5	51. 10. 1
Special wards, etc. in Tokyo	0.57～3.26	0.80～0.96	0.3or 2kℓ/day (0.1 and over)	52. 12. 1	0.3	51. 8. 1
Yokohama/Kawasaki, etc.	1. 5 (coastal areas in Yokohama /Kawasaki) 2. 5 (other)	0.865	1.0	52. 4. 1	1. 3 (coastal area in Yokohama /Kawasaki) 0. 32 (other)	51. 4. 1
Fujinomiya / fuji, etc.	2.8 (Fuji) 3.0 (other)	0.8	1.0	53. 4. 1	0.3 (Fuji) 0.5 (other)	52. 3. 21
Nagoya, etc.	1.54	0.95	0.5	51. 10. 1	1/3	51. 4. 1
Handa/Hekinan, etc.	2.63	0.95	0.5	51. 10. 1	0.4	51. 4. 1
Yokkaichi, etc.	4.0	0.819	0.5	51. 9. 1	0.3	51. 9. 1
Kyoto, etc.	1.6 (Kyoto) 3.2 (Yamashiro)	0.85	0.3	53. 5. 1	0.3 (Kyoto) 0.5 (Yamashiro)	53. 1. 1
Osaka, etc.	2.0 (Osaka City, etc) 3.0 (other)	0.85	0.8	53. 3. 31	0.3	52. 10. 1
Kishiwada / Ikeda, etc.	3.0 (coastal areas) 5.0 (other)	0.85	0.8	53. 3. 31	0.3	52. 10. 1
Kobe/Amagasaki, etc.	3.49 (Kobe) 2.01 (other)	0.85	0.3	53. 3. 31	0.3	51. 12. 1
Himeji/Akashi, etc.	3.51 (Himeji) 3.69 (Akashi)	0.85	0.3	53. 4. 1	0.3	52. 12. 1
Wakayama / Kainan, etc.*	4.73	0.8	0.8	53. 3. 31	0.5	52. 11. 11
Kurashiki (Mizushima)	3.70	0.8	0.5	53. 3. 31	0.3	52. 6. 3
Kurashiki (except for Mizushima)	4.15	0.8	0.5	53. 3. 31	0.6	52. 6. 3
Bizen	4.75 (Katakami) 5.0 (Mitsuishi)	0.9	0.5	53. 3. 21	0.6	52. 9. 3
Fukuyama	4.2	0.85	1.0	53. 4. 29	0.7	52. 10. 29
Otake	6.36	0.9	1.0	53. 5. 31	0.7	52. 11. 30
Ube/Onoda	3.30	0.9	1.0	53. 4. 1	0.3	53. 4. 1
Tokuyama / Kudamatsu, etc.	5.40 (Hikari) 3.32 (other)	0.9	1.0	53. 4. 1	0.3	53. 4. 1
Iwakuni, etc.	4.00	0.85	1.0	53. 4. 1	0.3	53. 4. 1
Kita-Kyushu, etc.	3.78	0.84	1.0	53. 3. 31	0.3	51. 12. 28
Omuta	5.49	0.84	1.0	53. 5. 31	0.5	52. 12. 1

Note) Q : Permissible limits on the amount of sulfur oxides (m_N^3/h)

W : Amount of raw materials and fuels used in all the soot and smoke emitting facilities in specific factories, etc. (Converted to heavy oil value kℓ/h)

Wi : Amount of the raw materials and fuels used in the soot and smoke emitting facilities installed at all special factories, etc. after the date designated by the prefecture governor. (Converted to a heavy oil value kℓ/h)

a : Constant designated by a prefecture governor to achieve the goal of reduction.

b : Constant designated by a prefecture governor within the range of over 0.80 to 1.0.

r : Constant designated by a prefecture governor within the range of over 0.3 to 0.7.

※ Calculating equation : $Q= a(W-0.7)^b$ [Existing facilities], $Q= a\{(W-0.7)^b + r\cdot a\{(W+Wi-0.7)^b-(W-0.7)^b\} + 4.29$ [Enlargement]

Emission Standard for Nitrogen Oxides (Regulations attached table No.2 of 3)

(Unit: cm³ / m^3_N)

Ordinance attached table, Provision 1	Detailed No.	Classification of soot and smoke emitting facility *1	Scale (Amount of the maximum rated exhaust gas, ten thousand m^3_N /h)	Residual oxygen concentration (%)	Emission standard (ppm) *7								
					The facilities installed up to August 9, 1973	The facilities installed from August 10, 1973 by December 9, 1975	The facilities installed from December 10, 1975 by June 17, 1977	The facilities installed from June 18, 1977 by August 9, 1979	Liquid fuel small size boiler installed from June 18, 1977 by September 9, 1977	The facilities installed from August 10, 1979 by September 9, 1983	The facilities installed from September 10, 1983 by March 31, 1987	The facilities installed from September 10, 1983 by September 9, 1984	The facilities installed after April 1, 1987
1	①	Gas boiler	50 above 10 ~ 50 4 ~ 10. 1 ~ 4 0.5 ~ 1 0.5 under	5%	130 130		100 130 150	60 100 130 150					
	②	Low quality coal combustion boiler (Ceiling type burner) *2	70 above 50 ~ 70 20 ~ 50 4 ~ 20 1 ~ 4 0.5 ~ 1 0.5 under	6%	400 420 450(650) 480	300 350 380 480	300 350 480	300 350 380			300 350		200 250 350
	③	Low quality coal boiler (Ceiling type burner, 300 thousand m^3_N /h or above)	70 above 50 ~ 70 30 ~ 50	6%	480	300 350	300						200 250
	④	Low quality coal boiler (furnace of parting wall type, furnace heat generating rate,140 thousand kcal/m³·h or above, 500 thousand m^3_N /h or above)	70 above 50 ~ 70	6%	550	300							200 250
	⑤	Low quality coal boiler 300 thousand m^3_N /h or above, other than ③, ④	70 above 50 ~ 70 30 ~ 50	6%	480	300 350	300						200 250
	⑥	Low quality coal combustion boiler (furnace of parting wall type, furnace heat generating rate,140 thousand kcal/m³·h or above, other than ④, ⑤)	70 above 50 ~ 70 20 ~ 50 4 ~ 20 1 ~ 4 0.5 ~ 1 0.5 under	6%	400 420 450(550) 480	300 350 380 480	300 350 480	300 350 380			300 350		200 250 350
	⑦	Coal boiler (front combustion method, natural circulation type, furnace heat generating rate, 140 thousand kcal/m³·h or above, 200 to 250 thousand m^3_N /h or above)		6%	450(480)	350	300						250
	⑧	Coal boiler (Tangential line type tilting burner, 1 million m^3_N /h or above)		6%	430	300							200
	⑨	Coal combustion boiler (Fluidized bed combustion method, 40 thousand m^3_N /h under)	1 ~ 4 0.5 ~ 1 0.5 under	6%	450(480) 480	380 480	350 480	350 380		380 390 380	350	360	
	⑩	Coal combustion boiler (scattering stoker type, 40~100 thousand m^3_N /h)		6%	450(480)	350	300						
	⑪	Solid combustion boiler (Fluidized bed combustion method, 40 thousand m^3_N/h under)	0.5 ~ 4 0.5 under	6%	450(480) 480	380 480	350 480	350 380			350	360	
1	⑫	Solid combustion boiler (furnace heat generating rate 200 thousand kcal/m³·h or above, natural circulation boiler type with re-heating, re-generation, return water method. A thing to change into the solid combustion boiler by December 31, 1984; 500~700 thousand m^3_N /h)		6%	420		300						250
	⑬	Solid combustion boiler (other than ②~⑫)	70 above 50 ~ 70 20 ~ 50 4 ~ 20 0.5 ~ 4 0.5 under	6%	400 420 450(480) 480	300 350 380 480	300 350 480	300 350 380			300 350		200 250 350
	⑭	Liquid combustion boiler with de-SOx (Crude oil and tar, 1 million m^3_N /h under)	50 ~100 10 ~ 50 4 ~ 10 1 ~ 4 0.5 ~ 1 0.5 under	4%	210 280	180 280	150 280	130 150 180	280	130 150 180			
	⑮	Liquid combustion boiler (Crude oil and tar other than ⑭)	50 above 10 ~ 50 4 ~ 10 1 ~ 4 0.5 ~ 1 0.5 under	4%	180 190 250	180 250	150 250	130 150 180	250	130 150 180			
	⑯	Liquid combustion boiler with de-Sox, except crude oil and tar. 1 million m^3_N /h under *3 (Except for crude oil and tar, 1 million m^3_N /h under)	50 ~100 10 ~ 50 4 ~ 10 1 ~ 4 0.5 ~ 1 0.5 under	4%	210 250 280	180 250 280	150 280	130 150 180	280	130 150 180			
	⑰	Liquid combustion boiler *1 (other than ⑭~⑯)	50 above 10 ~ 50 4 ~ 10 1 ~ 4 0.5 ~ 1 0.5 under	4%	180 190 230 250	180 230 250	250	130 150 180	250	130 150 180			
	⑱	Small size combustion boiler for solid fuel (Heating area 10m² under)		6%									350
	⑲	Small size combustion boiler for liquid fuel (Heating area 10m² under other than kerosene, light oil, A heavy oil)		4%									*1 300 260
2	①	Gas generating furnace, Heating furnace		7%	170					150			
	②	Gas generating furnace used for manufacturing hydrogen gases (Ceiling burner combustion method)		7%	360					150			
13	①	Incinerator with floating rotary combustion method (continuous incinerator)	4 above 4 under	12%	900			450 900		450			
	②	Peculiar waste material incinerator *6 (continuous incinerator)	4 above 4 under	12%	300 900			250 900		250 700			
	③	Waste material incinerator (continuous incinerator other than ①,②)	4 above 4 under	12%	300			250 300		250			

Ordinance attached table, Provision 1	Detailed No.	Classification of soot and smoke emitting facility *1	Scale (Amount of the maximum rated exhaust gas ten thousand m_N^3/h)	Residual oxygen concentration (%)	Emission standard (ppm) *7								
					The facilities installed up to August 9, 1973	The facilities installed from August 10, 1973 by December 9, 1975	The facilities installed from December 10, 1975 by June 17, 1977	The facilities installed from June 18, 1977 by August 9, 1979	Liquid fuel small size boiler installed from June 18, 1977 by September 9, 1977	The facilities installed from August 10, 1979 by September 9, 1983	The facilities installed from September 10, 1983 by March 31, 1987	The facilities installed from September 10, 1983 by September 9, 1984	The facilities installed after April 1, 1987
13	④	Waste material incinerator (other than continuous incinerator)	4 above	12%				250					
28	①	Coke furnace (Otto type)	10 above 10 under	7%			200	170					
	②	Coke furnace (other than ①)	10 above 10 under	7%	350		200 350	170					

29		Classification of soot and smoke emitting facility	Scale (Amount of the maximum rated exhaust gas, ten thousand m_N^3/h)	Residual oxygen concentration (%)	Emission standard (ppm) (Construction start time)		
					2.1,1988	8.1,1989	2.1,1991
	①	Gas turbine engine (gas fuel)	4.5 above 4.5 under	16%	70 90	70 70	70 70
	②	Gas turbine engine (gas fuel/gas and liquid fuel mixing)	4.5 above 4.5 under		100 120	100 100	70 70
30	①	Diesel engine (large size (cylinder diameter 400mm or above))		13%	1600	1400	1200
	②	Diesel engine (large size (cylinder diameter 400mm under))			950	950	950

Total Mass Emission Regulation for Nitrogen Oxides

Region Ordinance attached table No.3 of 3	Existing Specified Factory, etc. (Total Mass Emission Control Standard)					New/Enlarged Specified Factory, etc. (Special total mass emission control standard)		
	Equation	Factor $a(k)$	Factor $b(l)$	Scale of Specified Factory, etc. W	Applied Date	Equation	Factor r	Applied Date
Special Wards, etc.	$Q = k\{\Sigma(C \cdot V)\}^l$	0.51	0.95	1	3/31/1985	$Q = k\{\Sigma(C \cdot V) + \Sigma(Ci \cdot Vi)\}^l$	—	11.30,1982 (3 / 31 / 1985 for existing facility)
Yokohama /Kawasaki, etc.	$Q = aW^b$	1.37	0.95	4	3/31/1985	$Q = aW^b + r \cdot a\{(W+Wi)^b - W^b\}$	0.7	4.1,1982 (3 / 31 / 1985 for existing facility)
Osaka City, etc.	$Q = k\{\Sigma(C \cdot V)\}^l$	0.6	0.95	2	3/31/1985	$Q = k\{\Sigma(C \cdot V) + \Sigma(Ci \cdot Vi)\}^l$	—	11.1,1982 (3 / 31 / 1985 for existing facility)

Q : NO_x emissions volume (m_N^3/h)

C : Facility factor

V : Exhaust gas volume (10,000 m_N^3/h)

W : Fuel consumption (kl/h)

Ci : New/enlarged facility factor

Vi : New/enlarged exhaust gas volume (10,000 m_N^3/h)

Wi : New/enlarged facility fuel consumption (kl/h)

General Emission Standards and Special Emission Standards for Soot and Dust (Regulations attached table No.2, etc.)

Ordinance attached table No.1	Facility Name	Scale (ten thousand m_N^3/h)	General Provisions			Supplementary Provisions		
			General (g/m_N^3)	Special (g/m_N^3)	O_2 (%)	General (g/m_N^3)	Special (g/m_N^3)	Treatment of O_2
1	Gas boiler	above 20 4 to 20 under 4 Small size boiler	0.05 0.10	0.03 0.05	5 5 5	Controls do not apply for the time being	Controls do not apply for the time being	
1	Heavy oil and gas/ liquid mixing boiler	above 20 4 to 20 1 to 4 under 1 Small size boiler	0.05 0.15 0.25 0.30 0.30	0.04 0.05 0.15 0.15	4 4 4 4	Exiting facility is 0.07 for the time being. Exiting facility is 0.18 for the time being. (As for the kerosene, light oil or heavy oil used, controls do not apply for the time being. Exiting facility is not applied for the time being. The facility installed up to September 10, 1990 is 0.50.)	(As for the kerosene, light oil, or heavy oil used, controls do not apply for the time being. Exiting facility is not applied for the time being. The facility installed up to September 10, 1990 is 0.30.)	Application is postponed for the time being.
1	Black liquor combustion boiler	above 20 4 to 20 under 4 Small size boiler	0.15 0.25 0.30 0.30	0.10 0.15 0.15	O_2 O_2 O_2 O_2	Exiting facility is 0.20 for the time being. Exiting facility is 0.35 for the time being. (The facility installed is not applied for the time being. The facility installed up to September 10, 1990 is 0.50.)	(Exiting facility is not applied for the time being. The facility installed up to September 10, 1990 is 0.30.)	
1	Coal combustion boiler	above 20 4 to 20 under 4 Small size boiler	0.10 0.20 0.30 0.30	0.05 0.10 0.15 0.15	6 6 6 6	Exiting facility is 0.15 for the time being. Exiting facility is 0.25 for the time being. Exiting facility is 0.35 for the time being. (The facility installed is not applied for the time being. The facility installed up to September 10, 1990 is 0.50.)	The facility installed up to September 10, 1990 is 0.30.	
1	Catalyze regeneration tower of covering equipment attached boiler	— Small size boiler	0.20 0.20	0.15 0.15	4 4	Exiting facility is 0.30 for the time being. (Exiting facility is not applied for the time being. The facility installed up to September 10, 1990 is 0.50.)	(The facility installed is not applied for the time being. The facility installed up to September 10, 1990 is 0.30.)	
1	Coal combustion boiler (calorific value 5,000kcal or less)	—	—	—	—	Exiting facility is 0.70 for the time being.		Application is postponed for the time being.
1	Other boiler	above 20 4 to 20 under 4 Small size boiler	0.30 0.30	0.15 0.20 0.20	6 6 6	Exiting facility is 0.40 for the time being. (Exiting facility is not applied for the time being. The facility installed up to September 10, 1990 is 0.50.)	(Exiting facility is not applied for the time being. The facility installed up to September 10, 1990 is 0.30.)	Application is postponed for the time being.
2	Gas generating furnace	—	0.05	0.03	7			
2	Heating furnace	—	0.10	0.03	7			
13	Waste material continuous incinerator	above 4 under 4	0.15 0.50	0.08 0.15	12 12			Application is postponed for the time being.
13	Other waste material continuous incinerator	—	0.50	0.25	12			Application is postponed for the time being.
28	Coke furnace	—	0.15	0.10	7			

Note: 1. The special emission standards shall be applied for the following regions.

(1)Tokyo (special wards) (2)Kanagawa Pref. (Yokohama, Kawasaki, and Yokosuka cities) (3)Aichi Pref. (Nagoya, Tokai, and Chita cities, and part of Kaifu-gun) (4)Mie Pref. (part of Yokkaichi city, Kusunoki-cho, Asahi-cho, and Kawagoe-cho in Mie-gun) (5)Osaka (Osaka, Sakai, Toyonaka, Suita, Izumi-Otsu, Moriguchi, Hirakata, Yao, Neyagawa, Matsubara, Daito, Monma, Settsu, Takaishi, Higashi-Osaka, Shijonawate, Katano, and Senboku cities) (6)Hyogo Pref. (part of Kobe city, Amagasaki, Nishinomiya, Ashiya, and Itami cities, part of Takarazuka and Kawanishi cities) (7)Okayama Pref. (Part of Kurashiki city) (8)Fukuoka Pref. (Kita-kyushu and Omuta cities)

27-11 Waste Water Standards (Summary)

[Waste water standards designated by the Order of the Prime Minister's Office
Order No.35 of the Prime Minister's Office on June 21, 1971.
Latest Amendment: Order No.3 of the Prime Minister's Office on January 13, 1997.]

Toxic Substances

① The target factory or business site
All specified business site (included specified facility of specified area)

② Effluent standards of toxic substances (Attached table No. 1 of Discharge of effluent standards designated by Order of the Prime Minister's Office.)

Type of Toxic Substances	Permissible Limits
Cadmium and its Compounds	Cadmium 0.1mg/l
Cyanide compounds	Cyanide 1mg/l
Organic phosphorous compounds (parathion, methyl parathion, methyl dimethone and EPN only)	1mg/l
Lead and its compounds	Lead 0.1mg/l
Sexivalent chrome compounds	Sexivalent chrome 0.5mg/l
Arsenic and its compounds	Arsenic 0.1mg/l
Mercury, alkyl mercury, and other mercury compounds	Mercury 0.005mg/l
Alkyl mercury compounds	Not detectable
PCB	0.003mg/l
Trichroloethylene	0.3mg/l
Tetrachroloethylene	0.1mg/l
Dichloromethane	0.2mg/l
Carbon tetrachloride	0.02mg/l
1,2-dichloroethane	0.04mg/l
1,1-dichloroethylene	0.2mg/l
Cis 1,2-dichloroethylene	0.4mg/l
1,1,1-trichloroethane	3mg/l
1,1,2-trichloroethane	0.06mg/l
1,3-dichloropropene	0.02mg/l
Thiram	0.06mg/l
Simazine	0.03mg/l
Thiobencarb	0.2mg/l
Benzene	0.1mg/l
Selenium and its compounds	Selenium 0.1mg/l

Remark:
1 "Not detectable" means that the result is less than the quantity limit of the concerned official approval method when authorizes the pollution state of discharge water by the method of the Director General of the Environment Agency defining based on the Articles 2 of the regulation.
2 The effluent standards about arsenic and its compounds, shall not applied for the time being for the discharge water concerning the business site belonging to the hotel business using the hot spring which is gushing now (Hot Spring Law (Law No.125 in 1948) provisions of Article 2), in case the government ordinance which revised a part of Water Pollution Control Law and Waste Disposal and Public Cleaning Law is enforced (Ordinance No.363 in 1974).

Items Related to Living Environment

① The target factory or business site.
All specified business site (included specified facility and specified area).

② Effluent standards related to living environment (Attached table No.2, of Discharge of effluent standards designated by Order of the Prime Minister's Office.)

Item	Permissible Limits
Hydrogen ion density (hydrogen exponent)	Over 5.8 to 8.6 (included) for those discharged into public water area except for area of the marine. Over 5.0 to 9.0 (included) for those to be discharged into the marine.
Biochemical oxygen demand (unit: mg/l)	160 (Daily average: 120)
Chemical oxygen demand (unit: mg/l)	160 (Daily average: 120)
Suspended solids (unit: mg/l)	200 (Daily average: 150)
Normal hexane extracted substance content (mineral oil content) (unit: mg/l)	5
Normal hexane extracted substance content (animal and vegetable fats content) (unit: mg/l)	30
Phenols content (unit: mg/l)	5
Copper content (unit: mg/l)	3
Zinc content (unit: mg/l)	5
Dissolved iron content (unit: mg/l)	10
Dissolved manganese content (unit: mg/l)	10
Chromium content (unit: mg/l)	2
Fluorine content (unit: kg/l)	15
Number of coliform group (unit: pcs/㎠)	Daily average: 3,000
Nitrogen content (unit: mg/l)	120 (Daily average: 60)
Phosphorous content (unit: mg/l)	16 (Daily average: 8)

Remark:
1 Permissible limits of daily average are defined the average pollution condition for discharge water per day.
2 The volume of the average discharge water per day applies the effluent standards in this table about the discharge water concerning the factory or place of business that is 50m^3 or more.
3 Effluent standard about hydrogen ion concentration and dissolved iron is not applied for the discharge water concerning the factory or business site belongings to the sulfur mining (include mining which work a mine sulfur coexist with iron sulfide)
4 Effluent standard about hydrogen ion concentration, copper, zinc, dissolved iron, dissolved manganese, chromium and fluorine is not applied for the time being for discharge water concerning the business site belonging to the hotel business using the hot spring which is gushing now, in case the government ordinance which revised a part of Water Pollution Control Law and Waste Disposal and Public Cleaning Law is enforced.
5 Effluent standard about biochemical oxygen demand apply to only effluent discharge water for public water excluding costal water and lakes and marshes, and effluent standard about chemical demand oxygen apply to only effluent discharge water for costal and lakes and marshes.
6 Effluent standards about a nitrogen content apply the lake and marshes which the Director General of the Environment Agency specify as lake and marshes with a possibility that nitrogen may bring remarkable multiplication of lake-and-mashes phytoplankton, and the coastal water (that to which it is lake and mashes and the chlorine ion content of water exceeds 9000mg per l is included. it applies as below the same) with a possibility of bring remarkable multiplication of sea phytoplankton. Only within the discharge water discharged by the public water area which flows into the coastal water and these which the Director General of the Environment Agency defines.
7 Effluent standards about a phosphorus content apply the lake and marshes which the Director General of the Environment Agency specify as lake and marshes with a possibility that phosphorus may bring remarkable multiplication of lake-and-mashes phytoplankton, and the coastal water with a possibility of bring remarkable multiplication of sea phytoplankton. Only within the discharge water discharged by the public water bodies which flows into the coastal water and these that the Director General of the Environment Agency defines.

27-12 Regulation Standards for Noise (Summary)

Standards concerning the restrictions of noise generated in specific factories, etc.
The Ministry of Health and Welfare, the Ministry of Agriculture, Forestry and Fisheries, the Ministry of International Trade and Industry and the Ministry of Transport Notification №1 on November 27, 1968.
Latest Amendment: Environment Agency Notification №41 on July 13,1998.

Regulation Standards for Factory Nise

Time classification Region Classification	Daytime	Morning/Evening	Nighttime
Type 1 region	Over 45dB,less than 50dB	Over 40dB,less than 45dB	Over 40dB,less than 45dB
Type 2 region	Over 50dB,less than 60dB	Over 45dB,less than 50dB	Over 40dB,less than 50dB
Type 3 region	Over 60dB,less than 65dB	Over 55dB,less than 65dB	Over 50dB,less than 55dB
Type 4 region	Over 65dB,less than 70dB	Over 60dB,less than 70dB	Over 55dB,less than 65dB
Remarks	Type 1 region: Regions that must be kept quiet specially to protect the good residential environment. Type 2 region: Regions that are used for residences and must be kept quiet. Type 3 region: Regions used as residential, commercial, and industrial areas, and must be prevented from noises to protect the living environment. Type 4 region: Areas that are used mainly as industrial areas and must be prevented from significant noises to deteriorate the living environment. Daytime : from 7:00 a.m. or 8:00 a.m. to 6:00 p.m., 7:00 p.m. or 8:00 p.m. Morning : from 5:00 a.m. or 6:00 a.m. to 7:00 a.m. or 8:00 a.m. Evening : from 6:00 p.m., 7:00 p.m. or 8:00 p.m. to 9:00 p.m., 10:00 p.m. or 11:00 p.m. Nighttime: from 9:00 p.m., 10:00 p.m. or 11:00 p.m. to next day 5:00 p.m. or 6:00 a.m.		

27-13 Regulation Standards for Vibration (Summary)

Standards concerning the restrictions of the vibration generated in specific factories, etc.
Environment Agency Notification №90 on November 10, 1976.
Latest Amendment: Environment Agency Notification №41 on July 13, 1998.

Regulation Standards concerning with the Specific Factory

Time Classification Region Classification	Daytime	Nighttime
Type 1 region	Over 60 dB, less than 65 dB	Over 55 dB, less than 60 dB
Type 2 region	Over 65 dB, less than 70 dB	Over 60 dB, less than 65 dB
Remarks	Type 1 region: Good residential areas that must be kept quiet specially to protect the environment and residents. Type 2 region: Areas used as residential, commercial and industrial areas concurrently that must be prevented from vibration to protect the living environment, as well as the areas used mainly as Industrial areas that must be prevented from significant vibration to prevent the living environment from the deterioration. Those areas can be divided into two regions (residential and industrial areas) when authorized to be necessary. Daytime : from 5:00 a.m., 6:00 a.m., 7:00 a.m. or 8:00 a.m. to 7:00 p.m., 8:00 p.m., 9:00 p.m. or 10:00 p.m. Nighttime: from 7:00 p.m., 8:00 p.m. or 9:00 p.m. to next day 5:00 p.m., 6:00 a.m., 7:00 a.m. or 8:00 a.m.	

27-14 Regulation Standards for Odor Substances (Summary)

Offensive Odor Control Law Enforcement, Ordinance №207 on May 30, 1972
Latest Amendment: Ordinance №322 on September 8, 1995
Offensive Odor Control Law Enforcement Regulation, Prime Minister's Office Ordinance №39 on May 30, 1972
Latest Amendment: Order №62 of the Prime Minister's Office on December 15, 1997

Regulation Standards on the Boundary Line of the Site

Substance	Regulation standard (ppm)
Ammonia	Over 1 and less than 5
Methyl mercaptan	Over 0.002 and less than 0.01
Hydrogen sulfide	Over 0.02 and less than 0.2
Methyl disulfide	Over 0.01 and less than 0.2
Dimethyle sulfide	Over 0.009 and less than 0.1
Trimethylamine	Over 0.005 and less than 0.07
Acetaldehyde	Over 0.05 and less than 0.5
Propion aldehyde	Over 0.05 and less than 0.5
N-Butyraldehyde	Over 0.009 and less than 0.08
Isovaleraldehyde	Over 0.02 and less than 0.2
N-Valericaldehyde	Over 0.009 and less than 0.05
Isovaleraldehyde	Over 0.003 and less than 0.01
Isobutyl alcohol	Over 0.9 and less than 20
Ethyl acetate	Over 3 and less than 20
Methyl isobutyl keton	Over 1 and less than 6
Toluene	Over 10 and less than 60
Styrene	Over 0.4 and less than 2
Xylene	Over 1 and less than 5
Prop ionic acid	Over 0.03 and less than 0.2
Butyric acid	Over 0.001 and less than 0.006
Valeric acid	Over 0.0009 and less than 0.004
Isovaleric acid	Over 0.001 and less than 0.01

Regulation standards at stack outlet

Ammonia, Hydrogen sulfide and Trimethylamine as regulation substance, results obtained by the following equation.

$$q=0.108\times He^2\cdot Cm$$

Where

q : Flow rate of specified offensive odor substance (m_N^3/h)

He : Effective stack height (m)

Cm : Value set as regulation standard at boundary (ppm)

(this formula shall not apply if the effective stack height is less than 5 meters.)

27-15 Environmental Standards for Soil Pollution (Summary)

Environmental Quality Standards for Soil Pollution,
the Environment Agency Notification №46 on August 23,1991.
Latest Amendment: An extra Notification №21 of the Environment
Agency on April 24,1998.

Environmental Quality Standards for Soil Pollution excluding Agricultural Land

Substance	Target level of soil quality examined through leaching test and content test	Remarks
Cadmium	0.01 mg/l or less in sample solution	1. The concentration of the sample solution of cadmium, lead, sexivalent chrome, arsenic, total mercury, and selenium shall be 0.03 mg, 0.03 mg, 0.15 mg, 0.03 mg, 0.0015 mg and 0.03 mg if the polluted soil is separated from the underground water level and the each concentration of those materials in the underground water not exceed 0.01 mg/l, 0.01 mg/l, 0.05 mg/l, 0.01 mg/l, 0.0005 mg/l and 0.01 mg/l. 2. Organic phosphorous means parathion, methylparathion, methyldimethone, and EPN.
Total cyanogens	Not detectable in sample solution	
Organic phosphorus	Not detectable in sample solution	
Lead	0.01 mg/l or less in sample solution	
Sexivalent chrome	0.05 mg/l or less in sample solution	
Arsenic	0.01 mg/l or less in sample solution	
Total mercury	0.0005 mg/l or less in sample solution	
Alkyl mercury	Not detectable in sample solution	
PCB	Not detectable in sample solution	
Dichloromethane	0.02 mg/l or less in sample solution	
Tetra chloromethane	0.002 mg/l or less in sample solution	
1,2-Dichloroethane	0.004 mg/l or less in sample solution	
1,1-Dichloroethylene	0.02 mg/l or less in sample solution	
Cis-1,2-Dichloroethylene	0.04 mg/l or less in sample solution	
1,1,1-Trichloroethane	1 mg/l or less in sample solution	
1,1,2-Trichloroethane	0.006 mg/l or less in sample solution	
Trichloroethylene	0.03 mg/l or less in sample solution	
Tetrachloroethylene	0.01 mg/l or less in sample solution	
1,3-Dichloropropene	0.002 mg/l or less in sample solution	
Thiram	0.006 mg/l or less in sample solution	
Simazine	0.003 mg/l or less in sample solution	
Thiobencarb	0.02 mg/l or less in sample solution	
Benzene	0.01 mg/l or less in sample solution	
Selenium	0.01 mg/l or less in sample solution	

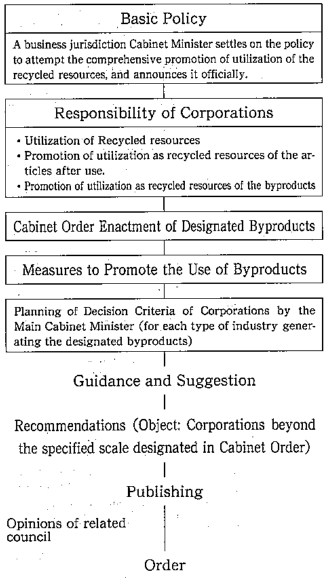
27-16 Law for the Promotion of Utilization of Recycled Resources (Summary)

Law №48 on April 26, 1991
Latest Amendment: Law No. 89 on November 12, 1993

Purpose

While reservation of effective use of resources is aimed at, in order to control of generating of waste and environmental preservation, that take steps for the necessary measures concerning promotion of utilization of recycled resources, and it contributes to sound development of national economy.

Outline of the electric power related to the Law for the Promotion of Utilization of Recycled Resources



Basic Policy

A business jurisdiction Cabinet Minister settles on the policy to attempt the comprehensive promotion of utilization of the recycled resources, and announces it officially.

Responsibility of Corporations

- Utilization of Recycled resources
- Promotion of utilization as recycled resources of the articles after use.
- Promotion of utilization as recycled resources of the byproducts

Cabinet Order Enactment of Designated Byproducts

Measures to Promote the Use of Byproducts

Planning of Decision Criteria of Corporations by the Main Cabinet Minister (for each type of industry generating the designated byproducts)

Guidance and Suggestion

Recommendations (Object: Corporations beyond the specified scale designated in Cabinet Order)

Publishing

Opinions of related council

Order

"Recycled resources": The articles after use or byproducts generated in factories, etc. that can be used as useful resources.

Designated byproducts related to electric power

Kind of byproduct	Business type	Requirement for recommendation, order etc.	Council
Coal ash	Electric power industry	Yearly power supply: 120,000,000 kWh and over	Industrial structure council

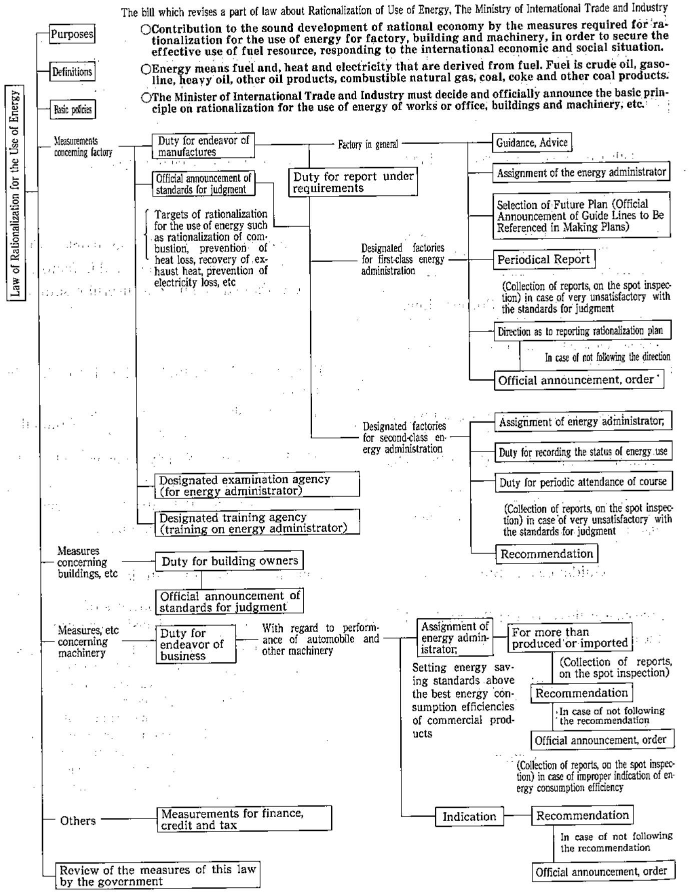
Contents of decision criteria

Kind of byproduct	Type of industry	Contents of decision criteria
Coal ash	Electric power industry	①The ash is processed in accordance with the standard or specification according to the applications. ②Preparation of the coal ashes use plan, documentation of the plan execution progress ③Maintenance of equipment, improvement of the technology, etc.

27-17 Law of Rationalization for the Use of Energy (Summary)

Law No.49 June 22, 1979
Last Revision, Extra Law No.96, June 5, 1998

Outline of the Law of Rationalization for the Use of Energy



The bill which revises a part of law about Rationalization of Use of Energy, The Ministry of International Trade and Industry

○Contribution to the sound development of national economy by the measures required for rationalization for the use of energy for factory, building and machinery, in order to secure the effective use of fuel resource, responding to the international economic and social situation.

○Energy means fuel and, heat and electricity that are derived from fuel. Fuel is crude oil, gasoline, heavy oil, other oil products, combustible natural gas, coal, coke and other coal products.

○The Minister of International Trade and Industry must decide and officially announce the basic principle on rationalization for the use of energy of works or office, buildings and machinery, etc.

27-18 The Atomic Energy Basic Law (Summary)

(December 19, 1955, Law of No. 186)
(Last revision, May 20, 1998 Law No.62)

This law specifies the fundamental idea and organization for the peaceful utilization of the atomic power in Japan. Its objectives are to secure energy resources in the future, to achieve the progress of science and technology and the promotion of industries by encouraging the research, development and utilization of nuclear power and thereby to contribute to the improvement of the welfare of the human society and of the national living standard.

Moreover, democracy, independence, and public presentation of results, so-called 3 principles on the peaceful utilization are herein established as the basic policy. This law also stipulates the establishment of the following organizations. The Atomic Energy Commission, which shall plan, review and decide the national policy on the research, development and utilization of atomic power, Nuclear Safety Commission for the safety of atomic power, Atomic Energy Research Institution for the research and development and Japan Nuclear Cycle Development Institute for the development of nuclear fuel material and fast breeder reactor.

27-19 The Law for Regulations of Nuclear Source Material, Nuclear Fuel Material and Nuclear Reactors (Summary)

(Law No.166, June 10, 1957)
(Last Revision, Law No.75, June 16, 1999)

This Law, in accordance with the spirits of the Atomic Energy Basic Law (Law No. 186, 1955), is enacted for the purposes of providing the necessary regulations on the refining business, the fabricating business, the storage business, the reprocessing business and the waste disposal business, as well as on the establishment and operation of reactors, and also for the purposes of providing necessary regulations on the uses of internationally controlled substances to execute the agreements or other international arrangements concerning the research, development and use of atomic energy, in order to ensure that the uses of nuclear source material, nuclear fuel material and reactors are limited to peaceful uses and carried out in a planned manner, and to ensure the public safety by preventing the hazards due to these materials and reactors.

This law regulates the peaceful uses of atomic power in detail for the businesses of refining, fabricating and storage of nuclear source materials, the installation and operation of reactors and the businesses of reprocessing of spent fuel and nuclear waste disposal. Nuclear facilities and their management are limited to the peaceful use and controlled to secure the maximum safety

This law does not regulate the design, construction method and inspection for commercial power and ship reactors.

Therefore, Electric Utilities Industry Law governs the construction permit and inspection of commercial power reactors.

27-20 Outline of the Ordinance for the Enforcement of the Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Nuclear Reactors

(Cabinet Order №324, November 21, 1957)
(Last Revision, Cabinet Order №321, October 14, 1999)

The Cabinet enacts this Cabinet Order pursuant to the provisions of the Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Nuclear Reactors (Law No. 166, 1957)

Chapter 1 Definitions
Chapter 1-2 Regulations Concerning the Business of Refining and Fabrication
Chapter 2 Regulations Concerning the Establishment, Operation, etc. of Nuclear Reactors
Chapter 2-2 Regulations Concerning the Reprocessing and Disposal Business
Chapter 3 Regulations Concerning the Use of Nuclear Fuel Material, Nuclear Source Material and International Controlled Material
Chapter 4 Miscellaneous Provisions
Chapter 5 Release of Foreign Vessels Subject to Collateral Money, etc
Supplementary Provisions

27-21 Outline of the Special Law of Emergency Preparedness for Nuclear Disaster

(Law of №156, December 17, 1999)

Nuclear Disaster Countermeasures

There are following peculiarities in nuclear disaster those are different from natural disasters, such as earthquake and volcanic eruption, etc.

① Quick and various actions are required for radioactive contamination which cannot be detected by the five senses.
② Special training, equipment, and advice by specialists are required to take effective actions for the disaster.
③ Identification of responsibilities of the nuclear plant operator, who has responsibilities for the accident and has full knowledge about the facility where the accident occurred, is indispensable to prevent expansion of the disaster.

↓

Establishment of The Special Law for the current Disaster Countermeasures Basic Law

1. Assurance for quick initial action and efficient cooperation of national government, prefectures, and municipalities

Speeding up of initial action→
- Imposition of duty to report of nuclear plant operators on unusual events
- The jurisdiction minister starts initial action and immediately establishes the "nuclear disaster countermeasures headquarters "with the prime minister as the director-general, according to the procedure established beforehand.
- Concerned municipalities and prefectures also establish countermeasure headquarters. The national government directs required actions, such as evacuation, etc. to local governments.

Reinforcement of cooperation of the national government and local governments→
- The government establishes "Local Nuclear Disaster Countermeasures Headquarters" on the spot.
- "Nuclear Disaster Joint Committee" shall be established at the Off-Site Center for effective cooperation between countermeasures headquarters of the national government and local governments.
- The implementation of comprehensive disaster countermeasures drills

2. Reinforcement of emergency response organization of the national government, for the particularity of nuclear disasters

Reinforcement of the organization of the national government →
- Legal identification of officers of the national government for prevention of nuclear disaster. They stay at the sites and play a central roll.
- The director-general directs matters required for emergency measures to the related administrate organizations and local governments.
- The director-general asks the Director- General of The Defense Agency for dispatches of self defense forces.
- The minister in charge specifies OFF-Site Center beforehand.
- Grant of legal positioning of technical advice of the Nuclear Safety Commission and the investigation committee members
- Assurance of organization for the quick deployment of various response functions in emergency of nuclear disasters . .

3. Clarification of role in countermeasures of nuclear plant operators in nuclear disaster

Assurance of responsibilities of nuclear plant operators→
- Clarification of the installation duties of radiation measuring instruments at the site, and the duties of the public announcement of the records.
- Clarification of report duties
- Establishment of nuclear plant operator's disaster prevention organization and the implementation of disaster emergency actions.
- Assignment of nuclear disaster response administrators in nuclear plant operators.
- Clarification of the duties of nuclear plant operators to establish the disaster countermeasure plan

Drastic Reinforcement of the Nuclear Safety Regulations

1. Preparation of framework for maintaining severe seriousness (revision of Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Reactors)

○Addition of periodical inspection system for manufacturers
(The implementation of periodical inspection on the performance of the hardware of current facilities of fabrications, just like nuclear reactors and other facilities.)

○Establishment of the inspection system about the observance situation of the safety preservation rules which owners and workers of all enterprises have to keep
(Software inspection for observing the safety preservation rules that each owner and its worker are supposed to keep by the article 22, the article 37 and the article 50, etc. of the present "Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Reactors")

○Placement of nuclear safety preservation inspectors to the major facilities
(Nuclear safety preservation inspectors are assigned on the Ministry of Economy, Trade and Industry. They are engaged in the above -mentioned soft inspection.)

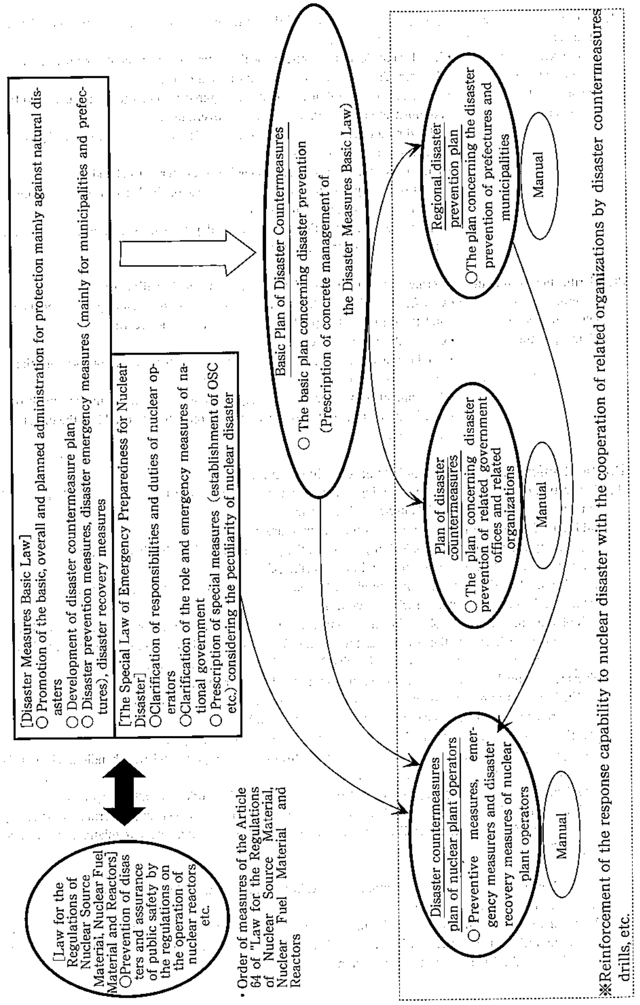
○Clarification of the duties of employee education by all nuclear plant operators
(Imposition of the duties of safety preservation education to the personnel who handle nuclear fuels or operate nuclear reactors of all enterprises)

○Establishment of the safety improvement proposal system by the workers of all enterprises
(Preparation of the environment where personnel can easily notify to licensing government offices by prohibition of disadvantageous disposal when there is a fact of violating safety regulations, etc. at nuclear facilities.)

2. Thorough countermeasures for prevention of criticality at nuclear fuel fabrication facilities, etc

○Measures at safety review
Reexamination of the thoroughness of countermeasures for prevention of criticality and for the time of criticality in nuclear fuel fabrication facilities, etc, based on the review of the on-going accident investigation committee of the Nuclear Safety Commission

Outline of Law related to Nuclear Disaster Prevention



· Basic Plan of Disaster Countermeasures (section of nuclear disaster countermeasures)

【Basic Concept】

As a basis of nuclear disaster countermeasures, measures for all possible situations are made. Furthermore, the flexible organization is prepared so that it can cope with the unpredicted case.

◎ This amendment in response to the enactment of the Special Law of Emergency Preparedness for Nuclear Disaster is to embody the contents of the law further. The main items (what is specified in the law is excluded.) among the matters that embody this law and reflect the accident of JCO are as follows.

Disaster Prevention Measures

【Role of the National Government】

- Preparation of the crisis management manual which prescribes the communication method for all concerned, the decision making method and the response actions on the spot, etc under emergency situation. Maintenance of the related government office's manual which defines the communication method etc.
- Preparation and maintenance of the operation centers that are equipped with required materials and equipments, such as telephone circuits and facsimiles, in the official residence of the prime minister and safety regulations enforcement offices
- Preparation of the manual which defines the contents of activities of officers for prevention of nuclear disaster during emergency, and implementation of the training for nuclear disaster prevention.
- Preparation of transportation plan for specialists and related government officials to the spot of every nuclear facility, after the adjustment with the Defense Agency, etc.

【Role of Local Governments】

- With support of the national government and nuclear plant operators, preparation of sheltering and evacuation guidance plan (with the consideration for the weak)

【Role of Nuclear plant operators】

- Preparation of the function for predicting effects of radioactivity and situation of nuclear facilities, etc.

Emergency Measures

【After Specified Event Generated】

- Notification to the official residence of the prime minister, safety regulations enforcement offices and related local governments, etc with the target of less than 15 minutes after the discovery of specified events 【Business Operators】
- Implementation of initial responses, such as setting-up of the Off-Site Center by officers for prevention of nuclear disaster, and information gathering on the spot by safety preservation inspectors 【The National Government】
- The related government offices share emergency measures activity information and disaster information, etc., by holding the related government offices accident measures liaison conference and the local accident measures liaison conference and center the information to the Off-Site Center as a general rule.
- Reinforcement of monitoring at normal time along with the emergency mustering of personnel and securing of required materials and equipments 【local government】
- Arrangements of the communication to the administrative organizations of the national government by the Ministry of Land, Infrastructure and Transport 【The National Government】

【After the Declaration of Emergency】

- The prime minister establishes nuclear disaster countermeasure headquarters and safety regulations enforcement governmental offices manage it. Dispatch of Parliamentary Vice Minister of the governmental offices as the Director-General of local countermeasures headquarters 【The National government】
- The Director-General of local countermeasures headquarters manages the nuclear disaster joint committee as a leader and, moreover, gathers specialists, such as those of Japan Atomic Energy Research Institute and Japan Nuclear Cycle Development Institute and summarizes the information on the emergency temporary measures by related organizations, and the disaster situation, etc.

- Preparation of the group of a small number of people, in advance, that decides the response measures on the spot
- Preparation of the announcement method to news media on the spot after conferring with news media in advance, and centralization of the press response on the spot to the nuclear disaster joint committee
- Stationing personnel in each groups divided by functions, such as comprehending of the facility situation, monitoring, medical matter and the situation of evacuation and sheltering of the residents, in The Off-Site Center, the local countermeasures headquarters and related organizations share the information.

Disaster Recovery

【Role of the National Government and Local Governments】
- Preparation of organization for health consultation to the residents, etc, public relation activities for reducing the influence of rumor damage, etc. and support measures to the suffered small and medium-sized enterprises and the agriculture, forestry and fishery workers, etc.

【Role of nuclear plant operators】
- Preparation of disaster recovery plan, establishment of the counsel office to claim for compensation etc and loan of materials and equipment necessary for monitoring and decontamination, etc.

Others
- Preparation of transportation plan and manual which prescribe the temporary measures and the role assignment, etc. for the disaster countermeasures of the accident during the transportation of nuclear fuel materials, etc. outside of the place of business
- The response to the nuclear disaster of a nuclear ship shall be noted in the disaster countermeasures plan of local governments.

27-22 Outline of the Ordinance for Establishing the Technical Standards of Nuclear Power Generation Facilities

(Ministry of International Trade and Industry Ordinance No. 62 June 15, 1965)

(Ministry of International Trade and Industry Ordinance No.34: revised finally on March 30,1998)

Article.	Outline
Article. 1	Scope of Application
Article. 4	Installation of Safeguard Facility etc.
Article. 5	Seismic Function
Article. 7	Fence Facility etc.
Article. 8	Reactor Facility
Article. 8-2	Safety System
Article. 9	Materials and Constructions
Article. 14	Thermal Shield
Article. 17	Emergency Core Cooling System
Article. 24-3	Emergency Countermeasure Place in the Nuclear Power Plants
Article. 25	Fuel Storage Facility
Article. 26	Fuel Handling System
Article. 27	Biological Shield Wall
Article. 29	Prevention of Contamination by Radioactive Material
Article. 30	Radioactive Waste Treatment System etc
Article. 31	Radioactive Waste Storage Facility etc.
Article. 32	Reactor Containment Facility etc.

27-23 Outline of the Technical Standards for Structures, etc. of Nuclear Power Generation Facilities

(Ministry of International Trade and Industry Notification No. 501 October 30, 1980)

(Ministry of International Trade and Industry Notification No. 446: last revised July 21, 1994)

(Classification of components, etc.)

Article. 1 Pursuant to the Article 9 of the Ministerial Ordinance to establish Technical Standards on nuclear power generation facilities (Ministry of International Trade and Industry Ordinance No. 62 1965, hereafter, called a "Ministerial Ordinance"), the classifications of vessels, pipes, main pumps, or main valves, (hereafter, called "components"), the main structures (hereafter, called "support structures") which support components, and the structures (hereafter, called "core support structures") which support the fuels in the reactor pressure vessel shall be as follows;

1 Vessels (Class 1 Vessel, Class 2 Vessel, Class 3 Vessel and Class 4 Vessel)
2 Piping (Class 1 Piping, Class 3 Piping, Class 4 Piping and Class 5 Piping)
3 Main Pumps (Class 1 Pump and Class 3 Pump)
4 Main Valves (Class 1 Valve and Class 3 Valve)
5 Support Structures (Class 1 Support Structure, Class 2 Support Structure and Class 3 Support Structure)
6 Core Support Structures

Section	Article	Outline
Section 1 General Provisions	Articles 1 and 2	Classification of components, Definition of terms
Section 2 Class 1 Vessel	Article 3 to Article 12	Materials of Class 1 vessel, Fracture toughness test, Non-destructive test for materials etc. (Table 1)
	Article 13	Limit of stress intensity and allowable stress for materials (Table 2, Table 3, Table 9, Table 10, Table 11, Table 12)
	Article 14 to Article 19−2	Elastic-plastic analysis, Vessel with cladding, Fatigue strength reduction factor, etc. (Table 2, Table 12)
Section 3 Class 2 Vessel	Article 20 and Article 21	Materials of Class 2 vessel, Code for construction of Class 2 vessel (Table 1, Table 4, Table 5)
	Article 22	Shell of vessel (Table 4, Table 5, Table 12)
	Article 23 to Article 29	Head of vessel, Flat head of vessel, Nozzle of vessel, etc. (Table 4, Table 11, Table 14)
Section 4 Class 3 Vessel	Article 30, Article 31	Materials of Class 3 vessel, Code for construction of Class 3 vessel (Table 1, Table 6, Table 7)
	Article 32	Shell of vessel (Table 6, Table 7, Table 12)
	Article 33 to Article 41	Head of vessel, Flat head of vessel, Tube plate of vessel, etc. (Table 6, Table 7, Table 8, Table 11, Table 14)
Section 5 Class 4 Vessel	Article 42 and Article 43	Materials of Class 4 vessel, Code for construction of Class 4 vessel (Table 1, Table 6, Table 7, Table 8, Table 11)
Section 6 Class 1 Piping	Article 44 and Article 45	Materials of Class 1 piping, Code for construction of Class 1 piping (Table 1)
	Article 46	Allowable stress for materials (Table 2, Table 9, Table 11, Table 12)
	Article 47	Elastic-plastic analysis (Table 2, Table 9, Table 11, Table 12)
	Article 48	Stress indices
	Article 49 to Article 53	Figure of piping, etc., Joint of piping, etc. (Table 2, Table 3, Table 6, Table 12, Table 14, Table 16)

Section	Article	Outline
Section 7 Class 3 Piping	Article 54 and Article 55	Materials of Class 3 piping, Code for construction of Class 3 piping (Table 1)
	Article 56	Allowable stress for materials (Table 6)
	Article 57	Stress indices
	Article 58	Figure of piping (Table 6, Table 7, Table 8)
	Article 59 to Article 62	Joint of piping, Openings and reinforcement, Fitting of piping (Table 6, Table 8, Table 11, Table 12, Table 14)
Section 8 Class 4 Piping	Article 63, Article 64	Materials of Class 4 piping, Code for construction of Class 4 piping (Table 1, Table 6, Table 7, Table 8, Table 14, Table 16)
Section 9 Class 5 Piping	Article 65 to Article 69	Materials of Class 5 piping, Code for construction of Class 5 piping, Figure of piping, etc. (Table 1, Table 14, Table 16)
Section 10 Class 1 Pump	Article 70 to Article 73	Materials of Class 1 pump, Code for construction of Class 1 pump, etc. (Table 1, Table 2, Table 6, Table 8, Table 9, Table 10)
Section 11 Class 3 Pump	Article 74 to Article 78	Materials of Class 3 pump, Code for construction of Class 3 pump, etc. (Table 1, Table 14)
Section 12 Class 1 Valve	Article 79 to Article 82	Materials of Class 1 valve, Code for construction of Class 1 valve, etc. (Table 1, Table 2, Table 3, Table 6, Table 9, Table 11, Table 12, Table 13, Table 14, Table 17)
Section 13 Class 3 Valve	Article 83 to Article 85	Materials of Class 3 valve, Code for construction of Class 3 valve, Figure of valve, etc. (Table 1, Table 6, Table 8, Table 13, Table 14, Table 15)
Section 14 Class 1 Support Structure	Article 86 to Article 89	Materials of Class 1 support structure, Code for construction of Class 1 support structure, etc. (Table 1, Table 2, Table 6, Table 8, Table 9, Table 10, Table 11)
Section 15 Class 2 Support Structure	Article 90, Article 91	Materials of Class 2 support structure, Code for construction of Class 2 support structure (Table 1)
Section 16 Class 3 Support Structure	Article 92, Article 93	Materials of Class 3 support structure, Code for construction of Class 3 support structure (Table 1)
Section 17 Core Support Structure	Article 94 to Article 100	Materials of core support structure, Code for construction of core support structure, etc. (Table 1, Table 2, Table 9, Table 10, Table 11, Table 12)
Section 18 Safety Valve etc.	Article 101 to Article 103	Code for Safety valve etc., Vacuum breaker, etc.
Section 19 Pressure Test	Article 104	Pressure test (Table 17)
Section 20 Surveillance, Test Specimen	Article 105	Surveillance test specimen

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Table 3	Design Stress Intensity Values (N/mm^2) for Bolting Materials, for Metal Temperature
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Table 5	Allowable Tensile Stress Values (N/mm^2) for Bolting Materials, for Metal Temperature
Table 6	Allowable Tensile Stress Values (N/mm^2) for Ferrous Materials, for Metal Temperature (Excluding Bolting Materials)
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Table 15	Minimum Thickness (㎜) of Ferrous Valve
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Table 1 Code for Materials used for Construction

Code for Materials	Notation	Classufiction of Components															
		Class 1 Vessel	Class 2 Vessel	Class 3 Vessel	Class 4 Vessel	Class 1 Piping	Class 3 Piping	Class 4 Piping	Class 5 Piping	Class 1 Pump	Class 3 Pump	Class 1 Valve	Class 3 Valve	Class1 Support Structure	Class2 Support Structure	Class3 Support Structure	Core Support Structure
JIS G 3101 (1987) Rolled steels for general structure	S S	–	–	–	○	–	–	○	○	–	–	–	–	○	○	○	–
JIS G 3103 (1987) Carbon steel and molybdenum alloy steel plates for boilers and other pressure vessels	S B	–	–	–	○	–	○	○	–	–	–	–	–	○	○	○	–
JIS G 3106 (1992) Rolled steels for welded structure	S M	–	○	○	○	–	○	○	○	–	○	–	○	○	○	○	–
JIS G 3115 (1990) Steel plates for pressure vessels for intermediate temperature service	S P V	–	○	○	○	–	○	○	–	–	○	–	○	○	○	○	–
JIS G 3118 (1987) Carbon steel plates for pressure vessels for intermediate and moderate temperature service	S G V	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
JIS G 3119 (1987) Manganese-molybdenum and manganese-molybdenum-nickel alloy steel plates for boilers and other pressure vessels	S B V	○	○	○	○	○	○	○	–	○	○	○	○	○	○	○	○
JIS G 3120 (1987) Manganese-molybdenum and manganese-molybdenum-nickel alloy steel plates quenched and tempered for pressure vessels	S Q V	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
JIS G 3126 (1990) Carbon steel plates for pressure vessels for low temperature service	S L A	–	○	○	○	○	○	○	–	○	○	○	○	○	○	○	–
JIS G 3302 (1987) Hot-dip zinc-coated steel sheets and coils	SGC, SGH	–	–	–	–	–	–	–	○	–	–	–	–	–	–	–	–
JIS G 4109 (1987) Chromium-molybdenum alloy steel plates for boilers and pressure vessels	S C M V	–	–	–	○	–	○	○	–	–	–	–	–	○	○	○	–
JIS G 3601 (1989) Stainless-clad steels		–	–	○	○	–	–	–	–	–	–	–	–	–	–	–	–
JIS G 3602 (1986) Nickel and nickel alloy clad steels		–	–	○	○	–	–	–	–	–	–	–	–	–	–	–	–
JIS G 3603 (1986) Titanium clad steels		–	–	○	○	–	–	–	–	–	–	–	–	–	–	–	–
JIS G 3604 (1986) Copper and copper alloy clad steels		–	–	○	○	–	–	–	–	–	–	–	–	–	–	–	–
JIS G 4051 (1979) Carbon steels for machine structural use	S－C	–	○	○	○	–	○	○	○	○	○	○	○	○	○	○	–
JIS G 4102 (1979) Nickel chromium steels	S N C	–	○	○	○	–	○	○	–	○	○	○	○	○	○	○	–
JIS G 4103 (1979) Nickel chromium molybdenum steels	S N C M	–	○	○	○	–	○	○	○	○	○	○	○	○	○	○	–
JIS G 4104 (1979) Chromium steels	S Cr	–	–	–	○	–	–	○	–	–	–	–	–	–	–	–	–
JIS G 4105 (1979) Chromium molybdenum steels	S C M	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	–
JIS G 4107 (1988) Alloy steel bolting materials for high temperature service	S N B	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	–
JIS G 4108 (1988) Alloy steel bars for special application bolting materials	S N B	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	–
Code for Nuclear Power Generation Alloy steel bolting materials for low temperature service	G B L	–	○	○	○	○	○	○	○	○	○	○	○	○	○	○	–
Code for Nuclear Power Generation Alloy steel nut materials for high temperature and high pressure service	G N H	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	–
JIS G 3201 (1988) Carbon steel forgings for general use	S F	–	○	○	○	○	○	○	○	○	○	○	○	○	○	○	–
JIS G 3202 (1988) Carbon steel forgings for pressure vessels	S F V C	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
JIS G 3203 (1988) Alloy steel forgings for pressure vessels for high temperature service	S F V A	–	–	○	○	○	○	○	○	–	○	○	○	○	○	○	–
JIS G 3204 (1988) Quenched and tempered alloy steel forgings for pressure vessels	S F V Q	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Code for Nuclear Power Generation Alloy steel forgings	G S T H	–	–	○	○	–	○	○	–	–	–	–	–	–	–	–	–
Code for Nuclear Power Generation Carbon steel forgings for low temperature service and alloy steel forgings for low temperature service	G L F	–	–	○	○	○	○	○	–	○	○	○	○	○	○	○	–

Table 1 (continued)

Code for Materials	Notation	Classification of Components															
		Class 1 Vessel	Class 2 Vessel	Class 3 Vessel	Class 4 Vessel	Class 1 Piping	Class 3 Piping	Class 4 Piping	Class 5 Piping	Class 1 Pump	Class 3 Pump	Class 1 Valve	Class 3 Valve	Class1 Support Structure	Class2 Support Structure	Class3 Support Structure	Core Support Structure
JIS G 3444 (1988) Carbon steel tubes for general structural purposes	S T K	–	–	–	–	–	–	–	–	–	–	–	–	○	○	○	–
JIS G 3445 (1988) Carbon steel tubes for machine structural purposes	S T K M	–	–	–	–	–	–	–	–	–	–	–	–	○	○	○	–
JIS G 3452 (1988) Carbon steel pipes for ordinary piping	S G P	–	–	–	○	–	–	○	○	–	–	–	–	○	–	○	–
JIS G 3454 (1988) Carbon steel pipes for pressure service	S T P G	–	–	–	○	–	–	○	○	–	–	–	–	○	○	○	–
JIS G 3455 (1988) Carbon steel pipes for high pressure service	S T S	○	○	○	○	○	○	○	○	–	○	–	○	○	○	○	–
JIS G 3456 (1988) Carbon steel pipes for high temperature service	S T P T	–	○	○	○	–	○	○	○	○	○	○	○	○	○	○	–
JIS G 3457 (1988) Arc welded carbon steel pipes	S T P Y	–	–	–	○	–	–	○	–	–	–	–	–	–	–	–	–
JIS G 3458 (1988) Alloy steel pipes	S T P A	○	○	○	○	○	○	○	–	○	○	○	○	○	○	○	○
JIS G 3460 (1988) Steel pipes for low temperature service	S T P L	○	○	○	○	○	○	○	–	○	○	○	○	○	○	○	○
JIS G 3461 (1988) Carbon steel boiler and heat exchanger tubes	S T B	–	○	○	○	○	○	○	–	–	–	–	–	○	○	○	–
JIS G 3462 (1988) Alloy steel boiler and heat exchanger tubes	S T B A	–	○	○	○	○	○	○	–	–	–	–	–	–	–	–	–
JIS G 3466 (1988) Carbon steel square pipes for general structural purposes	S T K R	–	–	–	–	–	–	–	○	–	–	–	–	○	○	○	–
JIS G 5526 (1989) Ductile iron pipes (D)	D	–	–	–	–	–	–	○	–	–	–	–	–	○	○	○	–
Code for Nuclear Power Generation Carbon steel pipes for low temperature service	G S T P L	○	○	○	○	○	○	○	–	○	○	○	○	○	○	○	–
JIS G 5101 (1991) Carbon steel castings	S C	–	–	–	○	–	–	○	–	–	○	–	○	–	–	–	–
JIS G 5102 (1991) Steel castings for welded structure	S C W	–	–	○	○	–	○	○	–	–	○	–	○	–	–	–	–
JIS G 5151 (1991) Steel castings for high temperature and high pressure service	S C P H	–	○	○	○	–	○	○	–	○	○	○	○	–	–	–	–
JIS G 5152 (1991) Steel castings for low temperature and high pressure service	S C P L	–	○	○	○	–	○	○	–	○	○	○	○	–	–	–	–
JIS G 5202 (1991) Centrifugally cast steel pipes for high temperature and high pressure service	SCPH－CF	–	–	–	–	–	○	○	–	–	–	–	–	–	–	–	–
Code for Nuclear Power Generation Carbon steel castings	G S C	○	○	○	○	○	○	○	–	○	○	○	○	○	○	○	○
JIS G 5502 (1989) Spherical graphite iron castings	F C D	–	–	–	–	–	–	○	–	–	–	–	–	○	○	○	–
JIS G 5702 (1988) Blackheart malleable iron castings	F C M B	–	–	–	○	–	–	○	–	–	–	–	–	○	○	○	–
JIS G 5703 (1988) White heart malleable iron castings	F C M W	–	–	–	○	–	–	○	–	–	–	–	–	–	–	–	–
JIS G 5704 (1988) Paralytic malleable iron castings	F C M P	–	–	–	○	–	–	○	–	–	–	–	–	–	–	–	–
JIS G 3214 (1988) Stainless steel forgings for pressure vessels	S U S F	○	○	○	○	○	○	○	○	○	○	○	○	–	–	–	○
JIS G 3446 (1988) Stainless steel pipes for machine and structural purposes	SUS－TK	–	–	–	–	–	–	–	–	–	–	–	–	○	○	○	○
JIS G 3459 (1988) Stainless steel pipes	SUS－TP	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
JIS G 3463 (1988) Stainless steel boiler and heat exchanger tubes	SUS－TB	○	○	○	○	○	○	○	○	○	○	○	○	–	–	–	○
JIS G 3468 (1988) Large diameter welded stainless steel pipes	SUS－TPY	–	–	–	–	○	○	○	○	–	–	–	–	–	–	–	–
JIS G 4303 (1991) Stainless steel bars	S U S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
JIS G 4304 (1987) Hot rolled stainless steel plates, sheets and strip	S U S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
JIS G 4305 (1991) Cold rolled stainless steel plates, sheets and strip	S U S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
JIS G 4309 (1988) Stainless steel wires	S U S	–	–	–	–	–	–	–	–	–	–	–	–	○	–	○	–
JIS G 4317 (1991) Hot rolled stainless steel equal leg angles	S U S	–	–	○	○	–	–	–	–	–	–	–	–	–	–	–	–
JIS G 5121 (1991) Stainless steel castings	S C S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Code for Nuclear Power Generation 13 chromium steel forgings and 13 chromium steel bars	G13C R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	○
Code for Nuclear Power Generation Stainless steel bars for high temperature service	G316C W	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	○
Code for Nuclear Power Generation Heat-resisting stainless steel	G X M	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Table 1 (continued)

Code for Materials	Notation	Classification of Components															
		Class 1 Vessel	Class 2 Vessel	Class 3 Vessel	Class 4 Vessel	Class 1 Piping	Class 3 Piping	Class 4 Piping	Class 5 Piping	Class 1 Pump	Class 3 Pump	Class 1 Valve	Class 3 Valve	Class1 Support Structure	Class2 Support Structure	Class3 Support Structure	Core Support Structure
Code for Nuclear Power Generation Corrosion-resisting stainless steel castings	GSCS16	—	—	○	○	—	○	○	○	—	○	—	○	—	—	○	—
Code for Nuclear Power Generation Corrosion-resisting stainless steel forgings	GSUS317HL	—	—	○	○	—	—	—	—	—	○	—	○	—	—	○	—
JIS G 4311 (1991) Heat-resisting steel bars	SUH	○	—	—	—	—	—	—	—	○	○	○	○	—	—	—	○
JIS G 4901 (1991) Corrosion-resisting and heat-resisting super alloy bars	NCF	○	○	○	○	○	○	○	—	—	—	—	—	—	—	—	○
JIS G 4902 (1991) Corrosion-resisting and heat-resisting super alloy plates and sheets	NCF	○	○	○	○	○	○	○	—	—	—	—	—	—	—	—	○
JIS G 4903 (1991) Seamless nickel-chromium-iron alloy pipes	NCF−TP	○	○	○	○	○	○	○	—	—	—	—	—	—	—	—	○
JIS G 4904 (1991) Seamless nickel-chromium-iron alloy heat exchanger tubes	NCF−TB	○	○	○	○	○	○	○	—	—	—	—	—	—	—	—	—
Code for Nuclear Power Generation Corrosion-resisting and heat-resisting alloy steel	GNCF	—	—	—	○	—	—	○	—	—	—	—	—	—	—	—	—
Code for Nuclear Power Generation Nickel-chromium-iron alloy 690	GNCF690H, GNCF690C, GNCF690HYS	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
JIS H 3100 (1986) Copper and copper alloy sheets, plates and strips	CXXXXP, PP,R	—	—	○	○	—	—	○	○	—	—	—	—	—	—	—	—
JIS H 3250 (1986) Copper and copper alloy rods and bars	CXXXXBD, BDS,BE,BF	—	—	○	○	—	—	○	○	—	—	—	—	○	○	○	—
JIS H 3300 (1986) Copper and copper alloy seamless pipes and tubes	CXXXXT, TS	—	—	○	○	—	—	○	○	—	—	—	—	—	—	—	—
JIS H 4000 (1982) Aluminum and aluminium alloy sheets and plates, strips and coiled sheets	AXXXXP, PC	—	—	—	○	—	—	○	—	—	—	—	—	—	—	—	—
JIS H 4040 (1982) Aluminum and aluminum alloy rods, bars and wires	AXXXXBE, BES,BD, BDS,W,WS	—	—	—	○	—	—	○	—	—	—	—	—	—	—	—	—
JIS H 4080 (1982) Aluminum and aluminum alloy seamless pipes and tubes	AXXXXTE, TES,TD, TDS	—	—	—	○	—	—	○	—	—	—	—	—	—	—	—	—
JIS H 4551 (1991) Nickel and nickel alloy plate, sheet and strip	NCuP	—	—	○	○	—	—	○	—	—	—	—	—	—	—	—	—
JIS H 4552 (1991) Nickel and nickel alloy seamless pipes and tubes	NCuT	—	—	○	○	—	—	○	—	—	—	—	—	—	—	—	—
JIS H 4600 (1988) Titanium sheets, plates and strips	TP, TR	—	—	○	○	—	—	○	—	—	—	—	—	—	—	—	—
JIS H 4630 (1988) Titanium pipes for ordinary piping	TTP	—	—	○	○	—	—	○	—	—	—	—	—	—	—	—	—
JIS H 4631 (1988) Titanium tubes for heat exchangers	TTH	—	—	○	○	—	—	○	—	—	—	—	—	—	—	—	—
JIS H 4650 (1986) Titanium rods and bars	TB	—	—	○	○	—	—	○	—	—	—	—	—	—	—	—	—
JIS H 5111 (1988) Bronze castings	BC	—	—	—	—	—	—	○	○	—	—	—	—	○	—	○	—

27-24 Notification for Equivalent Radiation Dose Rate Limits, etc. based on the Provisions of Rules for the Installation, Operation, etc. of Commercial Nuclear Power Reactors (Summary)

(Notification No. 131 by Ministry of International Trade and Industry on March 27, 1989)
(Final Revision: Notification No. 283 by Ministry of International Trade and Industry on June 27, 1993)

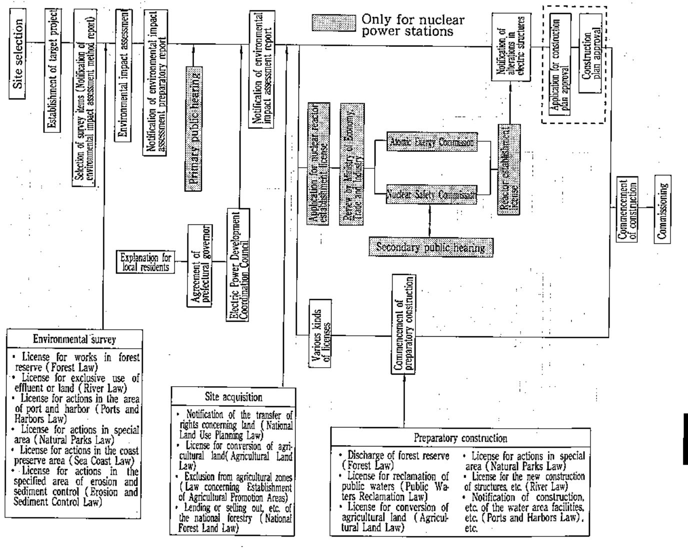
It is provided based on Rules for the Installation, Operation, etc. of Commercial Nuclear Power Reactors (Ordinance No.77 by Ministry of International Trade and Industry in 1978), and it regulates the equivalent radiation dose rate limits in the radiation controlled areas and the equivalent dose rate limits and the concentration limits of radioactive materials outside of peripheral monitoring area, etc.

These all are in accordance with "Notification for Equivalent Radiation Dose Rate Limits, etc. based on the Provisions of Rules for the Installation, Operation, etc. of Commercial Nuclear Power Reactors"" (Notification No. 131 by Ministry of International Trade and Industry on March 27, 1989)

27-25 Application Procedures and Related Laws and Regulations

(1) Procedures of Siting of Power Stations

Note) Notification for thermal power stations

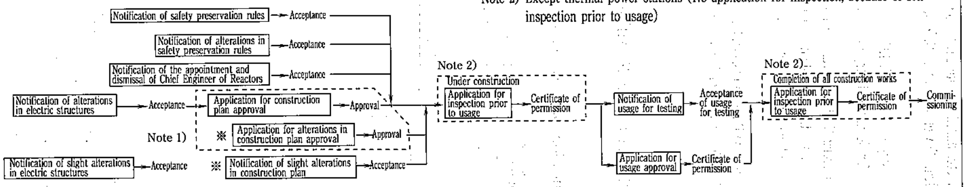


〔Source: The Thermal and Nuclear Power P.117, April 1998〕

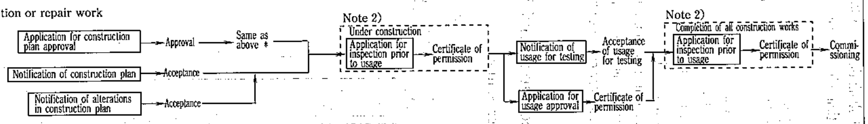
(2) Formalities concerning Construction, etc. of the Power Station

Note 1) Notification for thermal power stations
Note 2) Except thermal power stations (No application for inspection, because of self inspection prior to usage)

1. In case of new construction or enlargement of the power station



2. In case of renovation or repair work



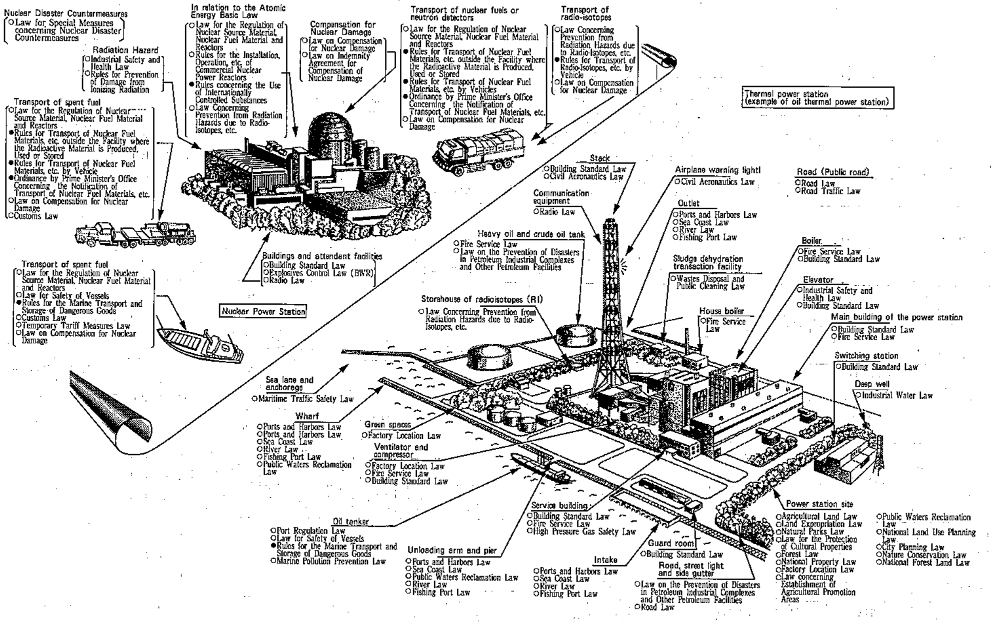
3. Other applications, notifications, reports, etc.

(1) Application Application for periodic inspection (For only nuclear power stations) Safety management review (prior to usage or periodic) (For only thermal power stations) Safety management review (welding inspection)

(2) Notification Notification of alterations in safety preservation rules Notification of the appointment and dismissal of Chief Engineer of Reactors

(3) Report Report of decommissioning or alterations of electric structures for private use Failure report (prompt report, detailed report) Semiannual operating reports of power stations for private use
Notification of soot and smoke (general soot and dust) emitting facility Notification of alterations in soot and smoke (general soot and dust) emitting facility Notification of noise (vibration) specified facility
Notification of decommissioning in soot and smoke (general soot and dust) emitting facility Notification of alterations in name (name, address, name of representative)

(3) Typical Laws applicable to Thermal and Nuclear Power Stations (Other than Electricity Utilities Industry Law)



〔Source: The Thermal and Nuclear Power P.84, Jan. 1991〕

(4) Main Laws and License Matters Related to Thermal and Nuclear Power Stations (other than Electric Utilities Industry Law)

Name of Law	Promulgation		Purpose of Law	Main items being applied to power stations	Main licenses and notifications	Applicable articles	Time of submission	Address	Name of main supervisory ministry or agency, bureau or department
Agricultural Land Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1952/ 7/15 1952/10/20 1952/10/20	Law No.229 Cabinet Order No.445 Ordinance No. 79 of Ministry of Agriculture, Forestry and Fisheries	It is to stabilize the status of cultivators and to raise productivity of agriculture, by facilitating the acquisition of agricultural lands by cultivators, protecting their rights and, for efficient use of land for agriculture, adjusting the utilization of agricultural lands.	①Conversion of agricultural land	①Application of license for conversion of agricultural land (Application to the minister for more than 2 ha, and application to the prefectural governor for less than and equal to 2 ha) ②Application of license for creation/transfer a right/rights on a lot/lots of agricultural land for the purpose of conversion(same as above)	Article 4, Paragraph 1 of the Law Article 4 of the Rules Article 5, Paragraph 1 of the Law Article 6 of the Rules	About three months before for the application to the minister, and about two months before for the application to the prefectural governor	Minister of Agriculture, Forestry and Fisheries Prefecture Governor	Ministry of Agriculture, Forestry and Fisheries Rural Development Bureau
Law concerning Establishment of Agricultural Promotion Areas Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1969/ 7/ 1 1969/ 9/26 1969/ 9/26	Law No.58 Cabinet Order No.254 Ordinance No. 45 of Ministry of Agriculture, Forestry and Fisheries	It is to promote the measures systematically for agricultural development in the areas where agriculture should be promoted, and promote the sound development of agriculture.	①Restriction of development actions in the designated areas	①Application for exclusion from agricultural zones	15 of Article 15 of the Law Article 34 of the Rules	At the time of Planning	Prefecture Governor	Ministry of Agriculture, Forestry and Fisheries
Land Expropriation Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1951/ 6/ 9 1951/10/27 1951/10/27	Law No.219 Cabinet Order No.342 Ordinance No.33 by Ministry of Construction	It is to regulate the matters concerning expropriation or use of public land, and contribute to the aptitude and rational usage of national land.	①Site acquisition	①Application for authorization of business ②Application for decision of expropriation	Articles 16 and 18 of the Law Articles 2 and 3 of the Rules Article 40 of the Law Articles 16 and 17 of the Rules	About three months before	Minister of Land, Infrastructure and Transport or Prefecture Expropriation Committee	Policy Bureau of Ministry of Land, Infrastructure and Transport
Public Waters Reclamation Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1921/ 4/ 9 1922/ 4/ 8 1974/ 3/18	Law No.57. Imperial Order No.194 Ordinance No. 1 by Ministry of Transport and Ministry of Construction	It is to regulate the matters concerning the reclamation of public waters.	①Reclamation work	①Application for license of public waters reclamation	Article 2 of the Law Article 1 and 2 of the Rules	At the time of Planning	Prefecture Governor	River Bureau of Ministry of Land, Infrastructure and Transport Ports and Harbors Bureau of Ministry of Land, Infrastructure and Transport
National Property Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1948/ 6/30 1948/ 8/20 1948/ 9/28	Law No.73 Cabinet Order No.246 Ordinance No. 92 by Ministry of Finance	It is to regulate the acquisition, maintenance and disposing of national property.	①Selling out of national property ②Lending of national property	①Application for the disposal or borrowing of national property	Article 20, Paragraph 1 of the Law	At the time of Planning	Minister of Finance	Financial Bureau of Ministry of Finance
Forest Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1951/ 6/26 1951/ 7/31 1951/ 8/ 1	Law No.219 Cabinet Order No.276 Ordinance No. 54 of Ministry of Agriculture, Forestry and Fisheries	It is to contribute to the conservation of national land and development of national economy by establishing the basic matters concerning forest such as forest plan or forest reserve, etc.	①Deforestation	①Application for the dissolution of forest reserve (in case of permanent facility) ②Application for the work in forest reserve ③Application of license for cutting down the trees in forest reserve	Article 27, Paragraph 1 of the Law Article 17 of the Rules Article 34, Paragraph 2 of the Law 9 of Article 22 of the Rules Article 34, Paragraph 1 of the Law 6 of Article 22 of the Rules 2 of Article 4 of the Ordinance	At the time of Planning No later than thirty days prior to the beginning of work	Minister of Agriculture, Forestry and Fisheries Prefecture Governor	Ministry of Agriculture, Forestry and Fisheries Forestry Agency
Road Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1952/ 6/10 1952/12/ 4 1952/ 8/ 1	Law No.180 Cabinet Order No.479 Ordinance No.25 by Ministry of Construction	It is to regulate the matters concerning designation, finding, management, structure, maintenance and cost sharing, etc. and promote the public welfare.	①For exclusive use of road for construction ②Road construction	①Application of license for exclusive use of road for construction ②Application of license for road construction	Article 32 of the Law 2 of Article 4 of the Rules Article 24 of the Law	At the time of Planning	Road supervisor (Minister or Governor)	Road Bureau of Ministry of Land, Infrastructure and Transport

Name of Law	Promulgation		Purpose of Law	Main items being applied to power stations	Main licenses and notifications	Applicable articles	Time of submission	Address	Name of main supervisory ministry or agency, bureau or department
Road Traffic Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1960/ 6/25 1960/10/11 1960/12/ 3	Law No.105 Cabinet Order No.270 Ordinance No. 60 by Prime Minister's Office	It is to contribute to the prevention of affection due to road traffic, preventing risks on the road and promoting traffic safety.	①Traffic restriction ②Blockage	①Application of license for usage of road	Article 77 of the Law Article 78 of the Law Article 10 of the Rules	About one month before	Head of the Jurisdictional Police Station	National Public Safety Commission of Cabinet Office Traffic Bureau of National Police Agency
National Forest Land Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1951/ 6/23 1954/ 6/ 1 1951/ 6/23	Law No.246 Cabinet Order No.121 Ordinance No. 40 of Ministry of Agriculture, Forestry and Fisheries	It is to aim at the maintenance of the national forest land.	①Site acquisition	①Application of buying, borrowing and usage of the national forest land	Articles 7 and 8 of the Law Articles 14 and 22 of the Rules	At the time of Planning	Head of District Forest Office (Head of Regional Forest Office for the application of buying)	Ministry of Agriculture, Forestry and Fisheries
National Land Use Planning Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1974/ 6/25 1974/12/20 1974/12/21	Law No.92 Cabinet Order No.387 Ordinance No. 72 by Prime Minister's Office	It is to adjust the land use regulating the necessary matters concerning the decision of national land use planning.	①Site acquisition (in the restricted area)	①Application of license for the transfer of rights, etc. for land	Article 14, Paragraph 1 of the Law	At the time of Planning	Prefecture Governor	Land and Water Bureau of Ministry of Land, Infrastructure and Transport
Ports and Harbors Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1950/ 5/31 1951/ 1/19 1951/11/22	Law No.218 Cabinet Order No.4 Ordinance No. 98 by Ministry of Transport	It is to promote the development and preservation of shipping lane together with the orderly maintenance and proper operation of ports and harbors.	①Construction work in ports and harbors ②Facilities for unloading oil or coal	①Application of license for (exclusive use for) the construction work, etc. in the areas of ports and harbors ②Notification of actions in the areas of ports and harbors ③Application of license for (exclusive use for) development and maintenance on the sea lane ④Application of license for (exclusive use for) construction and improvement of facilities, etc. in the water area ⑤Notification of (alterations for) construction and improvement of facilities, etc. in the water area	Article 37 of the Law Article 38, Paragraph 2 of the Law Article 43, Paragraph 8 of the Law Article 56 of the Law Article 56, Paragraph 3 of the Law	No later than sixty days prior to the beginning of construction	Head of Port and Harbor Supervisor Minister of Land, Infrastructure and Transport Prefecture Governor	Ports and Harbors Bureau of Ministry of Land, Infrastructure and Transport
Fishing Port Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1950/ 5/ 2 1950/ 7/28 1951/ 7/17	Law No.137 Cabinet Order No.239 Ordinance No.47 of Ministry of Agriculture, Forestry and Fisheries	It is to adjust and maintain the fishing port properly for development of fisheries.	①Construction in the area of fishing port	①Application of license for the construction of structures in the area of fishing port (Attachment of opinion of the fishing port supervisor)	Article 39, Paragraph 1 of the Law	At the time of Planning	Minister of Agriculture, Forestry and Fisheries	Ministry of Agriculture, Forestry and Fisheries
Sea Coast Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1956/ 5/12 1956/11/ 7 1956/11/10	Law No.101 Cabinet Order No.332 Ordinance No.1 by Ministry of Agriculture, Forestry and Fisheries, Ministry of Construction and Ministry of Transport	It is to protect the seacoast from the damage by tidal wave, high tide, seawater or ground fluctuation.	①Intake facilities Outlet facilities	①Application of license for exclusive use of the sea coast preservation areas ②Application of license for restricted actions in the sea coast preservation areas ③Application for construction approval concerning sea coast preservation facilities	Article 7 of the Law, Article 3 of the Rules Article 8 of the Law Article 4 of the Rules Article 13 of the Law	At the time of Planning	Sea Coast Supervisor	River Bureau of Ministry of Land, Infrastructure and Transport
River Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1964/ 7/10 1965/ 2/11 1965/ 3/13	Law No.167 Cabinet Order No.11 Ordinance No. 7 by Ministry of Construction	It is to promote the preservation of public safety by managing systematically the protection of disaster occurrence by river, and proper usage and function preservation of river.	①Use in the river areas ②Installation of structures in the river areas ③Intake water and drainage ③Dredge work of river	①Application of license for exclusive use of land ②Application of license for (new construction, reconstruction or elimination of) structures ③Application of license for exclusive use of the running water ④Application of license for gathering of river products ⑤Application of license for excavation of land, etc.	Article 24 of the Law, Article 12 of the Rules Article 26 of the Law, Article 15 of the Rules Article 23 of the Law, Article 14 of the Rules Article 25 of the Law, Article 13 of the Rules Article 27 of the Law, Article 16 of the Rules	At the time of Planning	River Supervisor	River Bureau of Ministry of Land, Infrastructure and Transport

Name of Law	Promulgation		Purpose of Law	Main items being applied to power stations	Main licenses and notifications	Applicable articles	Time of submission	Address	Name of main supervisory ministry or agency, bureau or department
Port Regulation Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1948/ 7/ 15 1965/ 6/ 22 1948/ 10/ 9	Law No.174 Cabinet Order No.219 Ordinance No. 29 by Ministry of Transport	It is to promote the safety of vessel traffic in the port and the arrangement in the port.	① Work in the port (in case that involved in navigation) ② Landing work of dangerous objects	① Application of license for construction (work) in the port ② Application of license for loading of dangerous objects (submitted by contractor)	Article 31 of the Law Article 16 of the Rules Article 23 of the Law Article 14 of the Rules	At the time of Planning	Head of Port	Coast Guard of Ministry of Land, Infrastructure and Transport
Maritime Traffic Safety Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1972/ 7/ 3 1973/ 1/ 26 1973/ 3/ 27	Law No.115 Cabinet Order No.5 Ordinance No. 9 by Ministry of Transport	It is to promote the safety of vessel traffic in the sea in which vessel traffic is congested.	① Construction and work on the shipping lane or its adjacent sea areas	① Application of license for construction, etc. on the shipping lane and its adjacent sea areas ② Notification of construction, etc. except the shipping lane and its adjacent sea areas	Article 30, Paragraph 1 of the Law Article 7 of the Order, Article 25 of the Rules Article 31 of the Law Article 27 of the Rules	At the time of Planning	Director-General, Coast Guard	Ministry of Land, Infrastructure
Erosion and Sediment Control Law (Sabo Law) Rules for the Enforcement of the above law	1955/ 3/ 30 1955/ 10/ 26	Law No.29 Imperial Order No.382	It is to restrict the maintenance of facilities and implementation of construction in the designated areas of erosion and sediment control on the river improvement and management.	① Work in the designated areas of erosion and sediment control	① Application of license for the work in the designated areas of erosion and sediment control	Article 4, Paragraph 1 of the Law	At the time of Planning	Prefecture Governor	Ministry of Land, Infrastructure and Transport
Landslide Prevention Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1958/ 3/ 31 1958/ 5/ 7 1958/ 5/ 27	Law No.30 Cabinet Order No.112 Ordinance No.1 by Ministry of Agriculture, Forestry and Fisheries and Ministry of Construction	It is to prevent the damage by landslide and collapse of dirt heap.	① Installation work of structures in the landslide prevention areas ② Restricted actions in the landslide prevention areas	① Application of license for actions in the landslide prevention areas ② Application of license for restricted actions in the landslide prevention areas	Article 11, Paragraph 1 of the Law Article 18 of the Law Articles 4 and 5 of the Order	At the time of Planning	Prefecture Governor	Ministry of Land, Infrastructure and Transport Ministry of Agriculture, Forestry and Fisheries
Living Aquatic Resources Protection Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1951/ 12/ 17 1952/ 6/ 14 1952/ 6/ 16	Law No.313 Cabinet Order No.194 Ordinance No.44 of Ministry of Agriculture, Forestry and Fisheries	It is to cultivate the living aquatic resources and maintain them up to the future.	① Construction of reclamation, dredge, etc. in protection water areas	① Application of license concerning the restriction of construction, etc.	Article 18, Paragraph 1 of the Law	At the time of Planning	Prefecture Governor or Minister of Agriculture, Forestry and Fisheries	Ministry of Agriculture, Forestry and Fisheries
Air Pollution Control Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1968/ 6/ 10 1968/ 11/ 30 1971/ 6/ 22	Law No.97 Cabinet Order No.329 Ordinance No. 1 by Ministry of Health and Welfare	It is to preserve the living environment by controlling emissions of soot and smoke	① Soot and smoke generating facilities concerning sulfur oxides	① Notification of decreasing plan of soot and smoke in an emergency	Article 23, Paragraph 2 of the Law Article 17 of the Rules	Immediately after installation	Prefecture Governor	Ministry of the Environment
Noise Regulation Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1968/ 6/ 10 1968/ 11/ 27 1971/ 6/ 22	Law No.98 Cabinet Order No.324 Ordinance No.1 by Ministry of Health and Welfare, Ministry of Agriculture, Forestry and Fisheries, Ministry of International Trade and Industry, Ministry of Transport and Ministry of Construction	It is to regulate the noise generated by the operation of factories and other types of work sites as well as construction work	① Specified construction work in designated areas	① Notification of undertaking of specified construction work	Article 14, Paragraph 1 of the Law	No later than seven days prior to the beginning of construction	Prefecture Governor	Ministry of the Environment
Vibration Regulation Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1976/ 6/ 10 1976/ 10/ 22 1976/ 11/ 10	Law No.64 Cabinet Order No.280 Ordinance No.58 by Prime Minister's Office	It is to regulate the vibration generated by the operation of factories and other types of work sites as well as construction work	① Specified construction work in designated areas	① Notification of undertaking of specified construction work	Article 14, Paragraph 1 of the Law	No later than seven days prior to the beginning of construction	Prefecture Governor	Ministry of the Environment

Name of Law	Promulgation		Purpose of Law	Main items being applied to power stations	Main licenses and notifications	Applicable articles	Time of submission	Address	Name of main supervisory ministry or agency, bureau or department
Industrial Water Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1956/ 6/ 11 1957/ 6/ 10 1957/ 6/ 29	Law No.146 Cabinet Order No.142 Ordinance. No.22 by Ministry of International Trade and Industry	It is to secure the reasonable supply of industrial water and promote the preservation of underground water source and the prevention of ground subsidence.	① Extraction of underground water in the designated areas	① Application of license for use of well	Article 4, Paragraph 1 of the Law	At the time of Planning	Prefecture Governor	Ministry of Economy, Trade and Industry
City Planning Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1968/ 6/ 15 1969/ 6/ 13 1969/ 8/ 25	Law No.100 Cabinet Order No.153 Ordinance No.49 by Ministry of Construction	It is to promote the sound development and orderly maintenance of the city.	① Siting in the city planning areas	① Application of license for the development in the city planning areas	Articles 29 and 30 of the Law Paragraph No.4 of the Schedule	At the time of Planning	Prefecture Governor	Ministry of Land, Infrastructure and Transport
Nature Conservation Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1972/ 6/ 22 1970/ 3/ 31 1970/ 11/ 9	Law No.55 Cabinet Order No.38 Ordinance No. 62 by Prime Minister's Office	It is to promote comprehensively the appropriate conservation of the natural environment	① Development actions in the conservation areas	① Application of license for actions in wilderness areas ② Application of license for actions in nature conservation areas (special areas and marine special areas)	Article 17, Paragraph 1 of the Law Articles 25 and 27 of the Law	At the time of Planning	Minister of the Environment	Ministry of the Environment, Natural Environment Bureau
Natural Parks Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1957/ 6/ 1 1957/ 9/ 30 1957/ 10/ 11	Law No.161 Cabinet Order No.298 Ordinance No. 41 by Ministry of Health and Welfare	It is to protect the places of scenic beauty and promote the use of them	① Facilities in national parks	① Application of license for the new construction of structures in special zones (special protection zones) ② Application of license for alterations of the land shapes in special zones (special protection zones) ③ Application of license for cutting down the trees and bamboos in special zones (special protection zones)	Article 17 (Article 18) of the Law Article 17 (Article 18) of the Law Article 17 (Article 18) of the Law	At the time of Planning	Minister of the Environment Prefecture governor for quasi-national parks	Ministry of the Environment, Natural Environment Bureau
Law for the Protection of Cultural Properties Ordinance for the Enforcement of the above law Rules concerning the Excavation of Buried Cultural Properties or the Discovery of Relics, etc. Rules concerning Application of License, etc. for Alterations of Present Condition, etc. of National Treasures or Important Cultural Properties	1950/ 5/ 30 1975/ 9/ 9 1954/ 6/ 29 1954/ 6/ 29	Law No.214 Cabinet Order No.267 Rules No.5 by Councilor on Cultural Properties Rules No. 3, same as above	It is to promote the conservation and utilization of cultural properties	① Construction (actions) to alter the present condition of cultural properties	① Application of license for alterations of present condition of important cultural properties, historic sites, scenic spots and natural monuments ② Advance notification of the works in the areas involving buried cultural properties ③ Notification of the discovery of relics	Article 43 and Article 80, Paragraph 1 of the Law 2 of Article 57, Paragraph 1 of the Law 5 of Article 57, Paragraph 1 of the Law	At the time of Planning No later than two months prior to the beginning of construction Without delay	Director-General, Agency for Cultural Affairs	Cultural Properties Protection Department of Agency for Cultural Affairs, Ministry of Education, Science, Sports and Culture
Wildlife Protection and Hunting Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1918/ 4/ 4 1948/ 8/ 31 1950/ 9/ 3	Law No.32 Cabinet Order No.254 Ordinance No.108 of Ministry of Agriculture, Forestry and Fisheries	It is to protect the wildlife and optimize hunting	① Development actions in the wildlife protection areas	① Application of license for actions in the special wildlife protection areas	8 of Article 8, Paragraph 5 of the Law	At the time of Planning	Minister of the Environment or Prefecture Governor	Ministry of the Environment, Natural Environment Bureau

Name of Law	Promulgation		Purpose of Law	Main items being applied to power stations	Main licenses and notifications	Applicable articles	Time of submission	Address	Name of main supervisory ministry or agency, bureau or department
Fire Service Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law Cabinet Order concerning the Regulations for Dangerous Goods Rules concerning the Regulations for Dangerous Goods	1948/ 7/ 24 1961/ 3/ 26 1961/ 4/ 1 1959/ 9/ 26 1959/ 9/ 29	Law No.186 Cabinet Order No.37 Ordinance No.6 by Ministry of Home Affairs Cabinet Order No.306 Ordinance No.55 by Prime Minister's Office	It is to prevent, precaution against and extinguish fire, and decrease the damage by disaster.	① Heavy or light oil tank ② Coal yard ③ Boiler burner surroundings ④ Turbine oil tank ⑤ Other storage facilities of dangerous goods ⑥ Installations for fire fighting	① Application of license for installation of handling facility, storage facility or manufacturing facility of dangerous goods ② Application for the inspection for completion of handling facility, storage facility or manufacturing facility of dangerous goods ③ Application for prevention regulations approval ④ Notification of the appointment of security supervisor for dangerous goods ⑤ Notification of the construction start of the Installations for fire fighting	Article 11, Paragraph 1 of the Law Article 8, Paragraph 1 of the Order Article 11, Paragraph 8 of the Law Article 8, Paragraph 1 of the Order Article 6 of the Rules 2 of Article 14 of the Law Article 13, Paragraph 1 of the Law 14 of Article 17 of the Law 18 of Article 33 of the Rules	At the time of Planning At the time of completion Without delay Without delay when assigned No later than ten days prior to the beginning of construction	Minister of Public Management, Home Affairs, Posts and Telecommunications Prefecture Governor or Mayer	Fire and Disaster Management Agency of Ministry of Public Management, Home Affairs, Posts and Telecommunications
High Pressure Gas Safety Law Ordinance for the Enforcement of the above law Rules for Vessel Safety Rules for Refrigeration Safety Rules for Liquefied Petroleum Gas Safety Rules for General High Pressure Gas Safety	1951/ 6/ 7 1997/ 2/ 19 1966/ 5/ 25 1966/ 5/ 25 1966/ 5/ 25 1966/ 5/ 25	Law No.204 Cabinet Order No.20 Ordinance No.50 by Ministry of International Trade and Industry Ordinance No.51 by Ministry of International Trade and Industry Ordinance No.52 by Ministry of International Trade and Industry Ordinance No.53 by Ministry of International Trade and Industry	It is to regulate manufacture, sales, storage, transfer, handling and consumption of high-pressure gas, and handling and manufacture of its vessel to prevent the disaster by the gas.	① Bomb or tank, etc. ② Freezer ③ Compressed gas (Hydrogen, nitrogen, etc.) ④ Liquefied gas (Ammonia, liquid nitrogen, etc.) * * ElectricUtilities Industry Law is applied to the facility in the thermal power station which is installed after June 1st in 1997.	① Application of license for the manufacture of high pressure gas ② Application for the inspection for completion of manufacturing facility, and notification of the opening of the facility ③ Notification of the supervisor of high pressure gas manufacturing safety, etc., and notification of the deputy supervisor ④ Notification of the starting of high pressure gas manufacture ⑤ Notification of regulations of harm prevention ⑥ Application of establishment license for the first sort and the second sort storages ⑦ Application for the inspection of completion of the first sort storage ⑧ Notification of the consumption of specialized high pressure gas ⑨ Notification of the chief handling person of specialized high pressure gas	Article 5, Paragraph 1 of the Law Articles 20 and 21 of the Law 2, 3, 4 of Article 27 and Article 33 of the Law Article 5, Paragraph 2 of the Law Article 5, Paragraph 2 of the Law Rules No.35 for Refrigeration Article 16, Paragraph 1 of the Law 2 of Article 17 of the Law Article 20 of the Law 2 of Article 24 of the Law Article 28, Paragraph 2 of the Law	At the time of Planning At the time of completion At the time of Planning No later than twenty days prior to the beginning of manufacturing At the time of Planning At the time of Planning At the time of completion No later than twenty days prior to the beginning of consumption At the time of Planning	Prefecture Governor	Ministry of Economy, Trade and Industry Industrial Science and Technology Policy and Environment Bureau
Building Standard Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1950/ 5/ 24 1950/ 11/ 16 1950/ 11/ 16	Law No.201 Cabinet Order No.338 Ordinance No.40 by Ministry of Construction	It is to specify the minimum criteria concerning the site, structure, installation and purpose of the building.	① Buildings (main building, etc. of power generating station) ② Building service facilities other than buildings (electric or gas facilities, etc.) ③ Elevator ④ Structures (stack, outdoor boiler, etc.)	① Application for the architecture validation (buildings, elevators, structures, building service facilities other than buildings) ② Notification of building construction ③ Notification of completion of construction	Article 6, Paragraph 1 of the Law Article 1 of the Rules Article 15, Paragraph 1 of the Law Article 8 of the Rules Article 7, Paragraph 1 of the Law	No later than twenty one days prior to the beginning of construction No later than seven days prior to the beginning of construction for the building facilities No later than twenty one days prior to the beginning of construction Within four days after completion	Building Official Prefecture Governor Building Official	Housing Bureau of Ministry of Land, Infrastructure and Transport
Wastes Disposal and Public Cleaning Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1970/ 12/ 25 1971/ 9/ 23 1971/ 9/ 23	Law No.137 Cabinet Order No.300 Ordinance No.35 by Ministry of Health and Welfare	It is to preserve the living environment through the appropriate disposal of wastes and the conservation of a clean living environment.	① Industrial solid waste treatment facilities (Incinerator, sludge dehydrator, ultimate disposal place, etc.)	① Application of establishment license for waste treatment facility, etc.	Article 15, Paragraph 1 of the Law	No later than thirty days No later than sixty days for the ultimate disposal place	Prefecture Governor	Ministry of the Environment
Radio Law Rules for the Enforcement of the above law	1950/ 5/ 2 1950/ 11/ 30	Law No.131 Rules No.14 by Radio Regulatory Council	It is to assure the fair and efficient usage of radio wave.	① Communication installation ② Propagation obstruction	① Application for the radio station license ② Notification of the completion of radio station construction ③ Notification of appointment of the radio operator ④ Notification of scheduled construction work such as high-rise building, etc.	Article 6 of the Law Article 10 of the Law Article 51 of the Law 3 of Article 102 of the Law	At the time of installation At the time of completion At the time of assignment Prior to the beginning of construction	Minister of Public Management, Home Affairs, Posts and Telecommunications Regional Bureau of Telecommunications	Ministry of Public Management, Home Affairs, Posts and Telecommunications

Name of Law	Promulgation		Purpose of Law	Main items being applied to power stations	Main licenses and notifications	Applicable articles	Time of submission	Address	Name of main supervisory ministry or agency, bureau or department
Industrial Safety and Health Law Ordinance for the Enforcement of the above law Rules for Industrial Safety and Health	1972/ 6/ 8 1972/ 8/ 19 1972/ 9/ 30	Law No.57 Cabinet Order No.318 Ordinance No.32 by Ministry of Labor	It is to promote the systematic measures for harm protection through the establishment of danger protection criteria for industrial accident prevention and the clarification of responsibility organization.	① Industrial accident prevention of labors (representatives of various organizations, supervisor for safety, work classification of various works, eligible, chief of workers)	① Notification of representative of joint venture ② Report of appointment of the generalized safety and health supervisor ③ Report of appointment of the safety supervisor ④ Report of appointment of the health supervisor ⑤ Notification of appointment of the industrial physician ⑥ Notification of appointment of the chief of workers	Article 5 of the Law Article 10 of the Law Article 11 of the Law Article 12 of the Law Article 13 of the Law Article 14 of the Law	No later than fourteen days prior to the beginning of construction Within fourteen days after the occurred date	Director-General, Competent Prefecture Labor Bureau	Labor Standards Bureau of Ministry of Health, Labor and Welfare
Law on the Prevention of Disasters in Petroleum Industrial Complexes and Other Petroleum Facilities Ordinance for the Enforcement of the above law	1975/ 12/ 17 1976/ 5/ 31	Law No.81 Cabinet Order No.129	It Is to promote the prevention of occurrence and expansion of disasters concerning the special disaster prevention areas such as petroleum industrial complexes and other petroleum facilities.	① Installation of the handling facility of fuel storage, etc. ② Work to process the high pressure gas (the first sort business establishment)	① Notification of new construction, etc. of the first sort business establishment ② Notification of completion of new construction, etc. of the first sort business establishment ③ Notification of the special disaster prevention facilities, etc. ④ Notification of appointment of the disaster prevention supervisor ⑤ Notification of installation of the joint disaster prevention organization	Article 5 of the Law Article 11 of the Law Article 15 of the Law Article 17 of the Law Article 19 of the Law	Within ten days after completion of construction in new construction work Within seven days after installation Ditto Ditto	Minister of Economy, Trade and Industry and Minister of Public Management, Home Affairs, Posts and Telecommunications Telecommunications Prefecture Governor or Mayer	Fire and Disaster Management Agency of Ministry of Public Management, Home Affairs, Posts and Telecommunications Ministry of Economy, Trade and Industry Industrial Science and Technology Policy and Environment Bureau
Factory Location Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1959/ 3/ 20 1974/ 2/ 22 1971/ 3/ 29	Law No.24 Cabinet Order No.29 Ordinance No.1 by Ministry of Finance, Ministry of Health and Welfare, Ministry of Agriculture, Forestry and Fisheries, Ministry of International Trade and Industry and Ministry of Transport	It is to aim at the factory location being performed reasonable, being preserving the environment.	① Layout plan Site, Construction, Floor area of production facility, Production facility, Environment facility, Specially arranged facility (Air compressor, etc.)	① Notification of new construction of the specified factory ② Application for the shortening of the restricted enforcement period	Article 6, Paragraph 1 of the Law Article 11 of the Law	No later than ninety days prior to the beginning of construction of factory After the notification of the new construction of factory	Minister of Economy, Trade and Industry	Ministry of Economy, Trade and Industry Industrial Science and Technology Policy and Environment Bureau
Civil Aeronautics Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1952/ 7/ 15 1952/ 9/ 16 1952/ 7/ 31	Law No.231 Cabinet Order No.421 Ordinance No.56 by Ministry of Transport	It is to establish the prevention of trouble due to navigation for the safe navigation of the aviation.	① Installation of aircraft warning light and daytime obstruction indicator ② Flight of a stoned for meteorological observation	① Notification of installation of aircraft warning light and daytime obstruction indicator ② Application of license for the flight of free balloon	Article 51 and 2 of Article 51 of the Law Article 99, Paragraph 2 of the Law	Without delay after completion At the time of Planning	Director-General, Regional Civil Aviation Bureau	Coast Guard of Ministry of Land, Infrastructure Civil Aviation Bureau
Sewerage Law Ordinance for the Enforcement of the above law Rules for the Enforcement of the above law	1958/ 4/ 24 1959/ 4/ 22 1967/ 12/ 19	Law No.79 Cabinet Order No.147 Ordinance No.37 by Ministry of Construction	It is to specify the standards concerning the installation and management of the public sewerage and the city sewage way, etc.	① Drainage from power generating station (to public sewerage)	① Notification of the start of use, etc.	Article 11, Paragraph 2 of the Law	Within ten days after start of use	Sewerage Supervisor	Ministry of Land, Infrastructure and Transport

27-26 Codes and Guidelines for Thermal and Nuclear Power Plants

By Electric Technology Investigating Committee

List of Electric Technical Codes (JEAC), Electric Technical Guidelines (JEAG), Thermal and Nuclear Power Engineering Society Standards (TNS)

Number	Title
[Equipment Section]	
JEAC 8001−1995	Code for Electrical Apparatus Internal Wiring
JEAG 8101−1971	Guide for Protection Design against Grounding of Low Voltage Circuit
JEAC 8102−1993	Code for Handling of Electric Apparatus with PCB
JEAC 8701−1968	Required Capacity of Automatic Interceptor for Low Voltage Circuit
[Power Line Section]	
JEAC 7001−1999	Power Distribution Code (Low Voltage and High Voltage)
JEAC 7011−1994	Code for Design of 22(33) KV Power Line
JEAG 7101−1983	Guide for Design against Snow Hazard to Power Line
[Power Transmission and Communication Section]	
JEAC 6001−1993	Code for Overhead Power Transmission
JEAC 6011−1991	Code for Electric Power Security Communication
JEAC 6021−1991	Code for Subterranean Power Transmission
[Power Generation and Transformation Section]	
JEAC 5001−1993	Code for Power Generation and Transformation
JEAG 5001−1971	Guide for Noise Reduction from Power Plants and Substations
JEAG 5002−1992	Code for Fuel Cell Power Generation
JEAG 5002−1977	Guide for Fire Prevention of Power Plants etc
JEAG 5003−1998	Guide for Seismic Design for Electric Apparatus of Substation etc
[Nuclear Power Section]	
JEAG 4101−1993	Guide of Quality Assurance for Nuclear Power Plants
JEAG 4102−1998	Emergency Planning and Preparedness of Nuclear Power Plants
JEAC 4201−1991	Method of Surveillance Tests for Structural Materials of Nuclear Reactors
JEAC 4202−1991	Drop-Test Method for Ferritic Steel
JEAC 4203−1994	Primary Reactor Containment Vessel Leakage Testing
JEAG 4204−1990	Guide for Inspection of Nuclear Fuel
JEAC 4205−1996	In-service Inspection of Light Water Cooled Nuclear Power Plant Components
JEAC 4206−1991	Methods of Verification Tests of the Fracture Toughness for Nuclear Power Plant Components
JEAG 4207−1996	Ultrasonic Examination for In-service Inspection of Light Water Cooled Nuclear Power Plant Components
JEAG 4208−1996	Eddy Current Test Guide for In-service Inspections of Steam Generator Heat Transfer Tubes for Light Water Cooled Nuclear Power Plants
JEAG 4209−1996	Guide for Maintenance and Inspection of Nuclear Power Plant Equipment
JEAG 4601−1987	Technical Guidelines for Aseismic Design of Nuclear Power Plants
JEAG 4601−1984	Technical Guidelines for Aseismic Design of Nuclear Power Plants: Supplement: Allowable Stress, Classification
JEAG 4601−1991	Technical Guidelines for Aseismic Design of Nuclear Power Plants: Supplement

Number	Title
JEAG 4602−1992	Definitions of Nuclear Reactor Coolant Pressure Boundary and Reactor Containment Boundary
JEAG 4603−1992	Guide for Design of Emergency Electric Power Supply Systems for Nuclear Power Plants
JEAG 4604−1993	Guide for Design of Safety Protection Systems for Nuclear Power Plants
JEAC 4605−1992	Definitions of Engineered Safety Features and Related Features for Nuclear Power Plants
JEAG 4606−1996	Radiation Monitoring for Nuclear Power Plants
JEAG 4607−1986	Guide for Fire Protection of Nuclear Power Plants
JEAG 4608−1998	Guide for Seismic Design of Nuclear Power Plants
JEAG 4609−1989	Application Criteria for Programmable Digital Computer System in Safety -Related System of Nuclear Power Plants
JEAG 4610−1996	Personal Dose Monitoring for Nuclear Power Plants
JEAG 4611−1991	Guide for Design of Instrumentation & Control Equipment with Safety Functions
JEAG 4612−1998	Guide for Safety Grade Classification of Electrical and Mechanical Equipment with Safety Functions
JEAG 4613−1998	Technical Guide Lines for Protection Design against Postulated Piping Failures in Nuclear Power Plants
JEAG 4801−1995	Guide for Operating Manual of Nuclear Power Plants
JEAG 4802−1997	Guide for Education and Training for Nuclear power Plant Operator
[Thermal Power Section]	
JEAG 3101−1988	Guidelines of Quality Assurance for Thermal Power Plants
JEAC 3201−1998	Guidelines for Instrumentation and Control of Thermal Power Plants
JEAC 3202−1999	Guide for Non-Destructive Test of Steam Turbine Rotor for Power Generation
JEAG 3603−1999	Guide for Desulfurization Equipment of Exhaust Fumes
JEAG 3604−1999	Guide for Denitrification Equipment of Exhaust Fumes
JEAG 3605−1991	Guide for Seismic Design of Thermal Power Plants
JEAC 3701−1994	Guide for Power Generation Boiler
JEAC 3702−1994	Guide for Pressure Vessel Including Heat Exchanger etc.
JEAC 3703−1994	Guide for Power Generation Steam Turbine
JEAC 3704−1994	Guide for Power Generation Gas Turbine
JEAC 3705−1998	Guide for Power Generation Internal Combustion Engine
JEAC 3706−1994	Guide for Pressure Piping and Valves
JEAC 3707−1994	Guide for Welding of Thermal Power Plants
JEAC 3708−1994	Guide for Combustion Equipment
JEAC 3709−1994	Guide for Liquefied Gas Facilities
JEAC 3710−1989	Guide for Synchronous Generator of Thermal Power Plants
JEAC 8712−1988	Guide for Ammonia Supply Equipment
JEAC 3714−1998	Guide for Water Supply Processing Equipment
JEAG 3715−1999	Guide for Waste Water Treatment Equipment
JEAC 3716−1994	Guide for Geothermal Power Station
JEAC 3717−1991	Guide for Vibration of Steam Turbine and Generator for Power Plants
JEAC 3718−1991	Guide for Fire Protection of Steam Turbine and Generator for Power Plants
JEAC 3719−1994	Guide for Dust Catcher

Number	Title
[Thermal and Nuclear Power Engineering Society Technical Guides]	
TNS-G 2801－1985	Guide for Outer Surface Sleeve
TNS-G 2802－1985	Guide for Outer Surface Buttering
TNS-G 2803－1985	Guide for Water Cooled Re-welding
TNS-G 2804－1985	Guide for Stress Relief by High Frequency IH
TNS-G 2705－1986	Guide for Design of Emergency Control Center for Nuclear Power Plants
TNS-G 2806－1986	Guide for Repair Method by Back Plate Fillet Welding
TNS-G 2807－1986	Guide for Repair Method using Adhesives
TNS-G 2808－1986	Guide for Repair by the Filler

References for Thermal and Nuclear Power Generations

Code	Criteria, Appendix, and Guidance, etc.	Year of Issue
2004	Handbook for Thermal and Nuclear Power Engineers (The 5th Supplemental Revised Edition) A6	1993
2005	Same as the above A5	Same as the above
2006	Handbook for Thermal and Nuclear Power Engineers (English Edition)	1994
2007	Handbook for Thermal and Nuclear Power Plant Facilities (Revised Edition, 1999)	1999
3501	Handbook of Laws and Regulations for Electric Utilities Industry (Thermal Power Related) - Procedures and Examples of Forms -	1987
3014	Handbook of Laws and Regulations for Electric Utilities Industry (Thermal Power Related) - Question and Answer -	1993
3015	Guide for Periodical Inspection of Thermal Power Plants	1997
3016	Guide for Extension of Periodical Inspection Cycle of Power Generation Boilers - Explanatory Question and Answer -	1999
3005	Guide for Steam Turbine Overhaul	1987
3011	Guide for the Related Laws and Regulations for Thermal Power Plants Concerning Safety Preservation/ Disaster Prevention and Environment Reservation	1991
3706	Guide for Handling of Hazardous Materials (The 3rd Revised Edition)	1995
3009	Overview of Periodic Inspection of Nuclear Power Plants	1990
3013	Guide for Periodic Inspection of Nuclear Power Plants	1992
4013	Technical Standards for Welding of Electric Structures - Ministerial Order And Interpretations (Revised Edition of Fiscal Year, 2000)	2000
4017	Technical Standards for Welding of Electric Structures-Ministerial Order and Interpretation, Explanation (Revised Edition of Fiscal Year, 2000)	2000
4014	Technical Standards for Thermal Power Facilities (Revised Edition of 1997)	1997
4015	Technical Standards for Thermal Power Facilities, Ministerial Order and Notification, and Interpretations (Explanations) (Revised Edition of 1997)	1998
4613	Technical Standards for Nuclear Power Generation	1994
4007	Technical Standards for Nuclear Fuel Materials for Power Generation (Explanations)	1989
4012	Technical Standards for Structures of Nuclear Power Generation Facilities, Questions and Answers	1993
5019	Annual Report of Nuclear Power Plant Operational Administration, Edition of 2000(Actual Results of Fiscal Year, 1999)	2000
7601	Q&A for Response to Failures and Troubles of Thermal Power Plant (Operation)	1994
7702	Q&A for Response to Failures and Troubles of Thermal Power Plant(Maintenance)	1995
7003	Examples of Work Improvements for General·Repair Works	1996
7004	Investigation Reports of Actual Diagnosis for Thermal Power Facilities	1998

Code	Technical Guides (Private Sector Voluntary Criteria)	Reference Number
6001	SCG Countermeasure Technology, Guide for Outer Surface Sleeve	TNS-G2801-1985
6002	SCG Countermeasure Technology, Guide for Outer Surface Buttering	TNS-G2802-1985
6003	SCG Countermeasure Technology, Guide for Water Cooled Re-Welding	TNS-G2803-1985
6004	SCG Countermeasure Technology, Guide for Stress Relief by High Frequency	TNS-G2804-1985
6005	Design Guide for On Site Emergency Response Stations of Nuclear Power Plants	TNS-G2705-1986
6006	Guide for Repair Method by Back Plate Fillet Welding	TNS-G2806-1986
6007	Guide for Repair Method Using Adhesives	TNS-G2807-1986

Code	Technical Guides (Private Sector Voluntary Criteria)	Reference Number
6008	Guide for Repair Method Using Filler Materials	TNS-G2808-1986

Code	Lecture	Year of Issue
1001	Pumps (Revised Edition)	1988
1012	Boilers (Revised Edition)	1988
1015	Turbines and Generators (Revised Edition)	1990
1029	Thermal Power Plant - Whole Plants and Associated Facilities - (Revised Edition)	2000
1005	Lectures on Nuclear Power Plants (Whole Plants and Associated Facilities)	1982
1607	Lectures on Operation of Power Systems and the Electric equipment	1984
1009	Nuclear Fuel Cycle and Waste Disposal	1986
1010	Chemical Control for Thermal and Nuclear Power Plants	1987
1021	Related Codes and Regulations, and Their Applications for Thermal and Nuclear Power Plants	1988
1614	Fuel and Combustion	1989
1716	Better Understanding for Nuclear Power Generation	1990
3012	Technologies and Facilities for Environmental Preservation of Thermal Power Plants	1991
1017	Heat Exchangers, Pipes and Valves	1992
1019	Diagnosis of Remaining Life and Measures for the Improvement of Thermal Power Facilities	1993
1020	Control of Water Quality and Water Treatment Facilities	1993
1022	Materials for Thermal and Nuclear Power Generation Facilities	1993
1023	Control／Instrumentation and Automation	1994
1724	Construction, Test Operation and Maintenance of Power Plants	1995
1025	Explanations of "Handbook for Thermal and Nuclear Power Engineers"	1996
1027	Corrosion and Prevention for Power Generating Plants	1997
1028	Combined Cycle Power Generation (Revised Edition)	1998

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