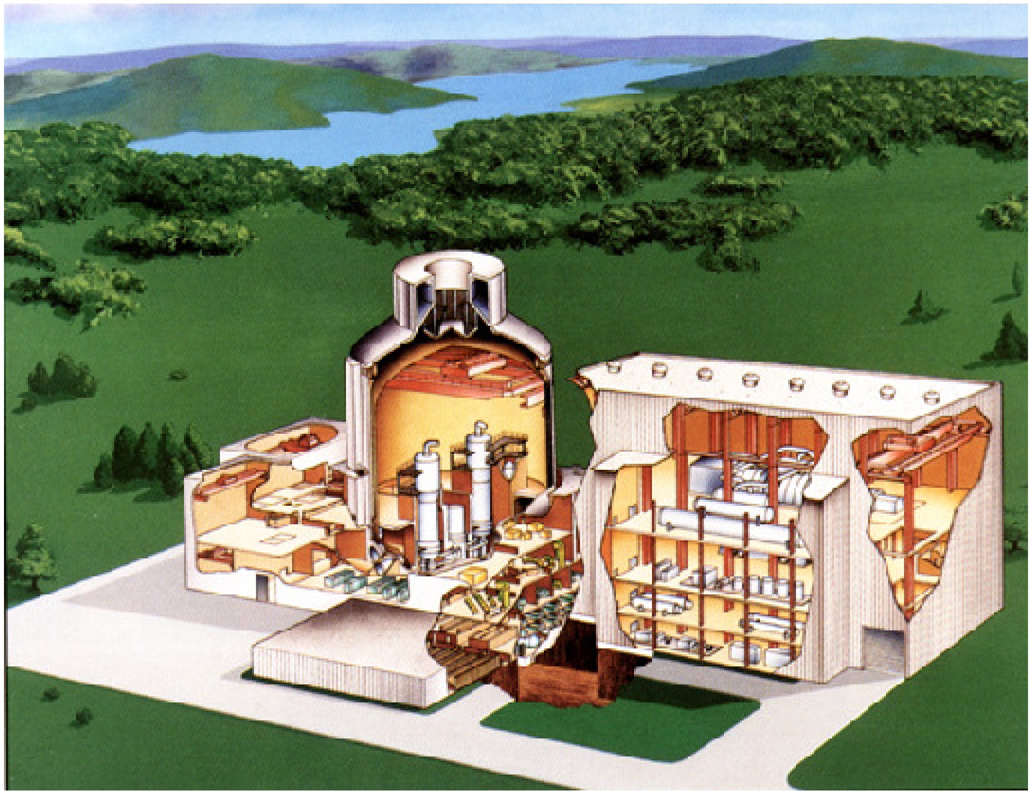
Nuclear Plant Systems

Lecture 0

Nuclear Plant Systems and the Role of a Nuclear Engineer

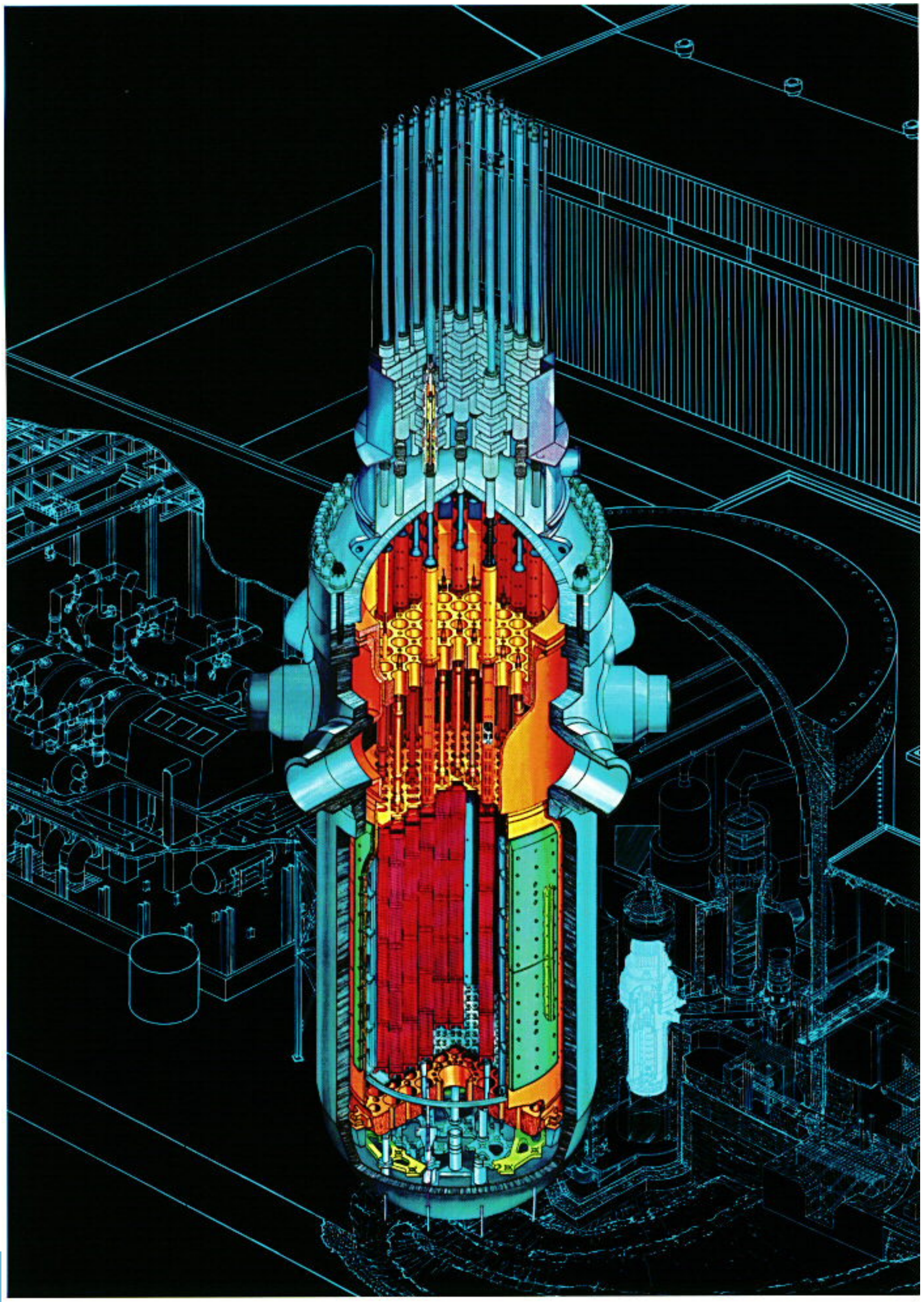
Outline

- Introduction
- Syllabus
- Delivery

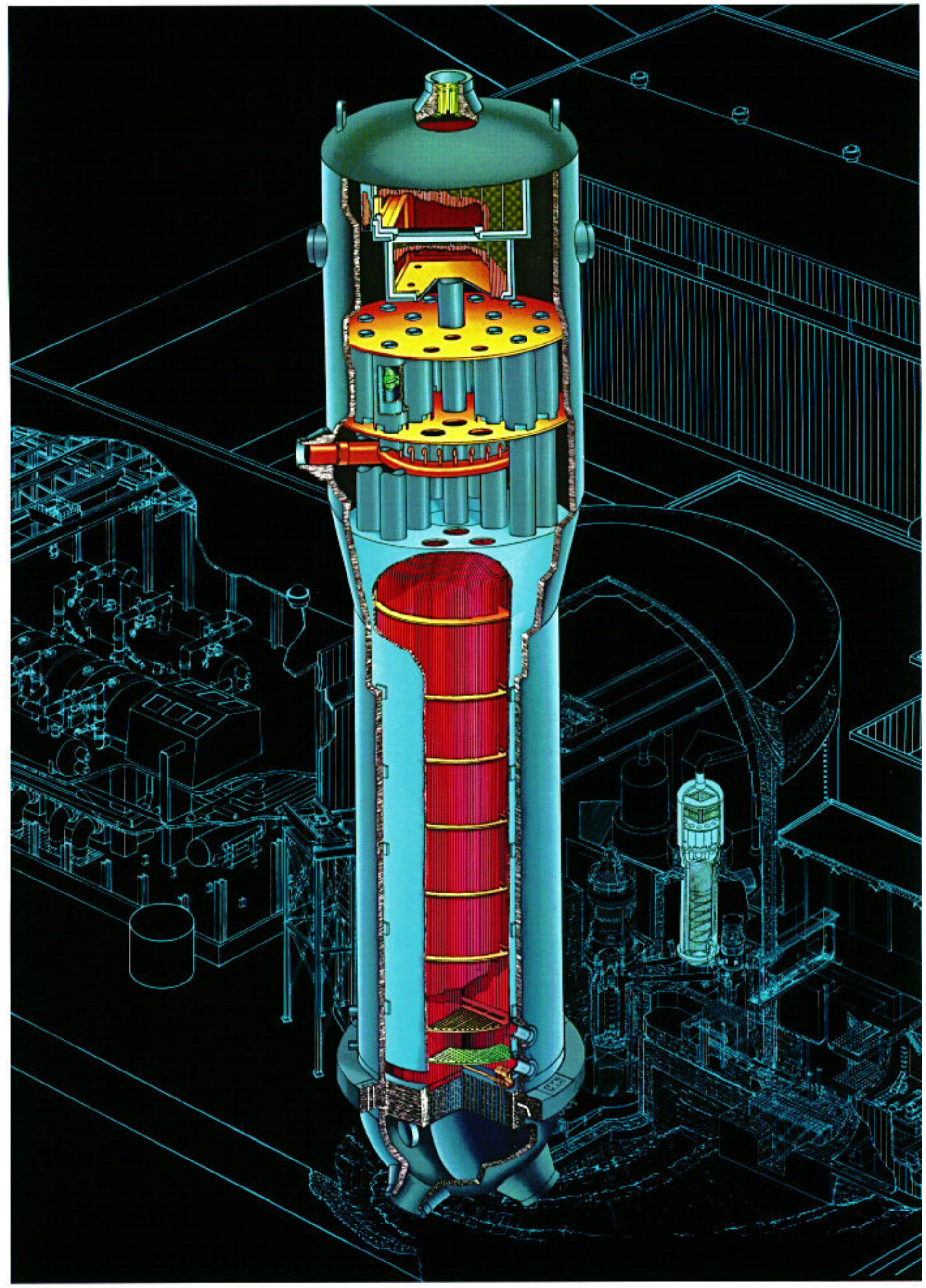


Introduction

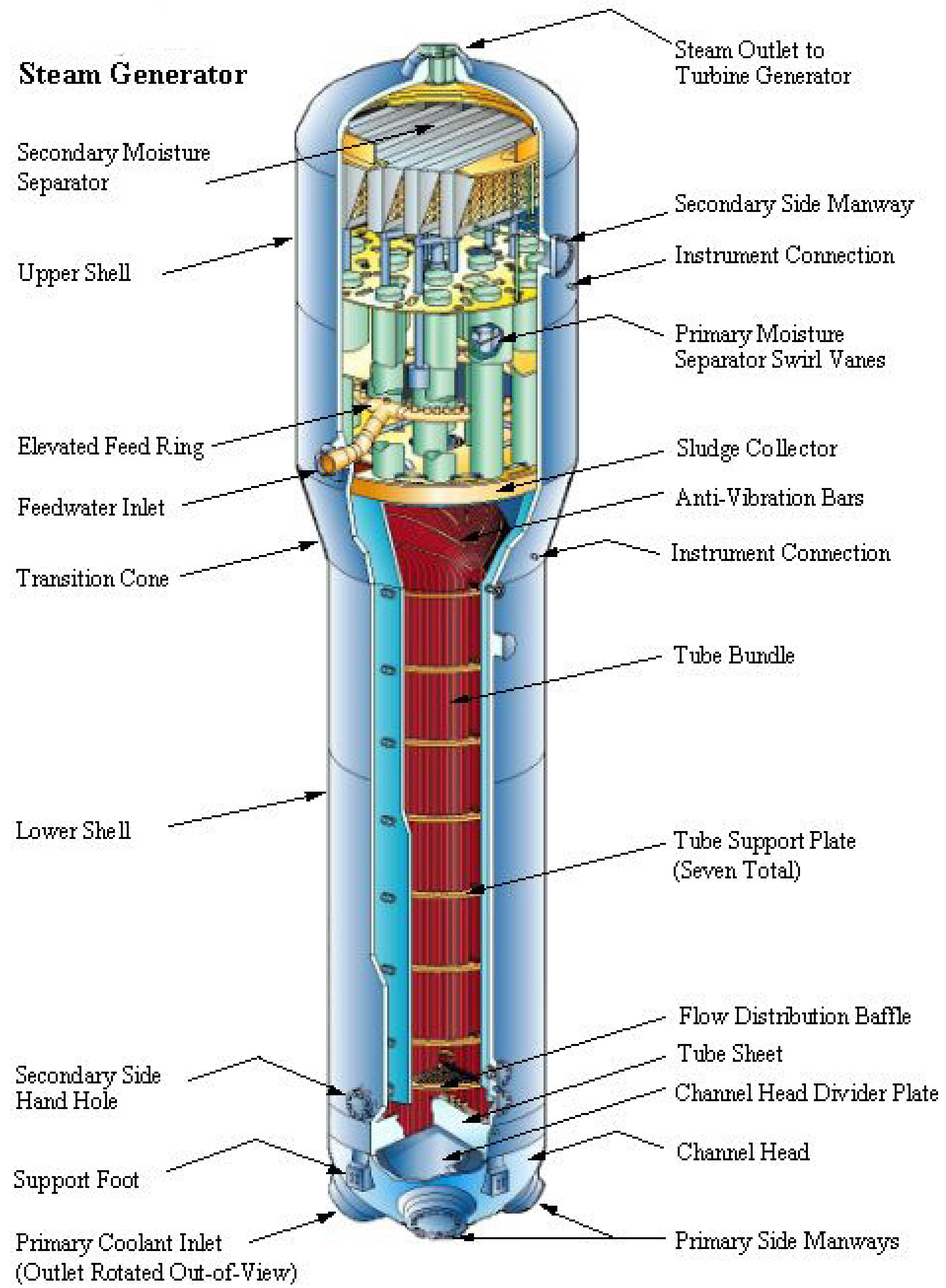
- Course Description
  - This course is offered to students pursuing non-nuclear majors as a part of the Nuclear Power Engineering Technology Certificate program.
  - Boiling Water Reactor (BWR) Systems: the systems unique to the BWR for control of the fission process and the associated systems and strategy for reactor safety.
  - Pressurized Water Reactor (PWR) Core Systems: the systems unique to the PWR for control of the fission process and the associated systems and strategy for reactor safety.
  - Power Plant Generation: the balance of plant equipment used in the steam cycle.
- Course Objectives
  - This course ensures that students understand engineering principles associated with systems and components used in two types of commercial nuclear power plants.
  - Students will become familiar with basic principles of the design and operation of various PWR Plant systems and components, including the primary system, reactor vessel, reactor core, reactor coolant pumps, steam generators, emergency core cooling system, and auxiliary systems. Students will understand the operation of the plant during start up, shutdown and other important evolutions.
  - Students will understand the design and operation of various BWR systems and components, including, the reactor vessel, reactor core, control rods, recirculating system, and reactor water cleanup system.



Westinghouse NUCLEAR REACTOR



Westinghouse STEAM GENERATOR


Steam Generator
Steam Outlet to
Turbine Generator
Secondary Moisture
Separator
Upper Shell
Secondary Side Manway
Instrument Connection
Primary Moisture
Separator Swirl Vanes
Elevated Feed Ring
Sludge Collector
Feedwater Inlet
Anti-Vibration Bars
Transition Cone
Instrument Connection
Tube Bundle
Lower Shell
Tube Support Plate
(Seven Total)
Flow Distribution Baffle
Tube Sheet
Secondary Side
Hand Hole
Channel Head Divider Plate
Support Foot
Channel Head
Primary Coolant Inlet
(Outlet Rotated Out-of-View)
Primary Side Manways

Instructor

• Instructor	Cable Kurwitz P.E, PhD
• Office	Texas A&M University
	Department of Nuclear Engineering
	Zach 60g
• Contact Information	Phone – 979-845-6126 or 979-845-8768
	Email – kurwitz@tamu.edu
• Office Hours	TBD

Texts

- Textbook purchase is not required
- **Textbooks/Lecture Notes:**
- Ronald Allen Knief "*Nuclear Engineering. Theory and technology of commercial nuclear power*". American Nuclear Society, Inc. 555 North Kensington Ave, La Grange Park, Illinois 60526 USA. ISBN-10: 0-89448-458-3
- Paul Cohen "*Water coolant technology of power reactors*". American Nuclear Society, Inc. 555 North Kensington Ave, La Grange Park, Illinois 60526 USA. ISBN: 0-89448-020-0
- Geoffrey F. Hewitt, John G. Collier, *Introduction to Nuclear Power*, 2nd ed., Taylor Francis.
- *Nuclides and Isotopes - Chart of the Nuclides,* Knolls Atomic Power Laboratory – Lockheed Martin, 16th ed., http://www.chartofthenuclides.com/products.html

- **Suggested reference texts:**
- John R.Lamarsh "Introduction to Nuclear Engineering", ISBN: 0201142007- 2ND edition, ISBN: 0201824981- 3^{D} edition
- Neil E. Todreas, Mujid S. Kazimi "Nuclear systems I, Thermal Hydraulics Fundamentals", 1989, ISBN: 0891169350 (case), ISBN: 1560320516 (paper)
- John G. Collier, Geoffrey F. Hewitt "Introduction to Nuclear Power", 1986, ISBN 0891162690
- M.M. El-Wakil "Nuclear Energy Conversion", 1992, ANS Publications, ISBN: 0894480154
- Pp20000-20024 – STP presentations for PWR Familiarization course based on ESP Orientation documents

Topics to be Covered

- **Introduction to Nuclear Power – Basic Nuclear Theory**
  - The Atom and Nuclear Stability
  - Nuclear Radiation, Radioactive Decay, and Nuclear Reactions
  - Nuclear Fission, Fission Products
  - Neutron Life Cycle
  - Energy Released in Fission
  - Nuclear Reactor Fuels
  - Nuclear Fuel Cycles
- **Reactor Heat Transfer, Fluid Flow, and Thermodynamics**
  - Fundamentals of Thermodynamics
  - Thermal Energy Generation, Deposition, and Heat Transfer
  - Fluid Flow and Balance of Plant
  - Nuclear Power Plant Components

Topics to be Covered (cont.)

- **Systems Overview**
  - Power Cycles
  - Types of Nuclear Reactors
  - Thermal Reactors: PWR, BWR
  - Major Components of Nuclear Reactors
    - Schematic Arrangements for Pressurized Reactors
    - Schematic Arrangements for Boiling Reactors
    - Schematic Arrangements for Gas-Cooled Reactors /optional/

Topics to be Covered (cont.)

- **Coolant System: Primary loop. Secondary loop.**
  – PWR Primary Systems
    - Reactor Coolant Flow Path Between the Major Components
    - Reactor Vessel
    - Pressurizer, Pressurizer Relief Tank
    - Primary Coolant Loop Pump
    - Steam Generator
  – PWR Secondary Systems
    - Turbine
    - Condensate
    - Feedwater
  – BWR Steam Supply Systems

Topics to be Covered (cont.)

- **PWR Support Systems**
  - Residual Heat Removal
  - Chemical and Volume Control
  - Emergency Core Cooling
  - Plant Cooling
- **Reactor Protection and Safeguards Actuation**
  - Reactor Control System
  - Nuclear Instrumentation
  - Turbine Control
  - Pressurizer Pressure and Level Control

Topics to be Covered (cont.)

- **Integrated Plant Operation**
  - Plant Heatup
  - Plant Startup
  - Plant Operation at Power
  - Plant Shutdown
  - Plant Cool Down
- **Support Systems /optional/**
  - Fuel Handling
  - Containment Support
  - Radioactive Waste
  - Fire Protection
  - Instrument/Station Air
- **Electrical Distribution /optional/**

Grading

- The grades will be determined on the usual scale:

Final Course Score	**Final Course Grade**
90% and above	**A**
80 - 89.5%	**B**
70 - 79.5%	**C**
60 - 69.5%	**D**

- Grades will be computed according to the table below.

Homework Assignments:	20%
Short Quizzes	10%
Mid-term exam #1	20%
Mid-term exam #2	20%
Final exam	30%

Grading

- Homework
  - Homework assignments will be assigned periodically. All homework assignments are to be emailed to kurwitz@tamu.edu with homework in the subject line. The solution sets are due by 9:00 pm on the assigned due date.
  - **No late homework will be accepted, except for university excused absences.**
  - Homework Preparation**:**
    - give an assignment number and attach assignment as a cover,
    - use only front side of each page and provide a brief problem statement,
    - be neat and legible and present work logically (step by step) to allow partial credit,
    - if asked for a numerical result, give formula and number with units,
    - send pdf of homework set to kurwitz@tamu.edu with homework in the subject line,
    - It is allowed to type your HW instead of handwriting, if you show all steps of your solution
  - Submission of the homework solution sets:
    - Work together is encouraged. The participating classmates must be listed on the first page. However, the final submitted assignments must be individual work efforts.
    - **If blatant copying is detected for the first time, the score will be 0 for all involved**
  - Late submission (1 week to explain and ask for a new due date):
    - If a student cannot submit his work by the due date, he has 1 week after the due date to explain the reasons for delay and ask for a new due date without GRADE PENALTY. If the student fails to contact instructor, the delayed work will not be accepted

Grading

- Short Quizzes
  - Short quizzes will be given to facilitate and enhance the learning process. Online quizzes will be based on the material from the preceding lectures and associated reading assignments.
  - The reading assignments may cover material before it is covered in the class. Short quizzes will be designed for approximately 10-15 min.
  - Quizzes will be taken using the e-learning site assessments
- Examinations
  - Two major exams and a final exam will be given during the semester.
  - These exams will be an in-class, closed-book, closed-notes exams.
  - A final exam for the class will be scheduled according to the approved University Final Examination Schedule.
  - All exams will be comprehensive and cover all information discussed up to the date of the exam.
  - **Questions about exam scores must be submitted in writing within one week after the exams have been returned or the scores will be considered correct.**

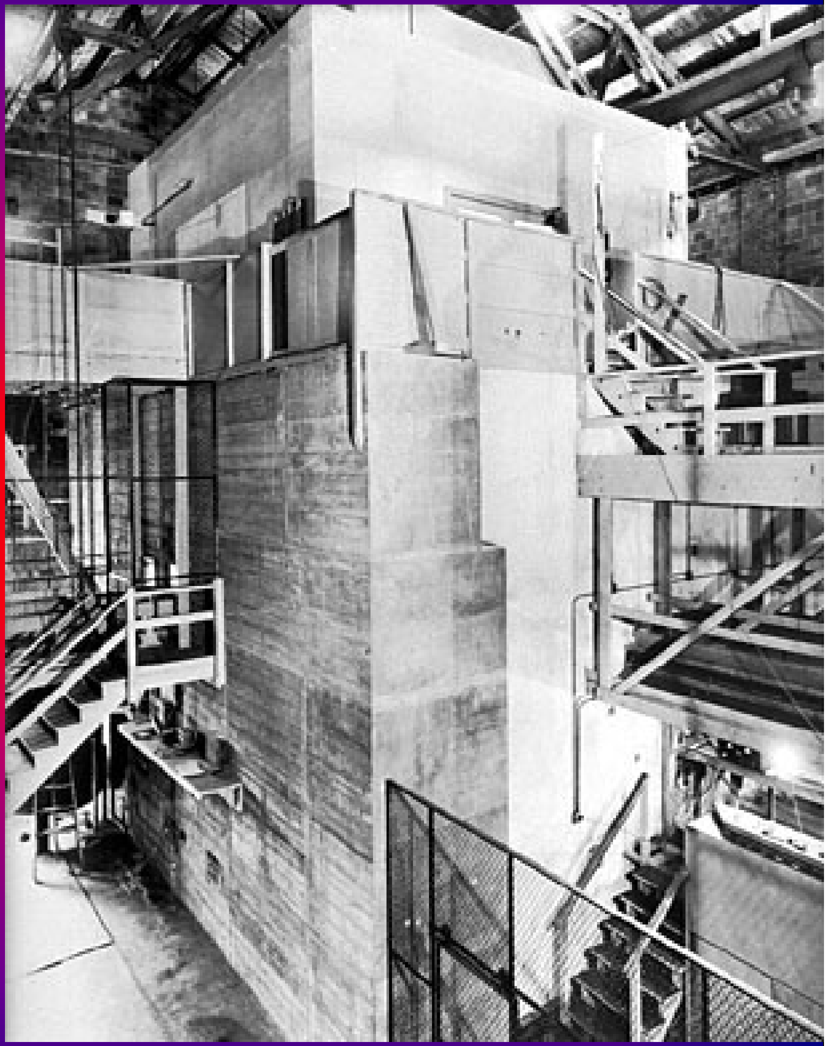
Delivery

- The course will be delivered online using TAMU elearning with periodic video conferences using the Centra/SABA system
- The elearning site will provide lecture notes, recorded lectures, homework assignments, quizzes, and other material
- Video conferences will be held to go over previous material and provide a forum to ask questions and discuss course material
- Video conferences will be recorded and saved on the elearning site for download

Role of a Nuclear Engineer

- In order to protect the health and safety of the public, the nuclear power plant engineer must have a knowledge of the regulatory and design basis requirements for the equipment and procedures used in the operation of the plant.
- Understanding the systems that work together to produce electricity from nuclear energy is the focus of this course

WHERE TO BEGIN



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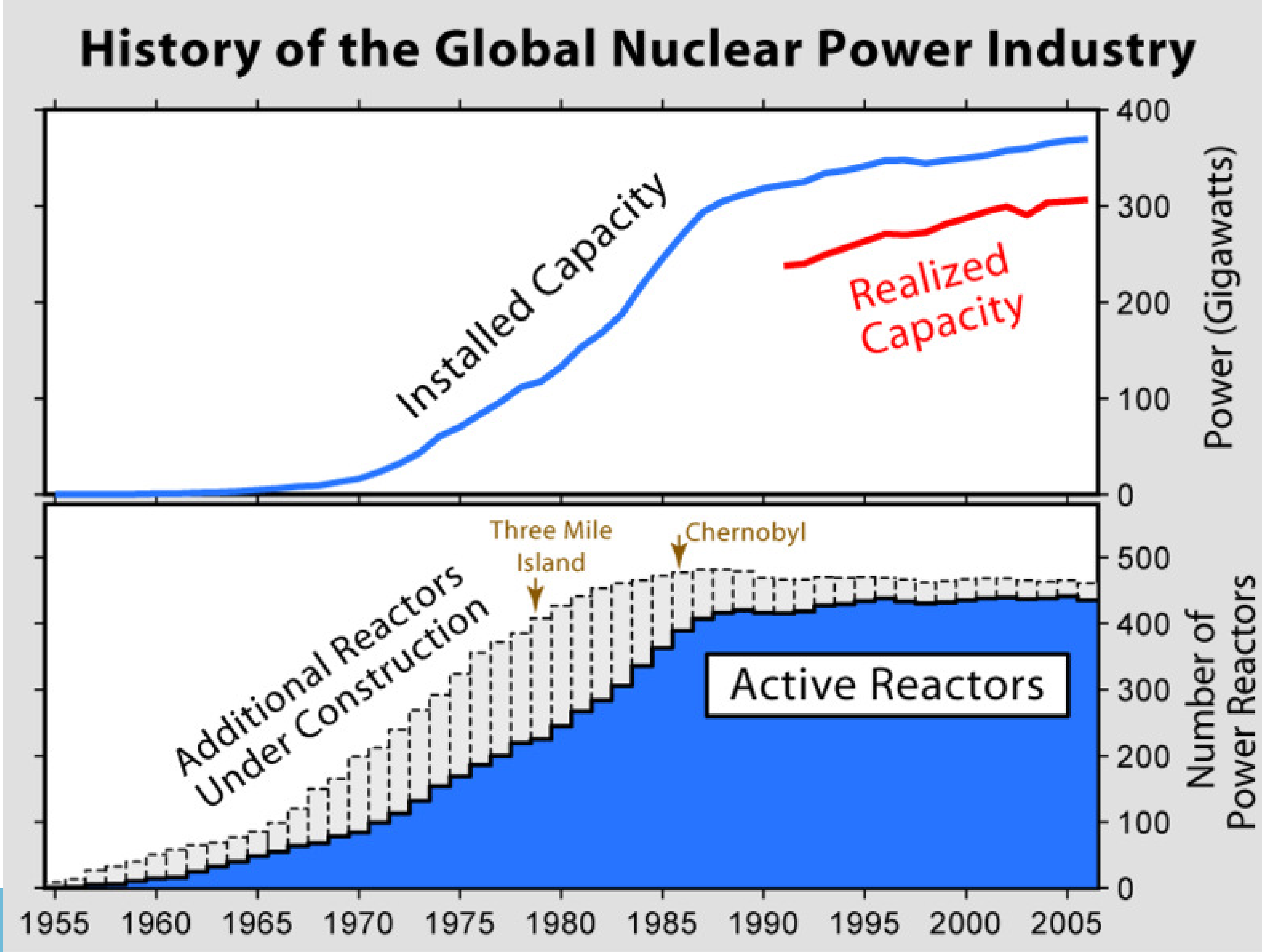
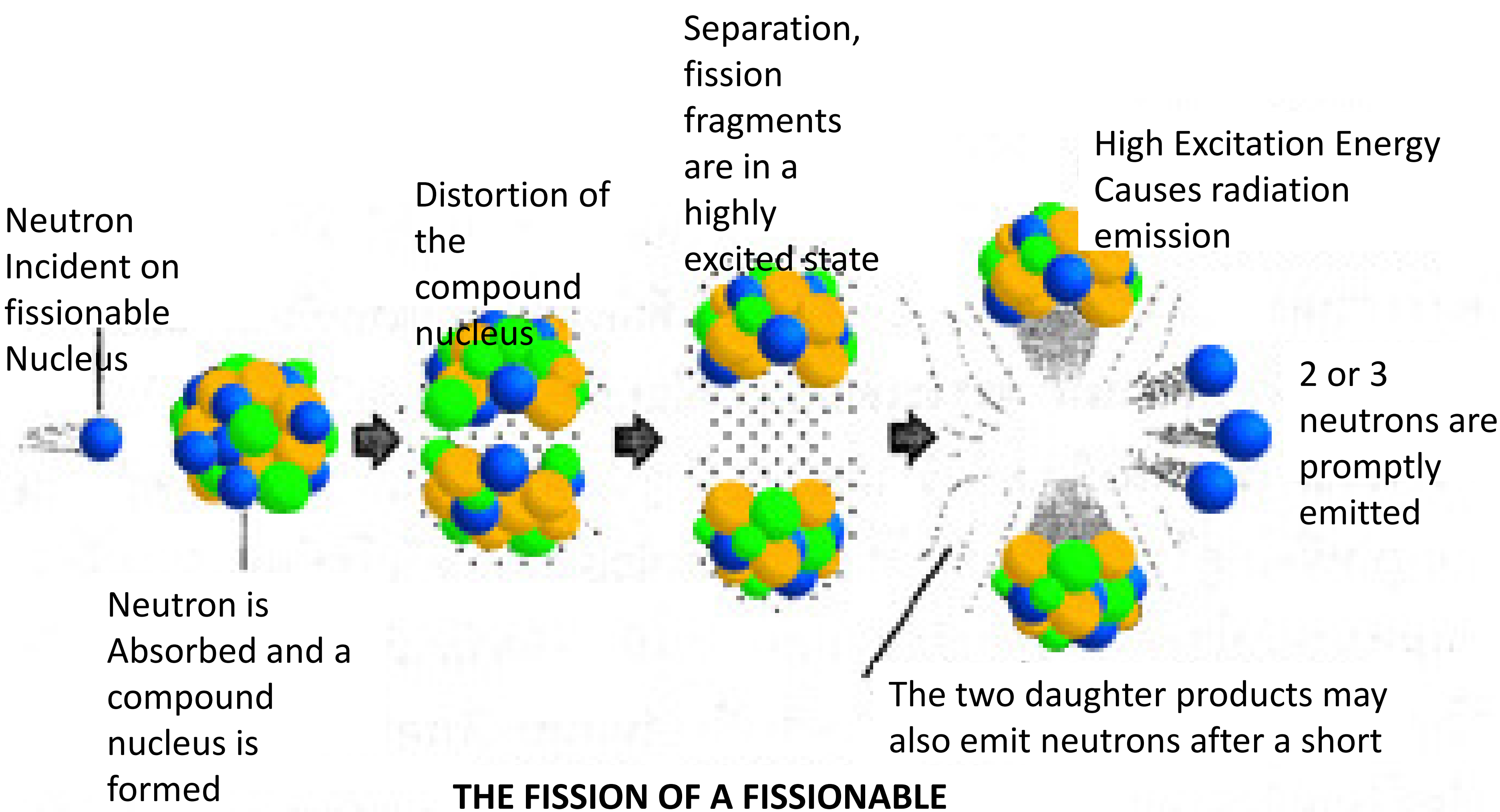
A Brief History of Nuclear Power

- Discovery of Fission in 1939
- Dec 2, 1942: First reactor went into operation under the west stands of the football field at the University of Chicago
  - Demonstration of self-sustaining chain reaction using natural occurring Uranium
- Dec 20, 1951: First electricity produced from nuclear energy in Idaho at Experimental Breeder Reactor 1
- Feb. 1958: First commercial operating reactor went into operation in Shippingport, PA.
- Reactor orders dramatically increase through the early 70s as uncertainty of fossil fuels drive utilities to ramp up nuclear power program
- Three Mile Island 1979 and Chernobyl
- Plant up-rates and the quiet improvement of nuclear power
- Nuclear renaissance


History of the Global Nuclear Power Industry
Installed Capacity
Realized Capacity
Power (Gigawatts)
0
100
200
300
400
Three Mile Island
Chernobyl
Additional Reactors Under Construction
Active Reactors
Number of Power Reactors
0
100
200
300
400
500
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005



THE FISSION OF A FISSIONABLE "NUCLIDE" SUCH AS URANIUM 235

Weight of Uranium vs. Coal

- One pound of Uranium^{235} when totally fissioned will produce approximately 3×10^{10} BTU of energy

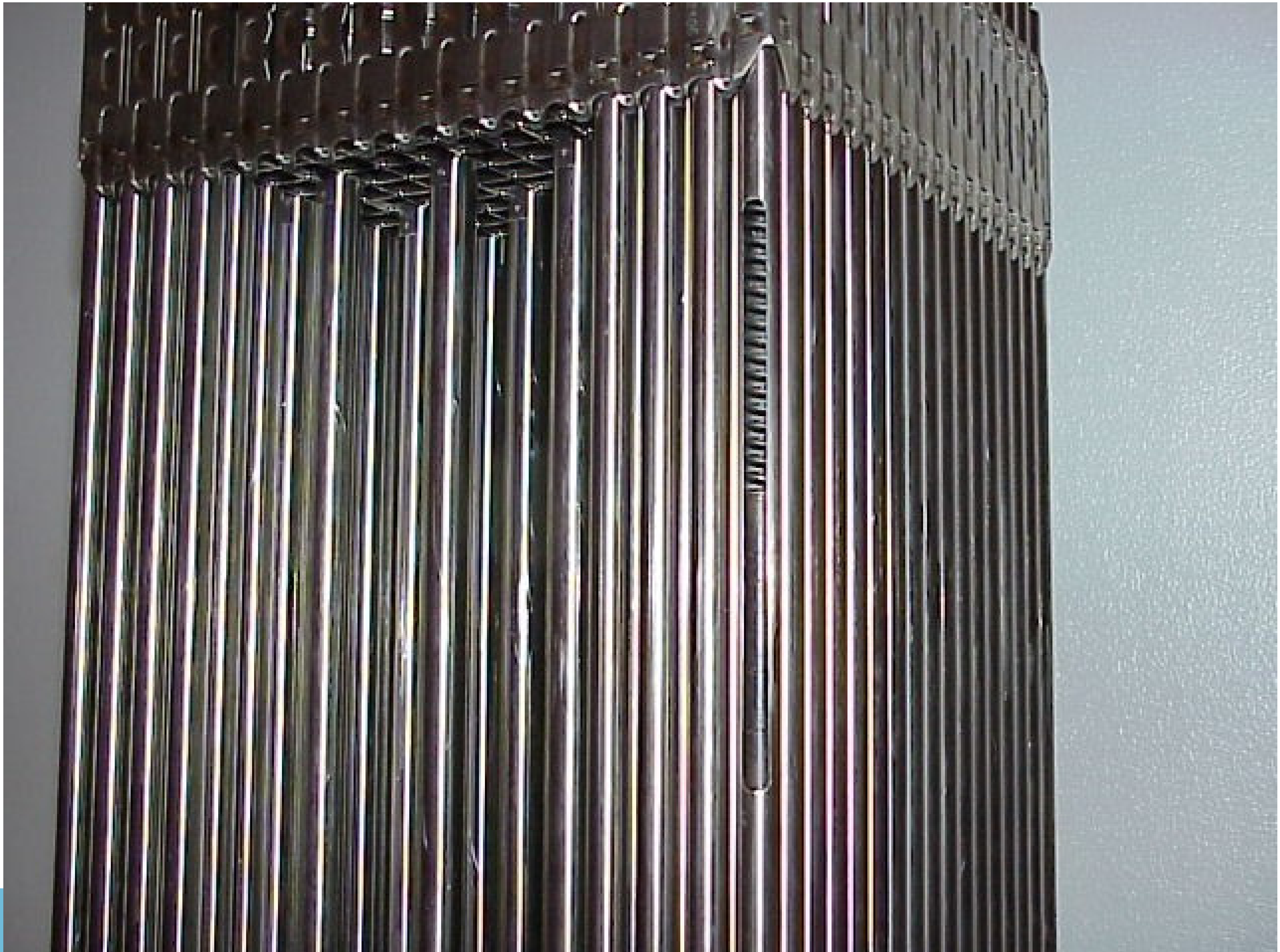
- This is equivalent to 3 billion pounds of coal

Reactor Requirements

- Fuel
  - Form – Ceramic, metal, aqueous
  - Type – Uranium, Plutonium, Thorium
- Coolant
  - Fluid – light water, heavy water, Sodium, Helium
  - State – single phase, two phase
- Neutron Spectrum
  - Fast vs. Slow
  - Moderator
  - Control Action
    - Material
    - Geometry

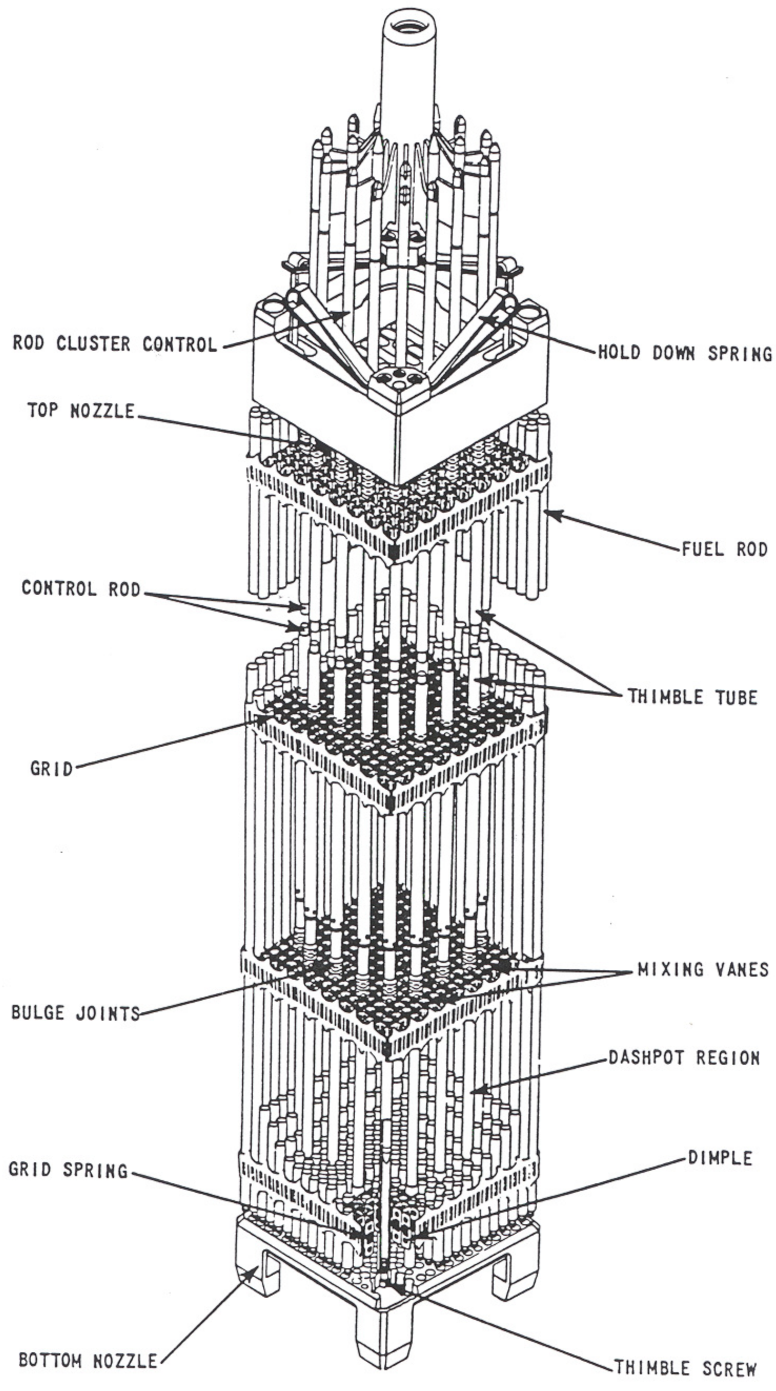
Nuclear Fuel

- Most use either
  - Natural Uranium or
  - Natural Uranium "enriched" with U235
- Can also use
  - Plutonium
  - Thorium
- Fuel type and form is designed to provide multiple barriers to the release of radioactive material
- The form, material, and geometry is based on the compatibility with other reactor materials, nuclear characteristics, thermal characteristics, and performance in the reactor environment



Energy Production

- Energy released from fission is mainly kinetic energy of fission fragments
- The slowing down of fission fragments and the absorption of radiation increases the temperature of the material
- Thermal energy is removed by coolant flowing past the fuel
- Fuel is cooled, coolant is heated
- Heater coolant is converted to mechanical energy to turn a generator producing electricity


ROD CLUSTER CONTROL
HOLD DOWN SPRING
TOP NOZZLE
FUEL ROD
CONTROL ROD
THIMBLE TUBE
GRID
MIXING VANES
BULGE JOINTS
DASHPOT REGION
GRID SPRING
DIMPLE
BOTTOM NOZZLE
THIMBLE SCREW

Fuel Consumption

- Fission Fragments are the result of fission
- Some fragments are neutron absorbers
- When too many fragments exist, and not enough fresh fuel exists to compensate, the fuel bundle must be replaced with a new or less “burnt” fuel assembly

Reactor Coolants and Moderator

- Coolants transfer thermal energy and keep the fuel from overheating
- Moderators slow neutrons down so they are available for fission
- Most reactors use water as both coolant and moderator
  - Some of these use “Heavy Water” at the moderator
- Some use graphite as the moderator

Moderators - Reflectors

- The purpose of the reflector is to reflect (as a mirror) some of the escaping neutrons back into the core area where they become available to induce fission. Water serves this function in most reactor designs.

CONTROL MATERIAL

- Control Rods
- Liquid material
- Installed Poisons

- All absorb neutrons, making them unavailable for fission

Reactor Size and Shape

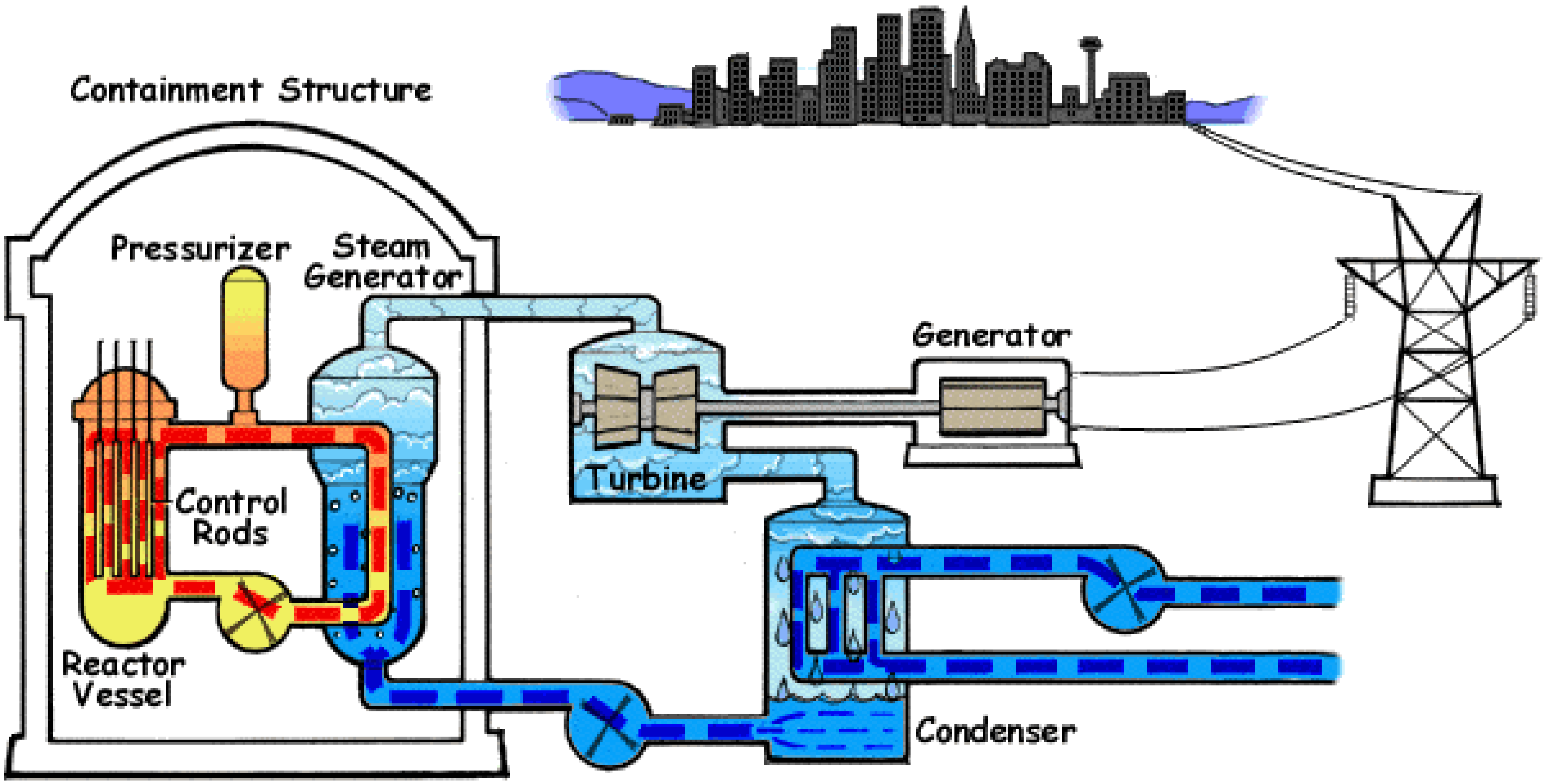
- Leakage depends on surface area of core
- Neutron production is enhanced with a larger core volume, since more fuel can be put into the core
- A Cylindrical shape is used
- Surface/Volume ratio will be small
- Reactor size is based on the desired power level and safety considerations

Nuclear Power

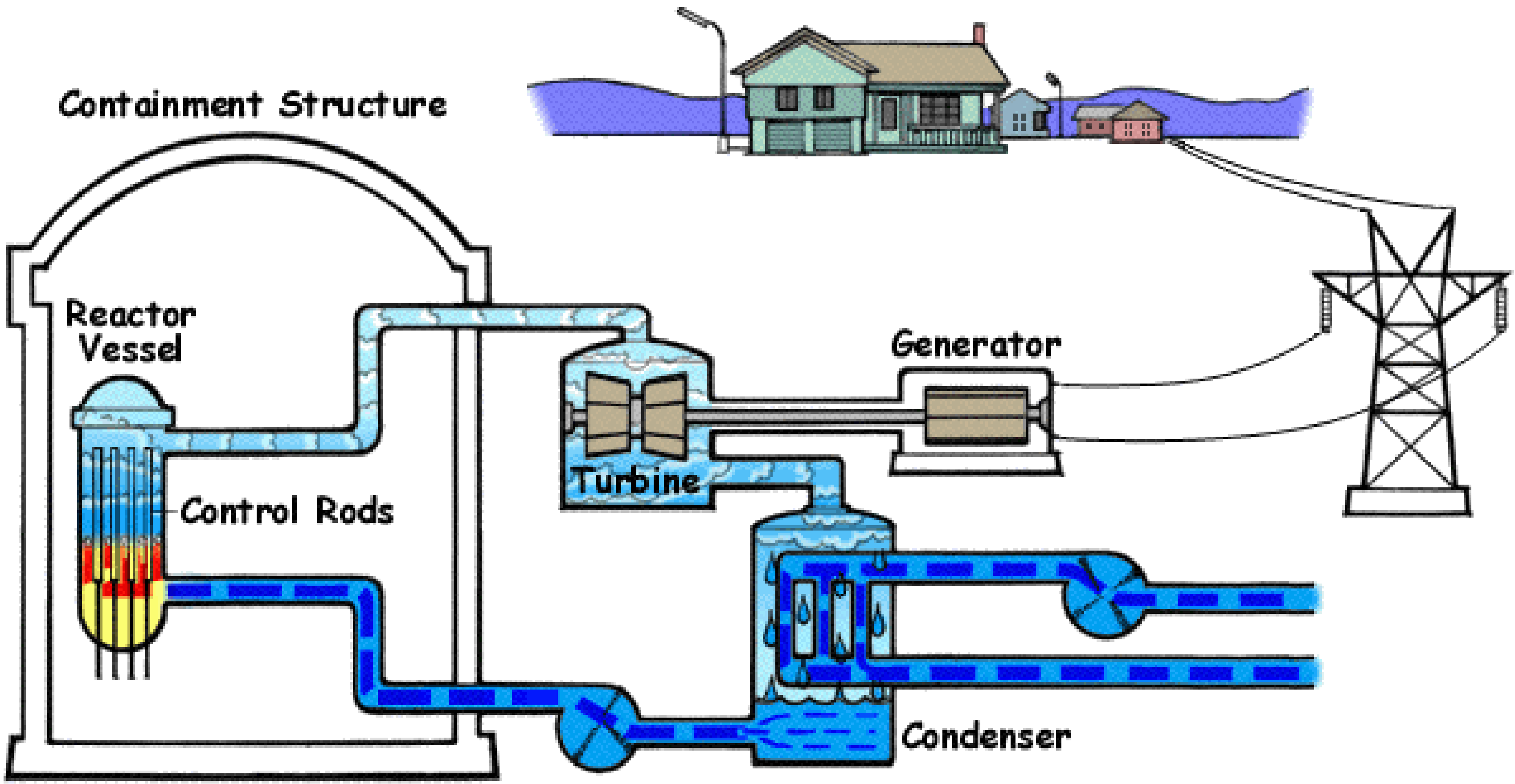
- Most nuclear electricity is generated using just two kinds of reactors which were developed in the 1950s and have been steadily improved since

- Over 16% of the worlds electricity is produced from nuclear energy, more than from all sources worldwide in 1960!

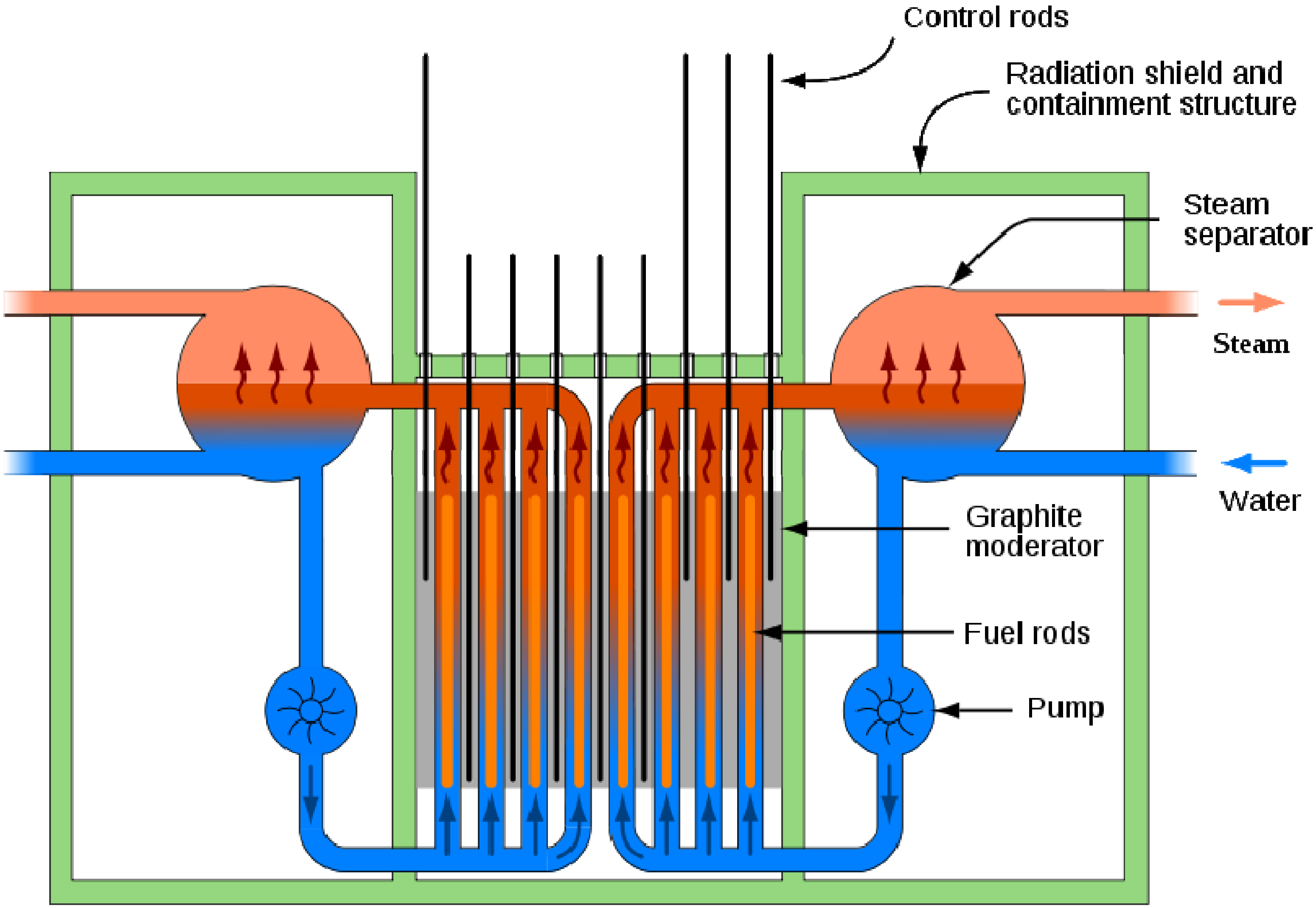
Pressurized Water Reactor (PWR)



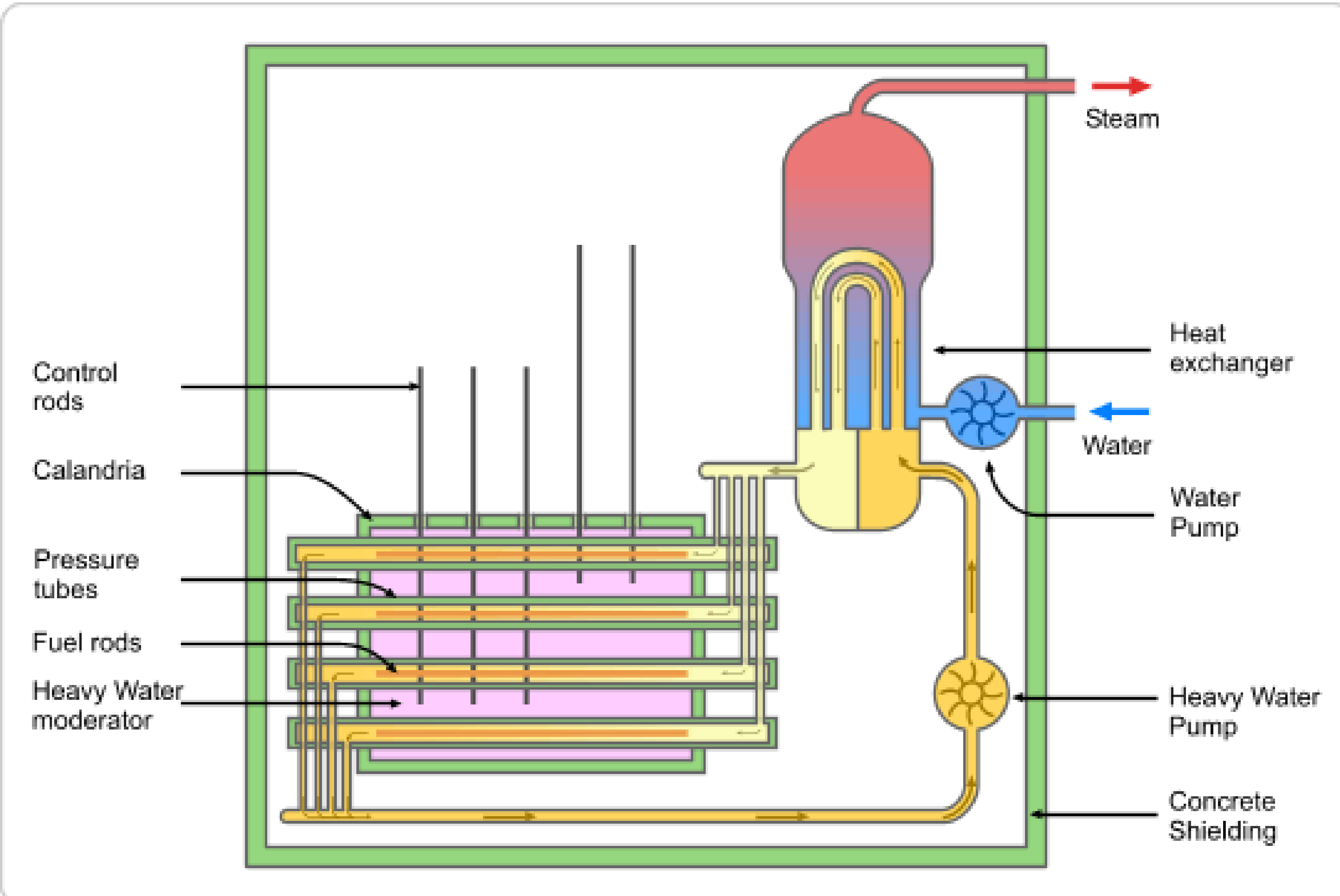
Boiling Water Reactor (BWR)



RBMK

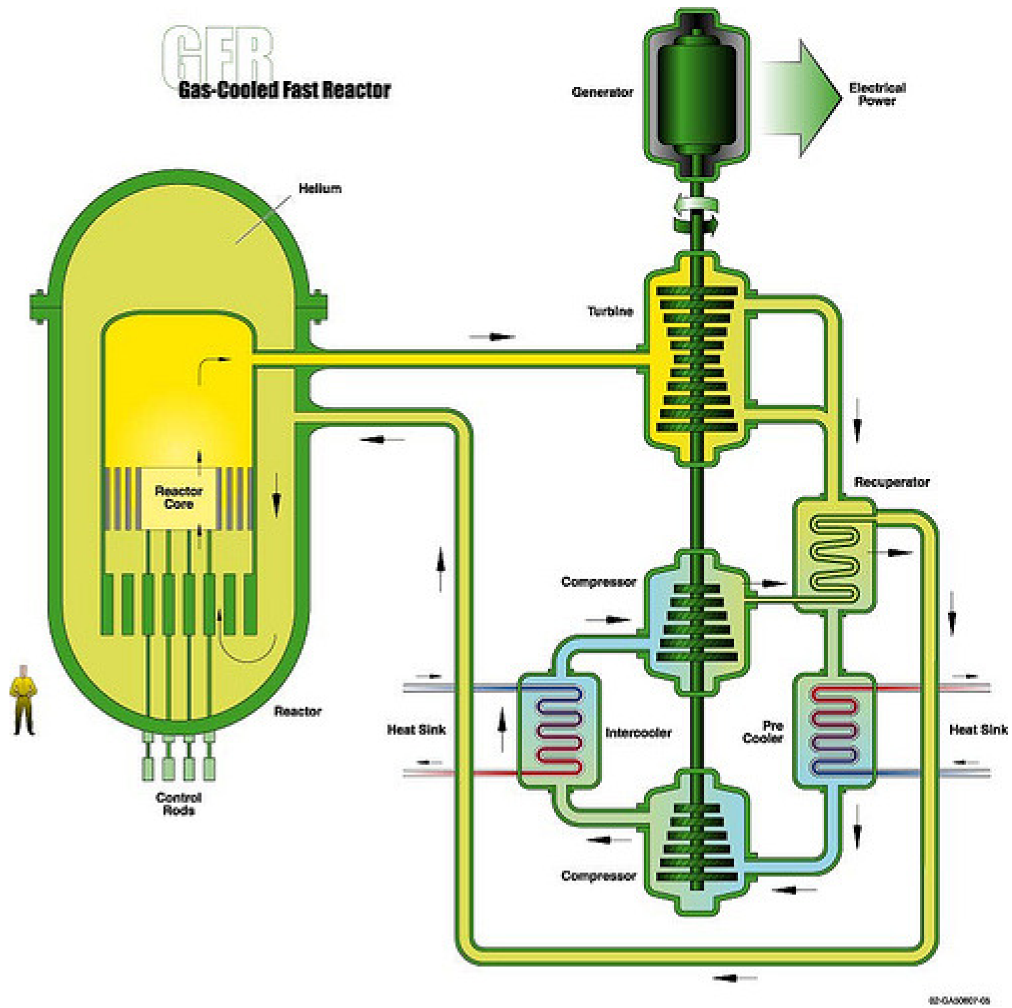

Control rods
Radiation shield and
containment structure
Steam
separator
Steam
Water
Graphite
moderator
Fuel rods
Pump

CANDU

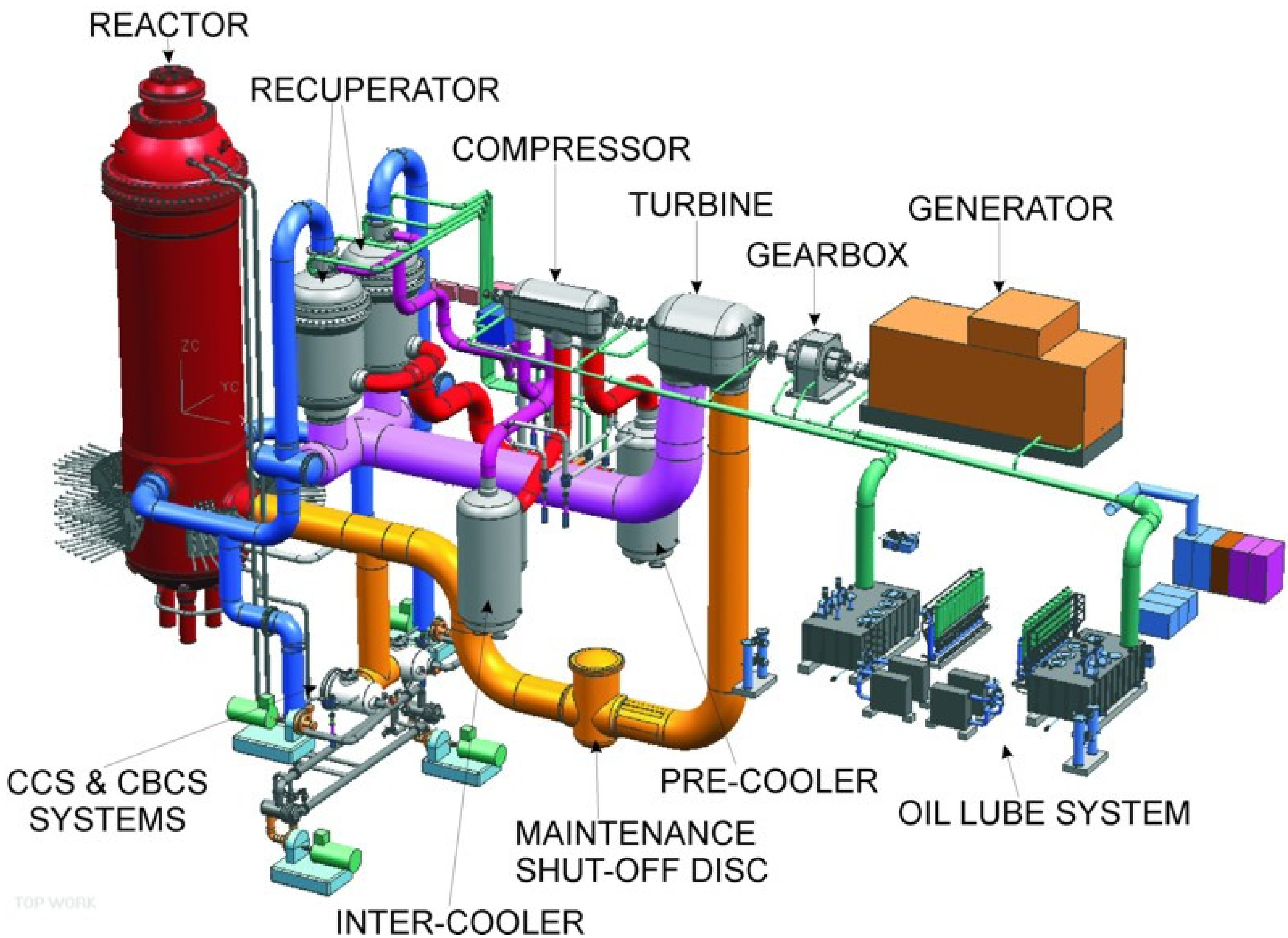


Steam
Heat
exchanger
Water
Water
Pump
Control
rods
Calandria
Pressure
tubes
Fuel rods
Heavy Water
moderator
Heavy Water
Pump
Concrete
Shielding

Gas Cooled Fast Reactor

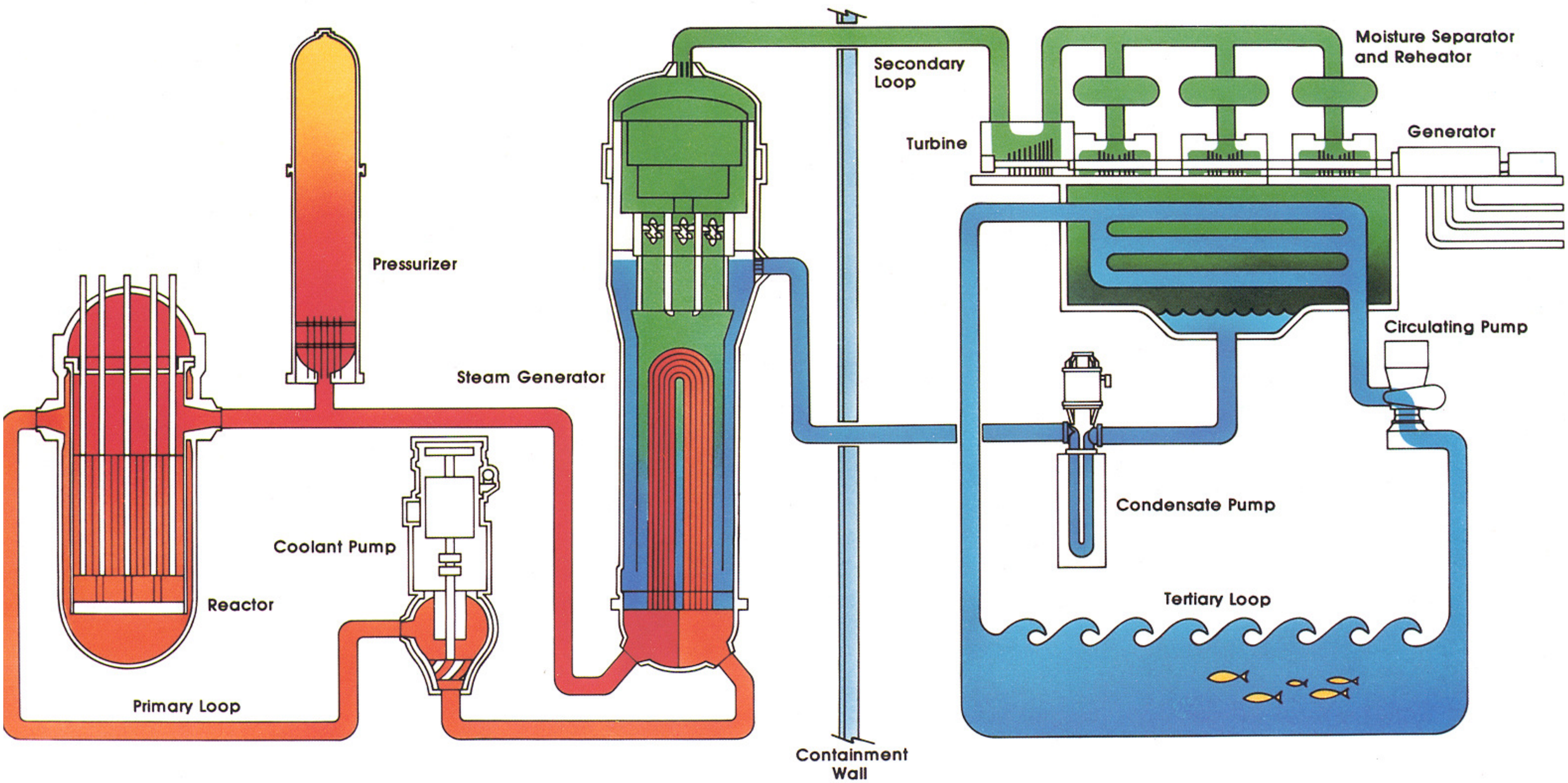


Packed Bed Modular Reactor



Engineers Place in Nuclear Power

- The design, development, operation, and decommissioning of nuclear power facilities is a labor intensive industry
- The expected growth of nuclear power as a competitive form of energy production requires new engineers
  - In the US,
    - Proposals for over twenty new reactors
    - The first 17 combined construction and operating licenses for these have been applied for.
    - It is expected that 4 to 8 new reactors will be on line by 2020.
  - 'Graying' of industry
  - Uncertainty of fossil fuels
  - Environmental concerns
- Engineers of all disciplines are needed to operate nuclear power plants and associated nuclear facilities economically and safely


Moisture Separator and Reheater
Secondary Loop
Turbine
Generator
Pressurizer
Steam Generator
Circulating Pump
Condensate Pump
Coolant Pump
Reactor
Tertiary Loop
Primary Loop
Containment Wall

Conclusion

- Course Objectives and Expectations
- Topics to be covered
- Grading
- Delivery
- Background
- Reactor Types