Recommendation and Limitation of Radiation Exposure, National and International, in Medicine.

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INTRODUCTION

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I - Types of Ionizing Radiation

1. Ionizing Radiation:

Radiation, which removes electrons from the atoms of material producing ionization when passes through it, that is called ionizing radiation. It produces direct chemical changes, that causing biologic damage to living tissue in humans. Accordingly all procedure should be taking into accounts to protect the human from these radiations during use in every medical task. [1]

The ionizing radiation can be results from, radioactive materials, or from x-ray machines, or from the cosmic rays come from the sun, or from nuclear reactions, and various ion beams from accelerators. Ionizing radiations are convenient to categories into two types: [2,3]

1.1. Particulate Radiation:

Beta particles (positive or negative), alpha particles, protons and neutrons are examples of these radiations [3]. They have mass and charge, except neutrons that are neutral particles. They travel with high velocity, but never attain exactly the velocity of light in vacuum [4]. **Table (1)** describes the types of ionizing radiation.

1.2. Electromagnetic Radiation:

These radiations are a form of energy in motion that do not have either mass or charge and can propagate as waves or as discrete packets of energy, known as photons. These radiations travel with the velocity of light. Examples of electromagnetic radiation include radio waves, radar waves, visible light, x-rays, γ-rays and cosmic rays. They differ from each other in wavelength,

frequency and hence in energy. However, of these, only x-rays, γ-rays and cosmic rays are ionizing radiation [4]. The only difference between x- and γ-rays is the origin. X-rays are emitted during rearrangement of electron shells of atoms, and γ-rays originate from transitions within the nucleus itself. [3,6]

Table (1): Types of Ionizing Radiation. [5]

Type	Symbol	Mass (amu)	Charge	Description	Production
Alpha particle	α	4	+2	Doubly ionized helium atom ($_2^4H_e$)	Radioactive decay, mostly heavy atoms
Beta particle (negation)	β^-	0.00055	-1	Negative electron (e)	Radioactive decay
Beta particle (positron)	β^+	0.00055	+1	Positive electron (e^+)	Radioactive decay; pair production
Protons	P	1	+1	Hydrogen nuclei ($_2^1H$)	Van de Graaff generators; cyclotrons
Negative pi-mesons		0.15	-1	Negative particle	Accelerators
Heavy nuclei	Varies	Varies	Varies	Atom stripped of one or more electrons	Accelerators
Neutrons	n	1	0	Neutron of atom	Atomic reactor; cyclotrons
Gamma rays	γ	0	0	Electromagnetic radiation	Radioactive decay radiation
X-ray	X	0	0	Electromagnetic radiation	X-ray tube; rearrangement of orbital electrons

2. Properties of Ionizing Radiation:

Ionization and penetration of various types of ionizing radiation in different materials, e.g., tissue or air is very important in the field of radiation protection. [2]

2.1. Alpha Particles:

Alpha particle is helium ion $(_2^4H_e)^{++}$ relatively low speed. It loses its energy via ionization and excitation. It suffers little deflection at each interaction and its path is characteristically straight line. Owing to the high ionization density of α-particles, they have low penetrating ability. [8]

The ranges of α-particles of energy 1 MeV in air are about 1 cm. Most naturally occurring alpha particles travel 4 to 8 cm in air, and in water or living tissue the range is up to tens of microns, depending on their energy. [2,5]

Alpha particles can be stopped by a very thin sheet of paper or by the outer layer of skin. They are not an external hazard, but once they are inhaled or ingested, they become very hazardous, because they produce internally high ionization density. [7,8]

2.2. Beta Particles:

β-particles have rang approximately 3 meters per MeV of energy in air, and up to tens of millimeters in water or living tissue depending on their energy [2,5]. In matter, β-particles don't follow straight lines, and gradually loses energy and slows down causing ionization. The density of ionization along its track increases until it is finally absorbed. β-particles have ionization ability less than that of α-particles. [8]

They can be shielded or stopped by thin sheets of metal, plastic, or clothing. They can cause burns and they are also harmful if inhaled or ingested, so they become an internal and external hazard [7]. So good protection should be made to safe the people in normal condition. Owing to the penetrating ability of β-particles, they are used in various medical purposes such as diagnosis and treatment of different kinds of disease. [5]

2.3. X-Rays and Gamma- Rays:

The ability of x-rays and γ-rays to ionization is low when passing through matter, and they follow tortuous paths, like β-particles [8]. They have no finite range in matter; and can penetrate to many meters without appreciable attenuation depending on their energy [9]. Lead, steel, and concrete are commonly used to shield and attenuate the intensity of these rays and the beam intensity decreases exponentially in these materials. [7]

These rays have wide uses in medical field. The x-rays are used in radiodiagnosis (deferent x-ray machines), and in therapy (linear accelerator). Radioactive materials are used to diagnose physical problem or destroy cancerous lesions, for example, radioactive Iodine-131 is used in nuclear medicine, Cesium-137 is used in brachytherapy, and Cobalt-60 is used in teletherapy. [5]

2.4. Neutrons Radiation:

The discovery of neutrons by Chadwick in 1932 led to the establishment of the neutron-proton model of atom [10]. Conventionally, neutrons are classified, according to their energy in three categories, namely, slow, fast and relativistic neutrons [11,12]. Fast and relativistic neutrons are particular importance in radiology and radiotherapy. [13]

Neutron radiation can cause ionization, because of their lack of charge; they can penetrate deep into target atoms and so interact with their nuclei. Fast neutrons (MeV rang) are slowed down as a result of several such collisions with nuclei, which themselves recoil and produce tracks of dense ionization. When the neutrons reach the eV range, they are termed slow or thermal neutrons. They are ultimately captured by target nuclei, and γ-rays are emitted, in turn producing their own characteristic ionization trails. Neutrons are very destructive of living tissue, being best absorbed in materials containing similarly "sized" particles, such as the hydrogen atoms in water or wax. [8]

3. Radioactivity:

Radioactivity, first discovered in 1896, is a phenomenon in which radiation is given off by the unstable nuclei of the elements. This radiation can be in the form of particles or electromagnetic radiation or both. They are α-particles, β^--particles, and γ-rays. [14]

A radionuclide has excess energy that is caused the instability of nucleus. The stability of nucleus depends on the relative number of neutrons and protons. All nuclides with an atomic number greater than 82 are radioactive and many of them are naturally occurring. A radionuclide is changed its physical identity to become a new isotope or element through what is called radioactive decay, or disintegration. [7]

Radioactive isotopes can be either natural or artificial. Naturally occurring radionuclides are nuclides that emit radiation spontaneously. Artificial radioactivity is that resulting from man-made nuclides. Such nuclides are made unstable by bombarding stable nuclides with high-energy particles. [15]

3.1. Radioactive Decay Law:

The radioactive decay is a random process. Thus, one can only talk about the average number of radionuclides disintegrating during a period of time, which is known as the disintegration rate of a particular radionuclide [4]. The radioactive decay can be expressed by the following equation which is known as the decay low:

$$N_{(t)} = N_0 e^{-\lambda t} \qquad (1)$$

Where, N_0 is the initial number of radioactive atoms at time $t = 0$, N is the number of radioactive atoms present in the sample after time t, and λ is the decay constant which is defined as the instantaneous fraction of atoms decaying per unit time. Each radioactive atom has its own characteristic decay constant. The term $e^{-\lambda t}$ is called the decay factor. The minus sign indicates that the number of the radioactive atoms decreases with time. [14,16]

3.2. Activity:

The activity of a radioactive material is defined as the number of decays per unit time, i.e., the rate of decay. Eq.(1) can be expressed in term of activity as:

$$A = A_0 e^{-\lambda t} \qquad (2)$$

Where, A is the activity after time t, A_0 is the original activity equals λN_0 [14,16]

The historical unit of activity was the curie (Ci), 1Ci = 3.7x 10^{10} dps. The SI unit for activity is becquerel (Bq), 1Bq = 1 dps. So the curie is related to the becquerel by: 1 Bq = 2.7 x 10^{-11} Ci. [3]

3.3. Half-Life ($T_{1/2}$):

It is defined as the time required to reduce the activity or the number of radioactive atoms to half the initial value. By substitute in equation (2) we get:

$$T_{1/2} = 0.693/\lambda \qquad (3)$$

Table (2) gives the half-lives of some radioisotopes [16], and **Figure (1)** illustrates the decay of equation (2) in terms of half-life. [4]

Table (2): Some radioisotopes frequently used for different applications.

Radioisotope	Half-Life	Radioisotope	Half-Life
^{60}Co	5.2 year	^{24}Na	15 hour
^{137}Cs	30 year	^{32}P	14.3 day
^{192}Ir	74 day	^{45}Ca	165 day
^{131}I	8 day	^{47}Ca	4.7 day
^{125}I	60 day	^{55}Fe	2.7 year
^{99m}Tc	6 hour	^{57}Co	270 day
^{198}Au	2.7 day	^{58}Co	71 day
^{206}Bi	6.3 day	^{110m}Ag	253 day
^{241}Am	432 year	^{11}C	20.4 minute
^{239}Pu	2.4x10^{4} year	^{3}H	12.3 year

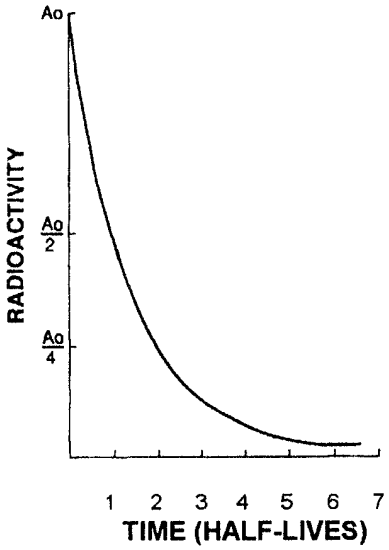


Figure (1): Plot of radioactivity versus time. [4]

3.4. Mean Life (T_a):

It is the average lifetime for the decay of a group of radionuclides, and is related to the decay constant λ and half life $T_{1/2}$ as follows:

$$T_a = 1/\lambda$$

$$T_a = 1.44\ T_{1/2} \qquad (4)$$

In one mean life, the activity of a radionuclide is reduced to 37% of its initial value [4,14,16]. Each radioactive material has its own decay rate and it can be characterized by any one of its own decay constant, half-life, or mean life.

3.5. Specific Activity:

The specific activity is the concentration of radioactivity in radioactive sample [16]. So it can be defined as the activity per unit mass or volume of radioactive sample, and it is expressed as radioactivity per mole of a labeled compound, such as, Ci/mole or Bq/mole for ^{3}H-, ^{14}C-, and ^{35}S-labeled compounds. The specific activity of a pure or carrier-free radioactive sample can be calculated by the relation:

$$\text{Specific activity} = \text{activity / mass} = \lambda A_v/A \qquad (5)$$

Where, A and A_v are the mass number of the sample and Avogadro's number respectively. [3,4]

II- Interaction of Radiation with Matter

The mechanisms by which radiation interact with matter help explain many important concepts in radiology and radiation protection [1]. When an ionizing radiation passes through a matter, it may interact with matter by transfer its energy to the medium, producing ionization and excitation of the atoms along radiation paths. If the absorbing medium consists of body tissues, sufficient energy may be deposited within the cells, destroying their reproductive capacity. [3]

Particulate radiations are known as directly ionizing radiation provided; they have sufficient kinetic energy to produce ionization by collision as they penetrate matter. Electromagnetic radiations such as x- and γ-rays in addition to neutrons are known as indirectly ionizing radiation since they liberate directly ionizing particles from matter when they interact with matter. [14]

In quantum physics, all interactions are random events. However, while the photon interaction are 'yes' or 'no' type of events (i.e., a photon either interacts and is lost or goes through without interaction) the particle interactions are a series of Coulomb interactions involving small amounts of energy loss. Accordingly, photon interactions lead to photon beam attenuation and absorption while the particle interactions lead to particle stopping power and particle energy deposition. [17]

1. Interactions of Photons with Matter

1.1. Types of Photon Interaction:

When photons (x- or γ-rays) pass through matter, they transmit, scatter, or are absorbed [5]. Unlike particles, the photons can lose all of their energy, or a fraction of it, in a single encounter. Because these rays travel a long path in the absorber before losing all energy, they are referred to as penetrating radiations.[4]

In general, photons are capable of having 12 different types of interactions with matter [18]. However, in the energy range of interest in medical purposes, there are five interactions are important [17]. Some of these interactions are very important in diagnostic radiography and, the other is important in the field of radiation therapy or in radiation protection. These interactions are as follows [19]:

1.1.1. Coherent Scattering:

This process occurs when the energy of photons in the beam is small compared with the ionization energy of the atoms of the absorber medium, i.e., it occurs with low energy radiation (below 10 keV).

The photon of radiation interacts with an electron in an atom and rebounding away in a different direction (**Figure (2)**). The photon does not lose energy because it does not have enough energy to release the electron from its shell. The interaction makes up only a small portion of photon scattering. This process is not a significant cause of attenuation at the x-ray energies normally used in radiography. [20]

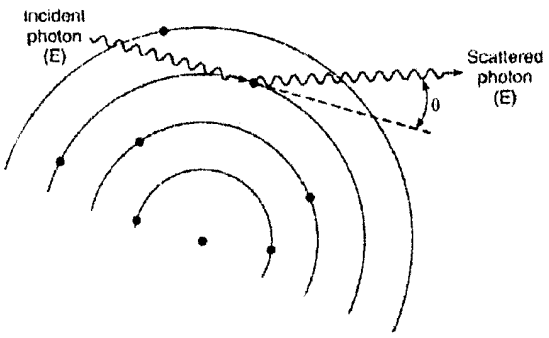


Figure (2): A classic, or coherent scattering. [19]

1.1.2. Photoelectric Effect:

Photoelectric interaction occurs when an incident photon having energy (E_i) just somewhat greater than the binding energy (E_b) of an inner-shell electron. This results in completely absorption of the incident photon and the ejection of an inner shell electron usually from K- or L-shell (**Figure (3)**). Any energy above this binding energy is transferred as kinetic energy (E_e) to the ejected photoelectron.

Energies of the ejected photoelectrons, that important in calculations of patient dose, can be determined by using the law of conservation of energy:

$$E_i = E_b + E_e \qquad (6)$$

Each time a photoelectric interaction occurs, an incident photon disappears, and an ion pair is created. The ejected photoelectron may also interact with other atoms, causing excitation or ionization, until all its kinetic energy disappears. The photoelectron is usually absorbed within a few microns of the medium. In the human body, the energy transfer results in increased patient dose and contributes to biologic damage of tissues. [19]

In general as a result of the photoelectric effect, a vacancy exists in the inner shell of the parent atom. So, an electron from an outer shell drops down to the vacated inner-shell releasing energy in the form of photon, which is termed a *characteristic radiation*. It is locally absorbed in the irradiated object. [1]

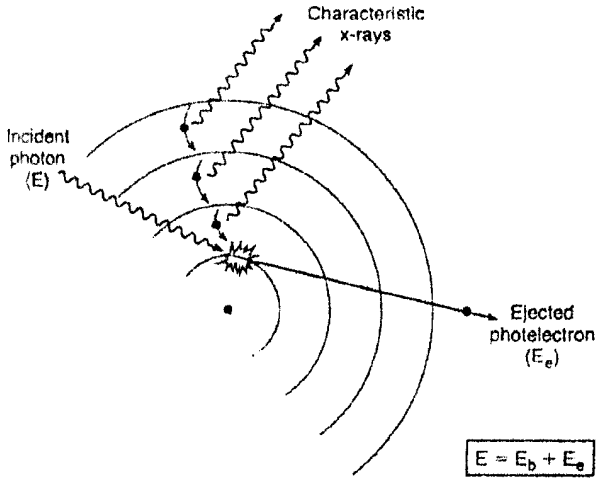


Figure (3): A photoelectric effect. [19]

The photoelectric interaction decreases as the energy of the incident photon increases. It is more likely to occur when the incident photon energy is just a little greater than the shell electron-binding energy. A photoelectric event increases also as the z number of the absorber increases [1,19]. Roughly, the probability of photoelectric effect is approximated as follows:

$$\tau \alpha Z^n/E^3 \quad (7)$$

Where n varies between 3 for low energy to 5 for high energy photon. [21,9]

1.1.3. Compton Scattering:

Compton scattering is a process in which a photon is partially absorbed by an outer-shell electron. The electron absorbs enough energy to break the binding energy and it is ejected while the remaining photon energy exits the atom (**Figure (4)**). The ejected electron is called a recoil electron and it may ionize other atoms in the same manner as mentioned in "Photoelectric Effect". The formula for Compton scatter is:

$$E_i = E_s + (E_b + E_e) \quad (8)$$

Where, E_i is incident photon energy, E_s is Compton scatter photon energy, E_b is binding energy of orbital electron and E_e is kinetic energy of recoil electron.

The Compton scatter photon has less energy than the incident photon, so it may interact with another atom and ionizes it through photoelectric process or Compton scattering. It also may emerge from the patient, in which case it may contribute to degradation of the radiographic image or produce a health hazard to the radiographer or radiologist. For this reason, scatter radiation is the primary source of occupational exposure for radiographers and radiologists. [5]

The probabilities of occurrence of Compton scatter increases as photon energy increases, in the diagnostic range (around 20 to 150 keV). However, the probabilities of Compton scatter decreases with an increase in photon energy above 500 keV. The Compton scattering probability is independent of the atomic number z of the absorber. [4,5]

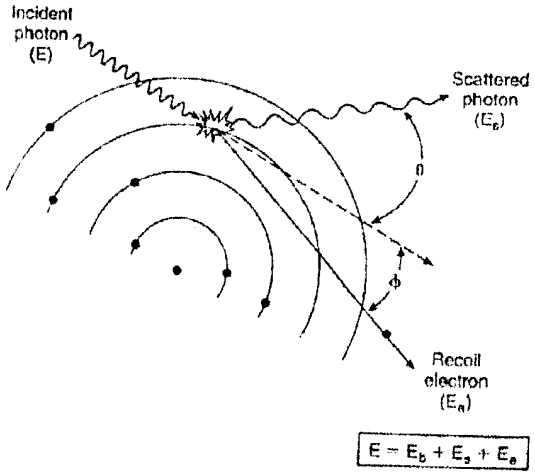


Figure (4): A Compton scattering interaction. [19]

The angle of the scattered photon may range from just above 0 ° (straight ahead) to 180 ° (backscatter) degrees. In general, for specific incident photon energy, as the scattering angle increases, the energy of the scattered photons decreases (**Figure (5)**). The direction of the scatter travels is a major factor in planning protection for members of medical radiology or radiotherapy. [5,19]

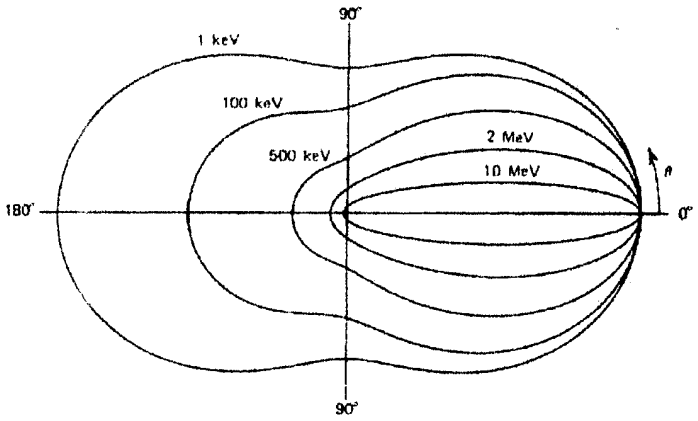


Figure (5): Energy of scattered radiation as a function of scattering angle. [3,19]

1.1.4. Pair Production:

In Pair production the high-energy photon (>1.022 MeV) strongly interacts with the nucleus of an atom of the absorber and disappears. The energy of the photon is transformed into two new particles, a negatron and a positron. Any energy of the incident photon excess than 1.022 MeV appears as kinetic energy of the electron-positron pair. (**Figure (6)**). [1,19]

During the interaction the positron and the electron annihilate each other, and in their place, energy appears that is carried off by two 0.511 MeV photons moving in opposite directions. These two photons may either penetrate or interact with the absorber through Compton and Photoelectric effects [1,19]. Pair production can be expressed as:

$$E_i = 1.022 \text{ MeV} + E_e + E_{e+} \quad (9)$$

Where, E_i is incident photon energy, E_e is electron kinetic energy and E_{e+} is positron kinetic energy. [1,19]

This type of photon interaction becomes important in tissue at energies greater than 10 MeV. The probability of pair production linearly increases with both z number and the energy of the photon [4,5]. Although pair production does not have any direct use in diagnostic radiology, it appears significantly in radiation therapy. An annihilation radiation is used in positron emission tomography (PET). [1,19]

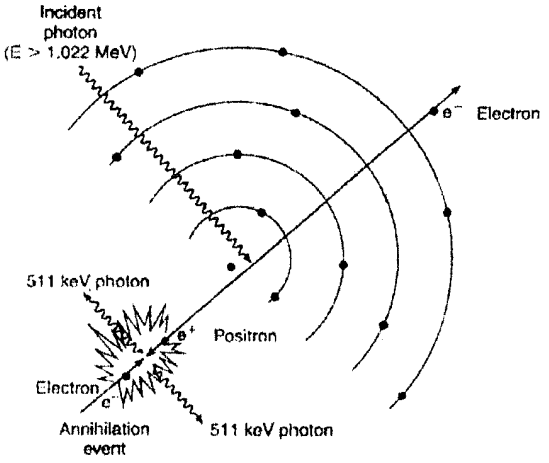


Figure (6): Pair production.

1.1.5. Photonuclear Effect:

In photonuclear effect, a high-energy photon (>10 MeV) as is found in radiation therapy, is absorbed by the nucleus. The nucleus undergoes excitation and becomes radioactive. To become stable again, the nucleus emits neutrons, protons, alpha particles, and clusters of fragments and/or gamma rays. [5]

The use of photons in the MeV energy range can make certain machinery components used in therapy radioactive for a short period of time after use. Even walls of rooms in which high-energy photon radiation is used for therapy may become slightly radioactive as a result of photonuclear interactions. The effect is usually short-lived and not a radiation hazard for personnel. [19,22]

Figure (7) shows the relative percentages of different photon interactions with water (soft tissue equivalent) as a function of photon energy.

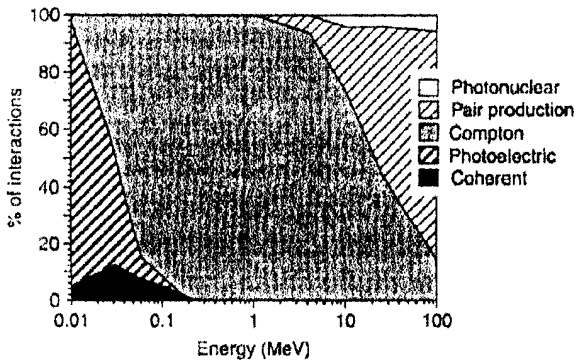


Figure (7): Relative percentages of photon interactions in water as a function of photon energy. [23]

1.2. Photon Attenuation:

1.2.1. Linear and Mass Attenuation Coefficients:

Attenuation results from absorption by the photoelectric effect, Compton scattering, and pair production, depending on the photon energy, the density and thickness of the absorber. Some of the photons may pass through the absorber without any interaction leading to the transmission of the photons. Attenuation of γ- and x- radiations is an important factor in radiation protection, in which shielding material thickness must be determined in order to reduce radiation exposure. [4,14]

As shown in **Figure (8)**, if a photon beam of initial intensity I_0 passes through an absorber of thickness x, then the transmitted beam I_x is given by the exponential equation:

$$I_x = I_0 e^{-\mu x} \qquad (10)$$

Where μ is the linear attenuation coefficient of the absorber for the photons of interest and has the unit of cm^{-1}. The factor $e^{-\mu x}$ represents the fraction of the photons transmitted. [4,14]

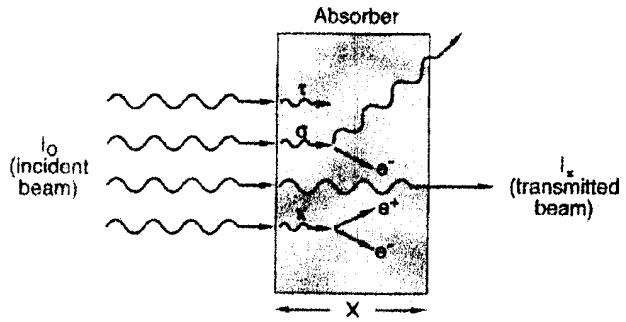


Figure (8): Illustration of attenuation of a photon beam (I_0) in an absorber of thickness x. [4]

The linear attenuation coefficient (μ) is the sum of photoelectric coefficient (τ), Compton coefficient (σ), and pair production coefficient (κ). [4,14]

$$\mu = \tau + \sigma + \kappa \qquad (11)$$

The linear attenuation coefficient (μ) is defined as the fraction of γ-ray or x-ray removed from the beam per unit thickness of a medium. [24]

Linear attenuation coefficient normally decreases with the energy of the γ-ray or x-ray photons and increase with the atomic number and density of the absorber. The relative contributions of photoelectric, Compton scattering, and pair production coefficients, in water (equivalent to body tissue) at different energies are illustrated in **Figure (9)**.

An important quantity, μ_m, called the mass attenuation coefficient, is given by the linear attenuation coefficient divided by the density ρ of the absorber i.e., $\mu_m = \mu / \rho$. The mass attenuation coefficient μ_m has the unit of cm^2/g or cm^2/mg. The mass attenuation coefficient for fat, bone, muscle, iodine, and lead are illustrated in **Figure (10)**. [4]

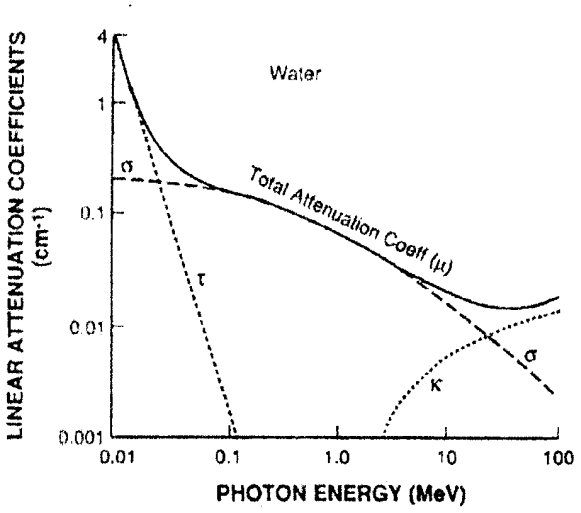


Figure (9): Plot of linear attenuation coefficient of γ-ray interaction in water as a function of photon energy. [4]

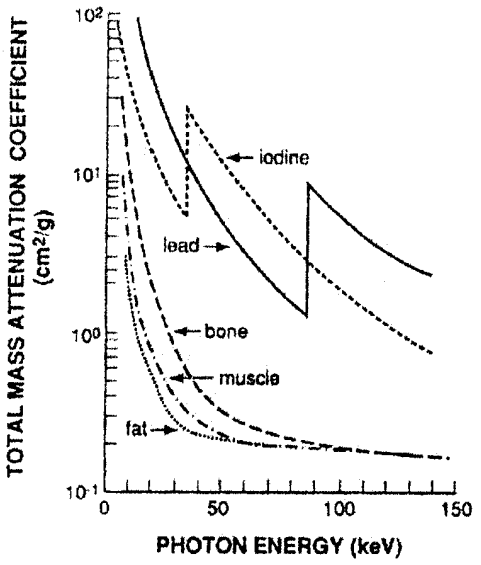


Figure (10): Attenuation coefficients for fat, muscle, bone, iodine, and lead as a function of photon energy. [25]

1.2.2. Half–Value Layer:

The concept of half-value layer (HVL) of an absorbing material for γ- or x- rays is important in the design of shielding for radiation protection. It is defined as the thickness of the absorber that reduces the intensity of a photon beam by one-half. The HVL depends on the energy of the radiation and the atomic number of the absorber. It is greater for high-energy photons and smaller for high-Z materials.

For monoenergetic photons, the HVL of an absorber is related to its linear attenuation coefficient by the relation:

$$HVL = 0.693/\mu \quad (12)$$

The HVL has units of cm. **Table (3)** gives the HVLs of lead for different radionuclides. In term of HVL the attenuation equation can be written as follows:

$$I_x = I_0\,(0.5)^N \quad (13)$$

Where, N = x/HVL (the thickness of the material in terms of half-value layers)

Table (3): Half-value layer values of lead for commonly used radionuclides. [26]

Radionuclides	HVL, Lead (cm)	Radionuclides	HVL, Lead (cm)
^{137}Cs	0.65	^{57}Co	0.02
^{99m}Tc	0.03	^{131}I	0.30
^{201}Tl	0.02	^{18}F	0.39
^{99}Mo	0.70	^{60}Co	1.2
^{67}Ga	0.10	^{192}Ir	0.6
^{123}I	0.04	$_{198}Au$	1.1
^{111}In	0.10	^{226}Ra	1.3
^{125}I	0.003		

Another important quantity, **Tenth-Value Layer (TVL)**, is the thickness of an absorber that reduces the initial beam intensity by a factor of 10. It is given by: [4]

$$TVL = \ln(0.1)/\mu = 2.30/\mu = 3.32\ HVL \quad (14)$$

A beam produced by an x-ray generator is polyenergetic. Attenuation of such a beam is no longer quite exponential. This effect is illustrated in **Figure (11)**, in which the plot of transmitted intensity is not a straight line. The slope of the attenuation curve decreases with increasing absorber thickness because the absorber or filter preferentially removes the lower-energy photons. [14]

In general, as the filter thickness increases, the average energy of the transmitted beam increases or the beam becomes increasingly harder. Thus, by increasing the filtration in such an x-ray beam, one increases the penetrating power or the half-value layer of the beam. [14]

Therefore, under conditions of poor geometry, i.e., for a broad beam or for a very thick shield, equation (10) underestimates the required shield thickness because it assumes that every photon that interacts with the shield will be removed from the beam, and thus will not be available for counting by the detector [27]. Thus the attenuation no longer follows an exponential process, as it is reduced by an amount known as the "build-up factor" for any particular source-shield arrangement [28].

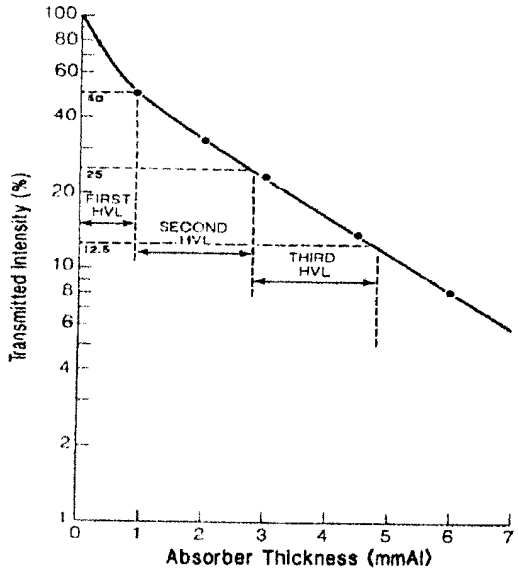


Figure (11): Schematic graph showing transmission of an x-ray beam with a spectrum of photon energies through an aluminum absorber. First HVL= 0.99 mm Al, second HVL= 1.9 mm Al, third HVL= 2.0 mm Al. [14]

2. Interaction of Charged Particles with Matter

Charged particles capable of undergoing different types of interactions with matter. But *elastic* and *inelastic* interactions are more important in medical purposes. In elastic interaction no change in the total kinetic energy of the interacting particles occurs, as the kinetic energy is just transferred from one particle to another. On the other hand, in inelastic interaction, the total kinetic energy is changed after the interaction because some of the kinetic energy is transformed into other types of energy such as x-rays or bremsstrahlung. [5,17]

Charged particles radiations interact with the matter atoms, by Coulomb force between the electric field of the incident particle and electric fields of

orbital electrons and nuclei of atoms of the material. Collisions between the particle and the atomic electrons result in ionization and excitation of atoms. Collisions between the particle and the nucleus result in radiative loss of energy. Particles also suffer scattering without significant loss of energy. [4,14,15]

There are four important quantities associated with the passage of charged particles through matter, these are described as follows:

2.1. Stopping Power:

Linear stopping power (S) for charged particles in a given absorber is simply defined as the rate of energy loss per unit path length and it is given by:

$$S = -dE/dx \qquad (15)$$

Linear stopping power is usually expressed in MeV . cm^{-1}. [3,14]

The rate of energy loss or linear stopping power is proportional to $1/v^2$ or to $1/E$, where v and E are the velocity and energy of charged particle (at least under non-relativistic condition) [3,29]. Also the stopping power is proportional to the square of particle charge and proportional to the atomic number of the absorber atoms (Z). Therefore, particles with the greatest charge will have the largest linear stopping power, and high atomic number or high-density materials will consequently result in the greatest linear stopping power. [3,14]

Since the electrons differ from heavy charged particles in that energy may be lost by radiative processes as well as by coulomb interactions. These radiative losses take the form of bremsstrahlung or electromagnetic radiation. Then, the total linear stopping power for electrons is the sum of the collisional and radiative losses:

$$dE/dx = (dE/dx)_c + (dE/dx)_r \qquad (16)$$

The radiative losses are most important for high electron energies and for absorber materials of large atomic number. The rate of energy loss of electrons (collisional and radiative losses) is shown in **Figure (12)**. For typical electron energies (less than a few MeV), the average bremsstrahlung photon energy is quite low. [3,17]

It is common to express the stopping power also as mass stopping powers, and mass stopping powers are derived by dividing the linear stopping powers by the density, ρ, of the material. As the linear stopping power is proportional to density, the mass stopping power is independent of density. [29]

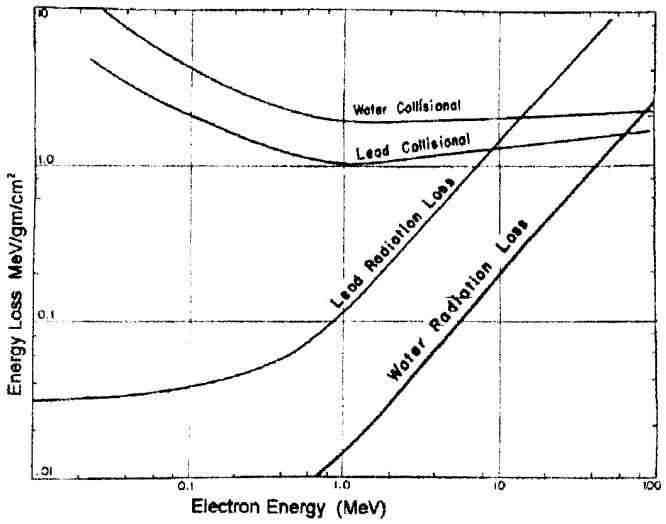


Figure (12): Rate of energy loss in MeV per g/cm^2 as a function of electron energy for water and lead. [30]

2.2. The Bragg Curve:

A plot of the rate of energy loss along the track of charged particle is known as a Bragg curve (**Figure (13)**). The peak near the end of the particle range is called the Bragg peak. This phenomenon is predominant for heavy charged particles, whereas it is not observed or is negligible for electrons.

Due to the Bragg peak effect and minimal scattering, protons and heavier charged particle beams provide a much sought – after advantage in radiotherapy – the ability to concentrate dose inside the target volume and minimize dose to surrounding normal tissues. [3,4,14]

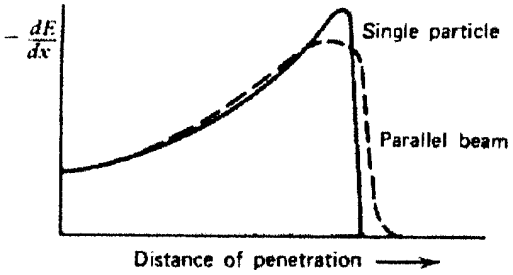


Figure (13): The specific energy loss along an alpha track and Bragg ionization peak. [3]

2.3. Linear Energy Transfer (LET):

It is defined as the amount of energy deposited by the radiation per unit length of the path. It can be expressed as:

$$LET = SI \times W \quad (17)$$

Where, SI is the specific ionization (number of ionizations per distance), and W is the average energy expended per ion pair produced. The LET is expressed in units of keV/μm and it is very useful in concepts of radiation protection and radiobiology. [4,15]

X- and gamma rays and β particles interact with matter, lose only little energy per interaction and therefore have low LETs / low SIs, so they relatively produce little biologic damage. In contrast, heavy charged particles (α-particles, deuterons, and protons) lose energy rapidly, producing many ionizations in a short distance, and thus have high LETs / high SIs, thereby they cause greater damage [4,5,15]. The relation between SI and LET is illustrated in **Table (4)**.

Table (4): Relationship between specific ionization (SI) and linear energy transfer (LET). [5]

Average SI	Average LET
≤ 100	≤ 3.5
100 – 200	3.5 – 7.0
200 – 650	7.0 – 23
650 – 1500	23 – 53
1500 – 5000	53 – 175

2.4. Particle Range:

It is the average distance traversed by the particle in an absorber, until it loses its excess kinetic energy, in the direction of the particle [4,9]. The range can be determined by using the following mathematic relationship: [15]

$$R = E / LET \quad (18)$$

Where, E is the energy of the incident particles in (MeV) and R is in units of (cm) or in mass per unit area (mg/cm^2). The range of charged particles of a given energy is thus a fairly unique quantity in a specific absorber material. [3,9]

In general, the range of a charged particle depends of the mass, charge, and kinetic energy of the particle. The heavier and more highly charged particles have shorter ranges than lighter and lower charged particles. The range of charged particles increases with the energy of the particle. The range of the particle also depends on the density of the absorber, in that the denser the absorber, the shorter the range. (4)

The ranges of all identical particles in a given absorber are not exactly the same but show a spread of 3% to 4% (**Figure (14)**). This phenomenon, referred to as the straggling of the ranges, results from the statistical fluctuations in the number of collisions and in energy loss per collision. The range straggling is less prominent with heavy particles but is severe with electrons because it is mostly related to the mass of the particle. The absorber thickness that reduces the beam intensity by one half is called the mean range. (4)

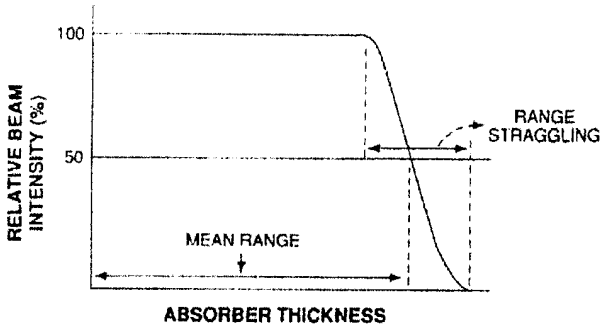


Figure (14): Mean range and straggling of charged particles in an absorber. (4)

2.5. Bremsstrahlung:

When high energetic electrons pass through matter and come close to the nucleus of the atom, they lose energy as a result of deceleration in the Coulomb field of atomic nuclei. The loss in energy appears as an x-ray, which is called bremsstrahlung and it is commonly used in radiographic procedures. (4,15)

Bremsstrahlung production increases with the kinetic energy of the particle and the atomic number (Z) of the absorber (4). For example the rate at which a 1 MeV electron loses energy by emitting radiation in tissue is less than 1% of its total rate of energy loss, and it is not until the electron energy exceeds 100 MeV that the radiation process predominates (29).

III- Radiation Units

Many quantities and units of radiation have been developed over the years by the International Commission on Radiological Protection (ICRP) and the International Commission on radiation Units and Measurement (ICRU). Some of these are rather specialized, and are only likely to be used by persons with a specific interest in radiation protection. [31]

In 1900 to 1930 the unit in use was called the **skin erythema dose,** defined as the received quantity of radiation that causes diffused redness over an area of skin after irradiation. Because the amount of radiation required to produce the erythema reaction varied from one person to another, it was a crude and inaccurate way to measure radiation exposure. In 1937 the ICRU defined the **roentgen (R)** as the unit of measurement for exposure to x- and γ-radiation. Also it was redefined in 1962 to increase accuracy and acceptability. [1]

1. Exposure (X):

Exposure is a measure of the ability of gamma- and /or x-rays to cause ionization in air. As the intensity of x-ray exposure of the air volume increases, the number of electron-ion pairs increases [2]. The exposure is precisely defined [32] in terms of the amount of ionization produced in air by the radiation source. Exposure is defined as the total electrical charge per unit mass of air only generated by x-ray and gamma-ray photons with energies up to 3 MeV. [1]

The traditional unit of exposure is the *roentgen (R)*, which is defined as the quantity of x- or γ- radiation that produces ions carrying electric charge, of either sign, equal to one electrostatic unit per 1 cm^3 of dry air under standard pressure and temperature (STP). The (SI) unit of exposure is coulomb per kilogram *(C/kg)*. It is defined as that quantity of x- or γ- radiation that produces in air, ions carrying 1 coulomb of charge (of either sign) per 1 kg air. The relation between the *C/kg* and *R* is: 1 C/kg = 3881 R. [2,27,28,33]

2. Absorbed Dose (D):

When matter is irradiated with ionizing radiation it is important to know how much energy is transferred from the radiation to material exposed. The quantity of energy transferred from radiation is known as the absorbed dose and is defined as the energy absorbed per unit mass of the irradiated medium [2,20,34]. The quantity absorbed dose has been defined to describe the quantity of radiation for all types of ionizing radiation, including charged and uncharged particles; all materials; and all energies. It is a measure of the biologically significant effects produced by ionizing radiation. [14,27]

The older unit of absorbed dose is *rad*, which represents the absorption of 100 ergs of energy per gram of absorbing material. The SI unit of absorbed dose is the gray (Gy), which represents 1 joule of energy absorbed per kilogram (kg) of material. So,

1 rad = 100 ergs/g
1 Gy = 1 J/kg
1 Gy = 100 rad

In diagnostic imaging, the levels of absorbed dose are likely to be expressed in milligray (mGy) or microgray (μGy). [20,31,35,36]

3. Relative Biological Effectiveness and Quality Factor:

Neutrons and alpha radiations have been found more effective and more toxic than x-rays, beta and gamma radiation in producing damages. When comparing the damage producing potential of various radiations, it is assumed that the comparison is on the basis of equal amounts of energy absorption. The ratio of the amount of energy of 200-keV x-rays required to produce a certain biologic effect to the energy required of given radiation to produce the same biologic effect is called the relative biological effectiveness (RBE) of that radiation [27,28]. So, the RBE is used to specify the variation in the degrees of effectiveness of different types of radiation. By recommendation of ICRU the

term RBE is thus restricted in application to radiation biology. For radiation protection purposes, a conservative upper limit of the RBE for the most important effect due to a radiation other than the reference radiation (200-keV x-rays) is used as a normalizing factor in adding doses from different radiations. This normalizing factor is called the quality factor (Q), and it is related to LET as shown in **Table (5)** [27]. Radiation with a high LET transfers a large amount of energy into a small area and can therefore do more biologic damage than radiation with a low LET. Thus a high- LET radiation has a quality factor that is greater than the quality factor for a low- LET radiation. [1]

Thus use of quality factor in radiation protection is analogous to the use of RBE in radiobiology. The Q factor encompasses RBEs in a very broad sense, independent of the organ or tissue or of the biological end point under consideration. [14]

Table (5): Relationship between quality factor and linear energy transfer. [27]

LET keV per micron in water	**QF**
3.5 or less	1
3.5 – 7.0	1 – 2
7.0 – 23	2 – 5
23 – 53	5 – 10
53 – 175	10 – 20

4. Dose Equivalent (H):

Different types of radiation tend to produce different degrees of biological damage even for the same absorbed dose. The dose equivalent took this biologic impact into consideration by using a weighting factor specified for different types of ionizing radiation that is called quality factor (Q) to adjust the absorbed dose value. [20,35]

Recently, the ICRP commission has decided to replace the dose equivalent (H) what is called Equivalent dose of symbol (H_T). It defines as the

absorbed dose averaged over a tissue or organ (rather than at a point). The change of name also serves to indicate the change from quality factor to radiation weighting factor. The equivalent dose in tissue T is given by the expression:

$$H_T = \sum_R W_R \cdot D_{T,R} \qquad (19)$$

Where $D_{T,R}$ is the absorbed dose averaged over the tissue or organ T, due to radiation R. [34]

The radiation weighting factor (W_R) is a dimensionless factor selected to account for the differences in the biological effectiveness of different types of radiation, within the range of doses of concern in radiation-protection activities [37]. **Table (6)** illustrates radiation weighting factor (W_R) for various types of ionizing radiation.

The SI unit for the dose and the dose equivalent is joules per kg. The special name of the SI unit of dose equivalent is sievert (Sv). The traditional unit of dose equivalent was the rem where 1 Sv = 100 rem. The gray is based on physical factors only, whereas the sievert is based on both physical and biological factors. [2,27,33]

Table (6): Quality factors or radiation weighting factor W_R for various types of ionizing radiation. [1,34,37]

Type of ionizing radiation	Q or W_R
X-ray photons	1
Beta particles	1
Gamma photons	1
Thermal neutrons	5
Fast neutrons	20
High-energy external protons	1
Low-energy internal protons †	20
Alpha particles	20
Multiple charged particles of unknown energy	20

† Protons produced as a result of neutrons interacting with the nuclei of tissue molecules.

5. Effective Dose Equivalent (H_E):

Whole body exposures are rarely uniform. Some organs and body tissue vary considerably in the absorbed dose received and their sensitivity to random radiation-induced responses. To take into account these non-uniform irradiation situations the concept of effective dose equivalent has been adopted by the ICRP and the NCRP. [1,14,20,34]

The effective dose equivalent is a quantity measuring the biological risk in exposing to ionizing radiation a single organ or tissue or several organs simultaneously [2]. The effective dose equivalent is defined as the sum of the products of the dose equivalent for irradiated tissues or organs and the weighting factor applicable to each of the body organs or tissues that are irradiated [14,37,38,39,40]. Mathematically:

$$H_E = \sum W_T \cdot H_T \leq H_{wb} \qquad (20)$$

Where W_T is the weighting factor of tissue T, H_T is the mean dose equivalent received by tissue T and H_{wb} is the dose equivalent when the whole body is irradiated uniformly. Effective dose is also expressed in sievert (Sv). [27,31,37,38,40]

The weighting factors of tissue (W_T) represent the proportionate risk (stochastic) of tissue when the body is irradiated uniformly. They are derived from risk coefficients (i.e., risk per unit dose equivalent) [38]. This factor assigns risk for potential biologic responses from various type of ionizing radiation [1]. If radiation dose is uniform throughout the body then the total risk factor is 1 [27]. **Table (7)** gives the weighting factors for various types of tissues and organs.

Effective dose is similar, in terms of overall risk, to a uniform whole-body exposure in which each organ receives an equivalent dose equal to the effective dose. It is used extensively in radiation protection, and is also useful for categorizing diagnostic imaging procedures [41–44]. Because of the averaging procedures involved, however, some caution needs to be exercised in applying

effective dose to individual patients or workers, where it may only be interpreted as an approximate indicator of risk. [45–47]

Table (7): Tissue weighting factor (W_T) for different tissues and organs. [a] [34,37,48]

Organ or tissue	W_T
Gonads	0.20
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05
Whole body	1

[a] The values have been developed for a reference population of equal numbers of both sexes and a wide range of ages. In the definition of effective dose, they apply to workers, to the whole population and to either sex. These W_T values are based on rounded values of the organ's contribution to the total detriment.

6. Kerma (K):

In the case of indirectly ionizing radiation, such as x-, gamma-rays and fast neutrons, we sometimes interested in the initial kinetic energy of the primary ionizing particles (the photoelectrons, Compton electrons, or positron-negatron pairs in the case of photon radiation) produced by the interaction of the incident radiation per unit mass of interacting medium. This quantity is called the kerma (k) (**k**inetic **e**nergy **r**eleased per unit **ma**ss). It is defined as the sum of the kinetic energy of all the charged ionizing particles liberated per unit mass of the specified material by uncharged ionizing particles. [32,49,50]

Kerma is measured in the same units as absorbed dose, i.e., joule per kilogram (J/kg) and its special name is gray (Gy). An air kerma of 1 Gy represents a transfer of 1 joule of energy from the x-ray beam to air per kg of air, and exposure of 1 R corresponds to an air kerma of 8.73 mGy. [32,49]

The quantity air kerma can be used as an alternative to exposure. Air kerma can be taken to have the same value as the absorbed dose in air. The numerical value of exposure in roentgens may be assumed to be approximately equal to the numerical value of air kerma in rads, which is equal to air kerma in centigray (cGy). [31,51]

7. Committed Doses:

Radiation doses received from radionuclides deposited in organs and tissues are distributed temporally depending upon the effective half-life of the radionuclide. To take account of this continuing irradiation of organs and tissues that occurs after the intake of radionuclides, committed dose concept are used.

The committed equivalent dose, $H_T(\tau)$, is the time integral of the equivalent dose-rate in a specific tissue T following intake of a radionuclide into the body. For a single intake of radionuclide at time t_o, $H_T(\tau)$ is given by:

$$H_T = \int_{t_0}^{t_0+\tau} \dot{H}_T \, dt \qquad (21)$$

Where H_T is the relevant equivalent dose-rate in and organ or tissue T at time t, and τ is the period of integration time (in years). If τ is not specified, an integration time of 50 y after the intake is recommended for the occupational case and 70 y for member of the public. [34,37]

The committed effective dose, $E(\tau)$, is defined as the effective dose equivalent accumulated in a given period of time (50y), due to the intake of radionuclide substances [20,34]. The general equations is:

$$E(\tau) = \sum W_T \, H_T(\tau) \qquad (22)$$

The both committed quantities are appropriate for all routine radiation protection purposes, for example, for assessing compliance with the annual effective dose limits and for planning and design. The annual effective dose limit referred to here is the sum of the external effective dose and the committed effective dose from internal emitters. [37,40]

8. Collective Doses:

The quantities referred to above all relate to the exposure of an individual. Further quantities related to exposed groups or populations are used. These quantities take account of the number of people exposed to a source by multiplying the average dose to the exposed group from the source by the number of individuals in the group. The relevant quantities are the collective equivalent dose, S_T, which relates to a specified tissue or organ, and the collective effective dose, S. If several groups are involved, the total collective quantity is the sum of the collective quantities for each group. The unit of these collective quantities is the man-sievert this was previously referred to as man-rem. The collective quantities can be thought of as representing the total consequences of the exposure of a population or group. [34,40]

9. K-Factor or Specific Gamma-Ray Emission:

The gamma radiation exposure rate from a point source of unit activity at unit distance is called the specific gamma-ray emission, and is given in units of coulombs per kilogram per hour at 1 meter from a 1-MBq point source (or, the exposure rate in units of roentgen per hour at 1 meter from a 1 Ci point source. **Table (8)** lists the specific gamma ray emission of some radionuclides. [2,27]

Table (8): Specific gamma-ray emission (K- factor) of some radionuclide.

Radionuclide	K-factor (R-m^2/Ci-h)	Radionuclide	K-factor (R-m^2/Ci-h)
Antimony-122	0.24	Mercuty-203	0.13
Cesium-137	0.33	Potassium-42	0.14
Chromium-51	0.016	Radium-226	0.825
Cobalt-60	1.32	Sodium-22	1.20
Cobalt-57	0.10	Sodium-24	1.84
Gold-198	0.23	Zinc-65	0.27
Iodine-125	0.07	Barium-133	2.00
Iodine-131	0.22	Americium-241	0.016
Iridium-192	0.48		

IV- Biological Effect of Radiation

Biological effects may be divided into a number of categories according to the way they affect different functions of the body and the different ways they take effect. A number of terms like 'genetic' and 'somatic', 'stochastic' and deterministic' and 'acute' or 'chronic' have been used to describe the radiation effects. [52]

1. Effects of Radiation on Cells

The nucleus of the cell is the most sensitive part to radiation and can undergo severe changes upon interaction with ionizing radiations. This sensitivity is mostly attributed to the DNA molecule.

1.1. Direct and Indirect Action of Radiation:

The DNA molecule of a cell is the most sensitive target to radiation. Radiation damage to the cell can be caused by the direct or indirect action of radiation on the DNA molecules. In the **direct action**, the radiation hits the DAN molecule directly, disrupting the molecular structure. Any change in DNA structure by ionizing radiations is called a *mutation*. The number of mutations in the DNA molecule increases with increasing radiation exposure. Some damage to DNA can be repaired by the cell, while some may persist with long-term consequences.

Chromosomes are likely to be affected by mutations of the DNA molecules. Chromosomes may themselves be affected by radiation, causing single or double breaks in the structure of the chromosome. Such alterations are called *chromosome aberrations*. Both DNA mutations and chromosome aberrations can propagate through cell division to future cell generations or may be repaired. Repair of chromosomes after irradiation depends on the sites of break in the DNA molecule or the chromosome, the total radiation dose, the dose rate, and the LET of the radiation. [4]

In the **indirect action**, the radiation hits the water molecules and other organic molecules in the cell, whereby free radicals such as (HO_2) and (RO_2) are produced. Free radicals are very reactive and therefore react with DNA molecules to cause cellular damage. The number of free radicals produced by ionizing radiation depends on the total dose but not on the dose rate. The majority of radiation-induced damage results from the indirect action mechanism, because water constitutes nearly 70% of the cell composition. [4,52]

1.2. Radiosensitivity of Cells:

In living matter, there are two types of cells: differentiated and undifferentiated cells. Undifferentiated cells are those cells that do not have any specific physiologic function except developing into mature cells. Undifferentiated cells undergo mitosis and serve as the precursors for mature cells. In contrast, all mature cells are differentiated and perform specific functions in the living body. For example, red blood cells (RBCs) are mature and differentiated cells performing the function of oxygen carriers, whereas erythroblasts are undifferentiated cells that develop into RBCs through mitosis.

According to the law of Bergonié and Tribondeau, *undifferentiated cells that are undergoing active mitosis are most sensitive to radiation, and differentiated or mature cells are least affected by radiation*. Radiosensitivity is best assessed by cell death. For differentiated cells, it means loss of cellular function, whereas for undifferentiated cell, it means loss of reproductivity. Gropes of cells and their relative radiosensitivity are listed in **Table (9)**. [53]

1.3. Cell Survival Curves:

When mammalian cells are irradiated, not all cells are affected to the same extent. Some cells may die, and others will survive. The cellular response to radiation is illustrated by what is called the *cell survival curve*. Typical cell survival curves are shown in **Figure (15)**. This curve is characterized by three parameters:

Table (9): Radiosensitivity of different types of cells. [53]

Types of cells	Radiosensitivity
Mature lymphocytes Erythroblasts Spermatogonia	Highly sensitive
Myelocytes Intestinal crypt cells Basal cells of epidermis	Relatively sensitive
Osteoblasts Spermatocytes Chondroblasts Endothelial cells	Intermediate sensitivity
Spermatozoa Granulocytes Erythrocytes Osteocytes	Relatively resistant
Nerve cells Muscle cells Fibrocytes	Highly resistant

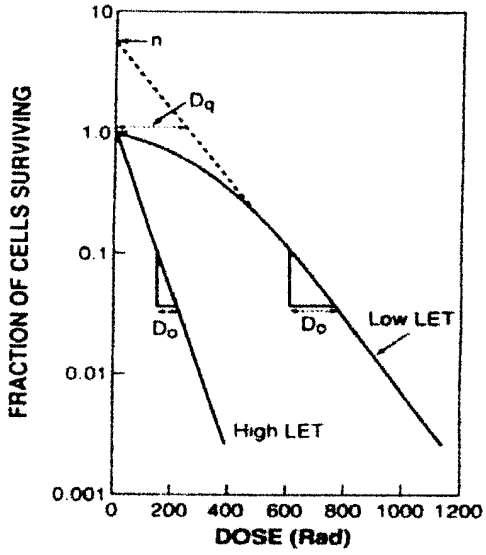


Figure (15): Typical cell survival curves. [4]

The quasithreshold dose, *Dq*, is the dose at which the cell survival curve tends to become a straight line and is given by the width of the shoulder of the curve. The *Dq* indicates that, at low doses, almost all cells repair after irradiation and that cell killing is minimal.

From the slope of the straight line portion of the survival curve D_0 is determined. It is the dose that kills 63% of the total number of cells or (dose at which 37% of cells survive). The value of D_0 is a measure of radiosensitivity of

a given type of cell. For example, a large value of D_0 for a type of cell means that the cells are less radiosensitive and vice versa.

The value of number n obtained by extrapolating the straight line portion of the survival curve back to the y-axis depends on the width of the shoulder of the survival curve, which gives some idea of the number of targets in the cells.[5,54]

1.4. Factors Affecting Cell Response to Radiation:

1.4.1. Dose Rate:

The dose rate that is the delivery of dose per unit time. There is a direct relationship between dose and effect. At low dose rates, only single breaks of chromosomes occur, and so cells have time to repair, whereas at high dose rates, double breaks occur, and so repair is less likely to occur because of the shorter time available to the cells between ionizing events. **Figure (16)** illustrates the effects of three dose rates on the cell survival curve.

At diagnostic levels of radiation, the concept of dose rate has no practical implications. However, dose rate is important in radiation therapy. When a total dose is given to a patient in fractions over a period of time, it should be kept in mind that the interval between fractional doses should be short enough to keep repair of sublethal cellular damage to a minimum. [54]

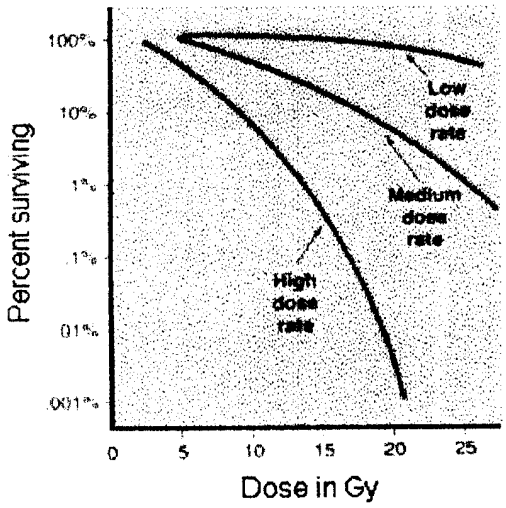


Figure (16): The cell survival curves indicating the effect of dose rates. [55]

1.4.2. Linear Energy Transfer and Relative Biologic Effectiveness:

Linear energy transfer (LET) is defined as the rate at which the energy of the radiation is transferred to tissue.

LET radiations may be divided into two general categories low and high LET radiation. High-LET radiations are densely ionizing radiations causing more double breaks in the chromosomes and thus causing more cell deaths than low-LET radiations. **Table (10)** compares low- and high-LET radiations in terms of physical and biological effects.

Because LET is so closely related to the amount of biologic damage, it is also closely related to the unit of measurement of biologic damage: the relative biologic effectiveness (RBE). [53]

1.4.3. Chemicals:

Several chemicals, if present during radiation exposure, have been found to augment or diminish the effects of radiation on cells. Agents that enhance the cell response to radiation are called *radiosensitizers* and those that protect cells from radiation-induced damage are called *radioprotectors*. [4]

Table (10): Comparison of Low- and High-LET Radiations. [5]

Low LET	**High LET**
< 10 keV/μm	> 10 keV/μm
Sparsely ionizing	Densely ionizing
Random interactions	Uniform energy deposition
Penetrating radiation	Superficial penetration
External radiation hazard	Internal radiation hazard
Indirect damage	Direct damage
Single strand break	Double strand break
Repair not error-prone	Highly error-prone repair
Damage to one side of DNA backbone – usually repairable	Damage to both sides of DNA backbone – not usually repairable
Sublethal	More likely lethal
Dependent oxygen concentration (maximum OER*)	Independent of oxygen concentration (minimum OER*)
Example: x-ray photon	Examples: fission fragments, charged particles

* OER is the oxygen enhancement ratio.

1.4.4. Oxygen Effect:

The concentration of oxygen in a cell or tissue has an important effect on the amount of biologic impact from radiation. It has been found that hypoxic or non-oxygenated cells are very resistant to radiation, whereas oxygenated cells are highly radiosensitive. The concept used to describe the impact of oxygen on radiation effects is called the *oxygen enhancement ratio* (OER). It is given by the ratio of the dose required to produce a given radiation damage to cells in the absence of oxygen to that required to produce the same damage in the presence of oxygen. Some radiations such as alpha particles (High-LET) seem to be insensitive to the presence of oxygen. Others, such as x-ray and gamma rays (Low-LET), have OERs as high as 3 and above. [5,4]

2. Deterministic and Stochastic Effects

High doses of radiation that damage many cells produce effects that can be related specifically to the radiation exposure. Some of these effects occur quite quickly, within days or weeks of exposure. Such effects include skin burns, various types of radiation sickness and damage to the lens of eye. For each of these effects to occur, a minimum radiation dose or threshold has to be exceeded. Once the threshold is exceeded, the severity of the effect increases with the dose.

Effects of this type are called deterministic i.e., the occurrence and severity of the effect is fairly predictable in any individual. The ICRP changed the terminology in 1991, the term deterministic effect has been used rather than nonstochastic or certainty effect. Examples of deterministic effects are central nervous, gastrointestinal and bone marrow systems, skin burns, hair loss, infertility and cataract formation.

The effects that take place even at very low dose levels, and the number of cells transforming increases with increasing dose, are called stochastic effects (i.e., there is no threshold). These are chance events, and by definition cannot be

predicted accurately in any one individual and can be quantified only in terms of probabilities derived from a study of a large, affected population. While the probability of their occurrence is a function of dose their effect on an individual dose not vary.

Cancer production affecting the breast, lung, blood, thyroid and other organs are the main stochastic effects of radiation. The mechanism involves transformation of the cell to increase its malignant potential with consequent development, after a latency period, of a detectable cancer. The three steps of initiation, promotion and progression ascribed to general development of cancer have been associated with radiation-induced tumors, though these concepts are not fully explained (**Figure (17)**).

For a deterministic effect, if the threshold is never exceeded when working with or subjected to radiation, then essentially no radiation danger exists. It is; therefore, very important to establish the level of threshold dose in order to keep below it. For stochastic damage all that can be done is to minimize the dose in order to minimize the problems. [52]

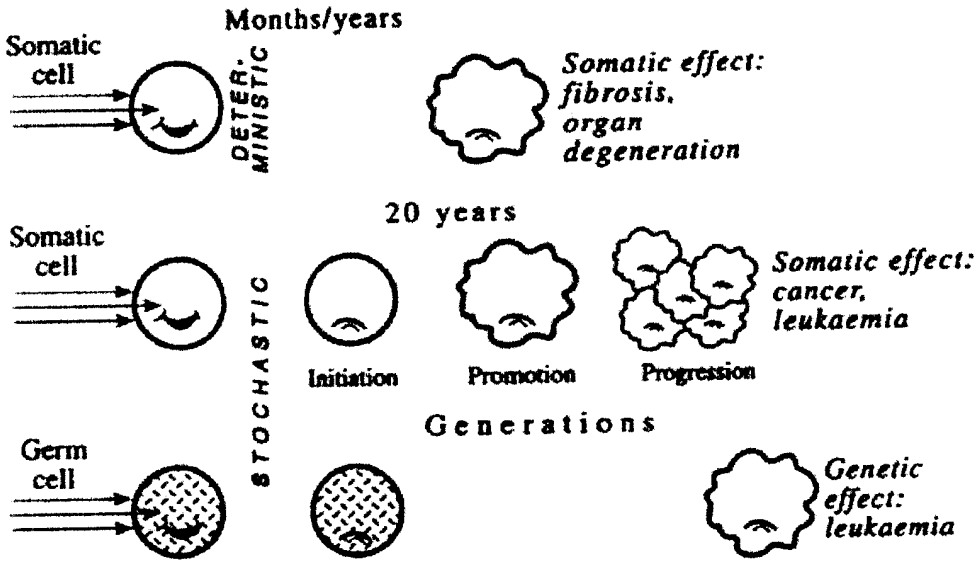


Figure (17): The long term time course and results of deterministic and stochastic effects on somatic and germ cells. [52]

V- Radiation Shielding Design

A shield has been defined as "a physical entity interposed between a source of ionizing radiation and an object to be protected such that the radiation level at the position of that object will be reduced... The object to be protected is most often a human being or anything that is sensitive to ionizing radiation". [56]

For controlling external radiation exposure the absorbing material of shielding used and the thickness required to attenuate the radiations to acceptable levels depend upon the type of radiation, its energy, the flux and the dimensions of the source. The amount of shielding material required may be calculated with reasonable accuracy in most instances. The absorbing material should be installed as close to the source as possible to obtain maximum economy. [28]

1. X-Ray and Gamma-Ray Shielding:

Shielding for protection against x-rays and γ-ray is called structural shielding or protective barriers. In any case, structural shielding is designed to protect people in an occupied area outside an area of high radiation intensity and to ensure the dose does not exceed the applicable maximum permissible value.

X-ray machines that are used for diagnosis and treatment, and high dose rate machines using ^{60}Co and ^{137}Cs sources are housed in rooms requiring of substantial shielding to reduce radiation level to acceptable levels for workers and public [30]. In such rooms, the walls, ceiling, and floors serve as protective barriers, and these could be made of concrete or lead or some other material. [19]

Shielding of diagnostic x-ray facilities is traditionally made using lead and concrete. Many other conventional building materials have been considered as alternatives such as gypsum. Panelcrete, Aquapanel and Betopan are cement-based building materials with used similar to those of gypsum wallboard, whose properties as a diagnostic x-ray shielding material. [57]

New radiation therapy treatment rooms are typically constructed of concrete. Concrete of density 2350 kg m^{-3} is well known radiation-shielding characteristics for x-ray and neutrons from electron linear accelerators (linacs), and gamma rays from radionuclides used in high dose machine. (30,58)

The areas surrounding the room are designated as *controlled* or *uncontrolled*, depending on whether or not the exposure of persons in the area is under the supervision of a radiation protection supervisor. According to the recommendations of the ICRP, the dose equivalent limit for occupational exposure is 50 mSv in 1 year, and the dose equivalent to an individual who is not a radiation worker must not exceed 5 mSv in 1 year. For protection calculation, the dose equivalent limit is assumed to be 1 mSv per week that is used as the design basis for shielding controlled areas and for uncontrolled areas is 0.1 mSv per week. These values approximately correspond to annual dose equivalent limits for occupational and public, respectively. (14,27)

Recently, in 1991 the ICRP in publication No. 60 recommended a new dose equivalent limit that is 20 mSv per year for occupational exposure and 1 mSv per year for public. Therefore, all the previous limits and statements and all next equations should be evaluated or adapted.

Protection is required against three types of radiation: the primary radiation, the scattered radiation, and the leakage radiation through the source housing. A barrier sufficient to attenuate the useful beam to the required degree is called the *primary barrier*. The required barrier against stray radiation (leakage and scatter) is called the *secondary barrier*. The shielding design for protection from x-ray and γ-ray beams is shown in **Figure (18)**.

The following factors enter into the calculation of barrier thicknesses:

1- The maximum kilovoltage at which the x-ray tube is operated.

2- The maximum milliamperes of beam current.

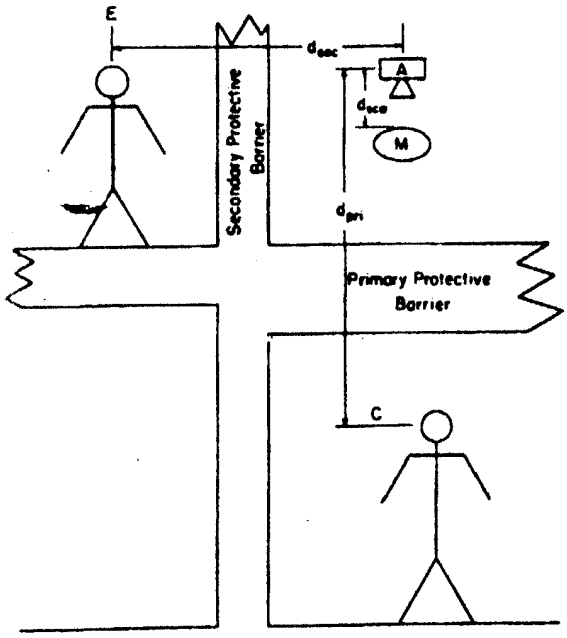


Figure (18): Elevation view of radiation room and its surroundings with indication of distances of interest for radiation shielding calculations. A is the radiation source, M represents the patient, and C and E are positions that may be occupied by persons. (59)

*3- **The Workload (W):*** for x-ray equipment operating below 500 kVp, the workload is usually expressed in milliampere minutes per week, which can be computed by multiplying the maximum mA with approximate exposure time per week in minute of beam "on" time. For megavoltage machines, the workload is usually stated in terms of weekly dose delivered at 1 m from the source. This can be estimated by multiplying the number of patients treated per week with the dose delivered per patient at 1 m. W is expressed in rad/ week at 1 m.

*4- **The Use Factor (U):*** it is the fraction of the workload during which the useful beam is pointed in the direction under consideration. This concept is useful in designing protection for a rotation unit. The use factor depends on the techniques used in a given facility. Typical values are given in **Table (11)**.

*5- **The Occupancy Factor (T):*** it is the factor by which the workload should be multiplied to correct for the degree or type of occupancy of the area in question. When adequate occupancy data are not available, the values for *T* given in **Table (12)** may be used as a guide in planning shielding.

6- The Distance (d): Distance in meters from the radiation source to the area to be protected. Inverse square law is assumed for both the primary and stray radiation. [14,27]

Table (11): Typical Use Factor for Primary Protective Barriers. [14]

Location	Use factor
Floor	1
Walls	¼
Ceiling	¼-1/2, depending on equipment and techniques

Table (12): Typical occupancy factors. [27]

Full occupancy T = 1	Control space, wards, workrooms, darkrooms, corridors large enough to hold desks, waiting rooms, restrooms used by occupationally exposed personnel, children's play areas, living quarters, occupied space in adjacent buildings
Partial occupancy T = ¼	Corridors too narrow for desks, utility rooms, rest rooms not used routinely by occupationally exposed personnel, elevators using operators, and uncontrolled parking lots
Occasional occupancy T = 1/16	Stairways, automatic elevators, outside areas used only for pedestrians or vehicular traffic, closets too small for future workrooms, toilets not used routinely by occupationally exposed personnel

1.1. Primary Protective Barrier:

If P is the maximum permissible dose equivalent for the area to be protected (e.g., 1 mSv/week for controlled and 0.1 mSv/week for uncontrolled area), and B is the transmission factor for the barrier to reduce the primary beam dose to P in the area of interest, then B is given by:

$$B = \frac{P \cdot d^2}{WUT} \qquad (23)$$

It is expressed in $\frac{\text{R/mA - min}}{\text{week}}$ at 1 meter. The results of measuring this value for broad beams of x-rays of various energies that have been transmitted through lead or concrete shields of varying thicknesses are shown in **Figures (19) to (21)**. These transmission curves may be used for the design of shielding

against any x-rays and γ-ray within the range of the maximum potentials as given in the figures.

The choice of barrier material, e.g., concrete, lead, or steel, depends on structural and spatial considerations. The walls and roof barriers are usually constructed out of concrete because it is relatively cheap. Lead or steel can be used where space is at a premium. (28)

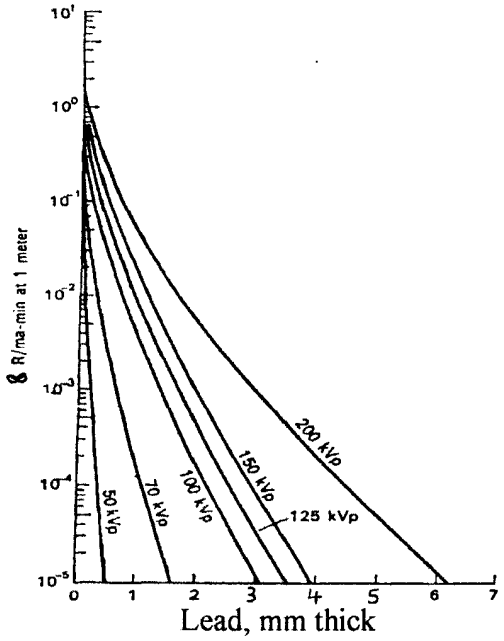


Figure (19): Broad beam attenuation in lead of X-rays produced by potentials of 50-200 kV peak. The measurements were made with a 90° angle between the electron beam and the axis of the pulsed waveform X-ray beam. The 50, 70,100, and 125 kVp X-rays were filtered with 0.5 mm aluminum; the 150 and 200 kVp X-rays were filtered with 3mm aluminum. (60)

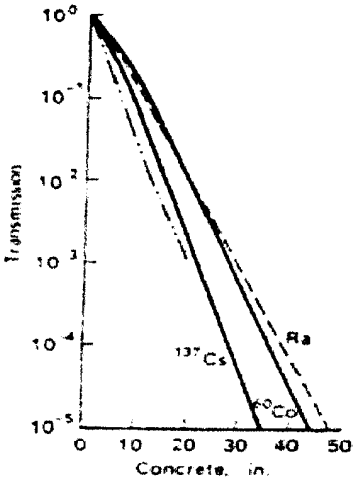


Figure (20): Fractional transmission of gamma rays from ^{137}Cs, ^{60}Co, and Ra (in equilibrium with its decay products) through concrete. The short broken curve represents transmission of ^{60}Co gamma rays under conditions of good geometry. The other curves represent transmission of broad beams. (62)

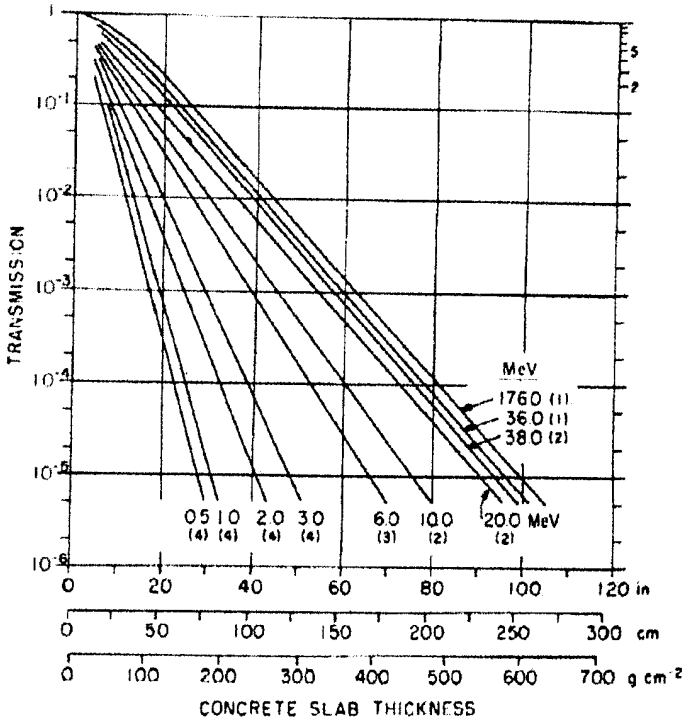


Figure (21): Transmission of thick-target x-rays through ordinary concrete (density 2.35 g cm^{-3}), under broad-beam conditions. Energy designations on each curve (0.5 to 176 MeV) refer to the monoenergetic electron energy incident on the thick x-ray production target. Curves represent transmission to dose equivalent index ratio. (61)

1.2. Secondary Protective Barrier for Scattered Radiation:

A barrier designed for primary radiation provides adequate protection against leakage and scattered radiation. If a barrier is designed for stray radiation only, the thickness is computed for leakage and scattered radiation separately. If the required thicknesses are about the same, we merely add an additional half-value layer to the greater thickness. If the difference between the two calculated thicknesses is one tenth-value layer or more, the thicker of the two will suffice. **Table (13)** shows the half- value layer and tenth-value layer.

The amount of scattered radiation depends on the scattering angle, the energy of the primary beam, and the scattering area (field size). **Table (14)** lists the ratio of the scattered radiation to incident radiation at a distance of 1 meter from the scatterer, for a field size (scattering area) of $400cm^2$.

Table (13): Half-Value and Tenth-Value Layers. [59]

Peak Voltage (kV)	Attenuation Material					
	Lead (mm)		*Concrete (cm)*		*Iron (cm)*	
	HVL	TVL	HVL	TVL	HVL	TVL
50	0.06	0.17	0.43	1.5		
70	0.17	0.52	0.84	2.8		
100	0.27	0.88	1.6	5.3		
125	0.28	0.93	2.0	6.6		
150	0.30	0.99	2.24	7.4		
200	0.52	1.7	2.5	8.4		
250	0.88	2.9	2.8	9.4		
300	1.47	4.8	3.1	10.4		
400	2.5	8.3	3.3	10.9		
500	3.6	11.9	3.6	11.7		
1000	7.9	26	4.4	14.7		
2000	12.5	42	6.4	21		
3000	14.5	48.5	7.4	24.5		
4000	16	53	8.8	29.2	2.7	9.1
6000	16.9	56	10.4	34.5	3.0	9.9
8000	16.9	56	11.4	37.8	3.1	10.3
10000	16.6	55	11.9	39.6	3.2	10.5
Cesium-137	6.5	21.6	4.8	15.7	1.6	5.3
Cobalt-60	12	40	6.2	20.6	2.1	6.9
Radium	16.6	55	6.9	23.4	2.2	7.4

Approximate values obtained at high attenuation for the indicated peak voltages under broad beam conditions; with low attenuation these values will be significantly less.

Table (14): Ratio, a, of Scattered to Incident Exposure [a] [59]

Source	Scattering Angle (From Central Ray)					
	30	45	60	90	120	135
X-Rays						
50 kV [b]	0.0005	0.0002	0.00025	0.00035	0.0008	0.0010
70 kV [b]	0.00065	0.00035	0.00035	0.0005	0.0010	0.0013
100 kV [b]	0.0015	0.0012	0.0012	0.0013	0.0020	0.0022
125 kV [b]	0.0018	0.0015	0.0015	0.0015	0.0023	0.0025
150 kV [b]	0.0020	0.0016	0.0016	0.0016	0.0024	0.0026
200 kV [b]	0.0024	0.0020	0.0019	0.0019	0.0027	0.0028
250 kV [b]	0.0025	0.0021	0.0019	0.0019	0.0027	0.0028
300 kV [b]	0.0026	0.0022	0.0020	0.0019	0.0026	0.0028
4 MV [c]	—	0.0027	—	—	—	—
6 MV [d]	0.007	0.0018	0.0011	0.0006	—	0.0004
Gamma Rays						
^{137}Cs [e]	0.0065	0.0050	0.0041	0.0028	—	0.0019
^{60}Co [f]	0.0060	0.0036	0.0023	0.0009	—	0.0006

[a] Scattered radiation measured at 1 m from phantom when field area is 400 cm^2 at the phantom surface; incident exposure measured at center of field 1 m from the source but without phantom.

[b] From (64). Average scatter for beam centered and beam at edge of typical patient cross-section phantom. Peak pulsating x-ray tube potential. [c] From (65), cylindrical phantom. [d] From (63), cylindrical phantom. [e] Interpolated from (66), these data were obtained from a slab placed obliquely to the central ray. A cylindrical phantom should give smaller values. [f] From (67), modified for F = 400 cm^2.

The scattered radiation, in general, has lower energy compared with the incident energy. However, when designing secondary protective barriers for scattered radiation, the following assumptions must be considered:

1. The energy of the scattered radiation, when the x-rays are generated at 500 kV or less, is equal to the energy of the useful beam. Then, the attenuation of the scattered radiation in the barrier is assumed to be the same as the primary.

2. Gamma ray and x-ray beams generated at high voltages greater than 500 kV are degraded in energy to that of a 500 kV beam after being scattered. Therefore, the transmission curves for the respective kilovoltages are used, whereas for all x-rays and γ-ray of higher energy, the 500 kV transmission curves are used in the design of shielding against scattered radiation [27,63].

If a transmission factor of B_s is required to reduce the scattered dose to an acceptable level P in the area of interest; then B_s is given by:

$$B_s = \frac{P}{aWT} \cdot \frac{400}{F} \cdot d^2 \cdot d'^2 \qquad (24)$$

Where a is the ratio of scattered to incident radiation, d is the distance from source to the scatterer, d' is the distance from the scatterer to the area of interest, and F is the area of the beam incident at the scatterer. The use factor (U) for the secondary barrier is considered unity. [30]

1.3. Secondary Protective Barrier for Leakage Radiation:

The National Committee on Radiation Protection (NCRP) specify the following protective source housings for medical x-ray and γ-ray installations:

1. Diagnostic type: the leakage radiation at a distance of 1 meter from the target cannot exceed 0.1 R (0.1 cGy) in 1 hour when the tube is operated at its maximum continuous rated current for the maximum rated tube potential.

2. Therapeutic type:

a) For x-ray generators in range 5 to 50 kVp; the leakage exposure rate shall not exceed 0.1 R (0.1 cGy) in any 1 h at any point 5 cm from the source assembly.

b) For 50 to 500 kVp x-ray tube range, the leakage exposure rate at a distance of 1 m from the source shall not exceed 1 R (1 cGy) in any 1 h hour when the tube is operated at its maximum continuous rated current for the maximum rated tube potential.

c) For x-ray tube in range greater than 500 kVp, the absorbed dose rate owing to leakage radiation (excluding neutrons) at any point outside the maximum field size, but within a circular plane of radius 2 m shall not exceed 0.2% of the useful beam dose rate at the treatment distance. The leakage dose rate from the source assembly at any point at a distance of 1 m from the electron path between the source and the target shall not exceed 0.5% of the useful beam dose rate at the treatment distance [49,51]. The neutron contribution to the dose within the useful beam shall be kept well below 1% of the x-ray dose. [49,68]

d) The average leakage dose rate in the off position around the γ-ray source housing cannot exceed 2 mrem/hr at 1 m, with a maximum of 10 mrem/hr at 1 m at any measurable location. The maximum permissible leakage in the on position cannot exceed 0.1 % of the useful beam at 1 m from the source. The 0.1% of the useful beam is the percent of the actual output of the γ-ray source in cGy/min. [49,51]

Because leakage radiation is present whenever the machine is operated, the use factor for leakage is unity. The required secondary barrier for leakage radiation has a transmission factor of B_L to reduce the leakage dose to the maximum permissible level P (mSv/week).

For diagnostic type protective tube housing:

$$B_L = \frac{P \cdot d^2 \cdot 600\, I}{WT} \tag{25}$$

Where I is the maximum tube current.

For therapy units below 500 kVp:

$$B_L = \frac{P \cdot d^2 \cdot 60\, I}{WT} \tag{26}$$

For a megavoltage therapy unit (above 500kVp):

$$B_L = \frac{P \cdot d^2}{0.001WT} \qquad (27)$$

The factor 0.001 is the 0.1% leakage limit through the source housing. Any leakage limit may be used in this equation. However, most megavoltage units do not exceed the limit of 0.1% for source housing. (14)

The quality of leakage radiation is approximately the same as that of the primary beam. Therefore, the transmission curve for the primary beam should be used to determine the leakage barrier thickness. For megavoltage therapy installations, the leakage barrier usually far exceeds that required for the scattered radiation, because the leakage radiation is more penetrating than the scattered radiation. For the lower-energy x-ray beams the difference between the barrier thickness for the leakage and the scattered radiation is relatively less. (14)

1.4. Door Protective Barrier:

For megavoltage therapy room a maze entranceway is provided, and the door must provide shielding equivalent to the wall surrounding the door. A maze arrangement drastically reduces the shielding requirements for the door. The function of the maze is to prevent direct incidence of radiation at the door. With a proper maze design, the door is exposed mainly to the multiply scattered radiation of significantly reduced intensity and energy that can be shown in **Figure (22)**. The attenuation curves for the 500-kVp x-rays may be used to determine the door shielding from multiply scattered x-rays. In most cases, the required shielding turns out to be less than 6 mm of lead.

Where interlocks are on doors that form an essential part of the room shielding, it is important that the interlock interrupts the beam with the minimum practicable door opening. (58)

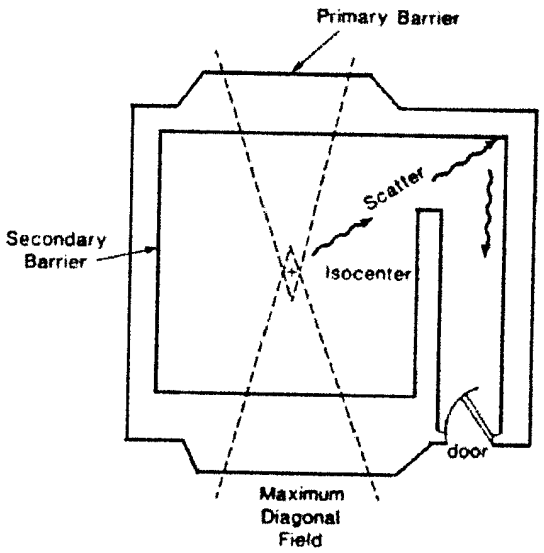


Figure (22): Schematic diagram of a megavoltage x-ray therapy installation. Radiation scatter from patient can reach the door, as shown.

2. Neutrons Shielding:

High-energy x-ray beams (e.g., >10 MV) of medical linear accelerators are contaminated with neutrons. These are produced by high-energy photons and electrons incident on the various materials of target, flattening filter, collimators, and other shielding components. The neutron production during electron beam therapy mode is quite small compared with that during the x-ray mode. (14)

Measurements have shown that in the 16 to 25 MV x-ray therapy modes the neutron dose equivalent along central axis is approximately 0.5% of the x-ray dose and falls off to about 0.1% outside the field. (69-71)

The energy spectrum of emitted neutrons within the x-ray beam is showing a broad maximum in the range of 1 MeV. The neutron energy is considerably degraded after multiple scattering from walls, roof, and floor. (72)

The selection of neutron shielding materials is completely different compared with those for gamma rays. It is most important to quickly moderate the neutron to low energies, where it can readily be captured in materials with high absorption cross sections. The most effective moderators are elements with low atomic number. Therefore hydrogen-containing materials such as concrete, paraffin, and polyethylene are the major component of most neutron shields. (3)

The absorption of neutrons is most easily accomplished at thermal energy levels in suitable materials. The absorption process gives rise to gamma-ray emission (called the capture γ-ray) [28]. These radiations have a spectrum of energies ranging up to 8 MeV, but most have energies in the region of 1 MeV [14]. That depends on the absorbing materials, where the absorbed neutrons in hydrogen give 2.2 MeV capture γ-ray [3,73] and the capture γ-rays produced in concrete is 3.6 MeV. [74]

When considering the neutrons that are produced as a secondary radiation by these accelerators [75]. In most new construction, radiation therapy equipment is placed in concrete "vault" to provide a reasonably economical method of radiation protection. Also the concrete contains from hydrogenous cement, where it is adequate absorber for neutrons. [76]

Accelerators operating at energies greater than 10 MeV produce photoneutrons which can enter the maze and produce capture gamma rays by reacting with the materials used to construct the maze. The radiation field in the maze is a complex mixture of photons scattered from the patient and room surfaces, head leakage photons, and neutrons with capture gamma rays [77]. Then, the maze door must be protected against neutrons and photons that diffuse into the maze and reach the door [78]. Shielding required for the door can be further reduced by the maze design. In general, a longer maze (>5 m) is desirable in reducing the neutron fluence and other photons (capture γ-ray) radiation at the door. Hence, the average energy of photons reaching the maze entrance may be somewhere between 100 keV and 500 keV, depending on the maze shape and the thickness of the adjacent wall. [79,80]

Finally, a thickness of a hydrogenous material such as combinations of polyethylene with boron or lithium or a thin layer of cadmium can be added to the door to absorb the thermal neutrons [3]. A steel or lead sheet may be added to the door to protect against photons radiation (scattered radiation and capture γ-rays). [14]

VI- Protection in Diagnostic Radiology

1. Protection of Workers in Radiology Procedure

In general, methods and techniques that used to reduce patient dose also reduce the dose of the radiographer. For example, beam limitation devices, high-speed image receptor systems, and repeat examinations should be avoided whenever possible to eliminate additional exposure. (5,81)

During a diagnostic examination the patient becomes a source of scattered radiation as a consequence of the Compton interaction process. At a 90-degree angle to the primary x-ray beam, at a distance of 1 m, the scattered x-ray intensity is approximately 0.1% of the intensity of the primary x-ray beam. (1)

The three cardinal principles of radiation protection are time, distance, and shielding. These are discussed as follows:

1.1. Time:

The radiographer must reduce the amount of time spent in the area of the radiation source. Time and radiation exposure are directly proportional. The less time spent near the source of radiation the less exposure is received. This concept is applicable in fluoroscopic examinations in which an x-ray tube may be on for minutes at a time. (5,19)

1.2. Distance:

Distance is considered the most effective and the simplest method to reduce radiation exposure by moving away from the radiation source (1). ***The inverse square law (ISL)*** is stated as follows: "the intensity of the radiation is inversely proportional to the square of the distance" (**Figure (23)**). The inverse square law may be stated as a formula:

$$\frac{I_1}{I_2} = \frac{d_2^2}{d_1^2} \qquad (28)$$

Where I_1 the exposure at the original distance, I_2 the exposure at the new distance, d_1 the original distance from the source of radiation, and d_2 the new

distance from the source of radiation [15,20]. Therefore, the basic concept is to apply the inverse square law by increasing the distance from the sources of exposure (patient or x-ray target) that will greatly reduce radiation exposure to the radiographers. [5,19]

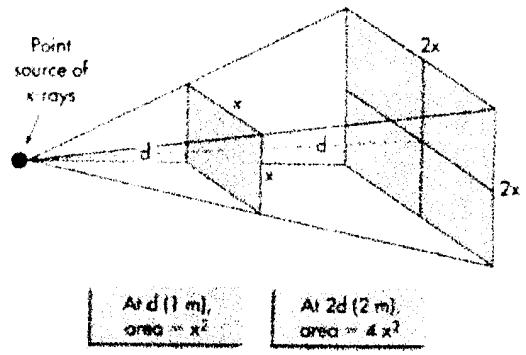


Figure (23): When the distance from a point source of radiation is doubled, the radiation at the new location spans an area four times larger than the original area. However, the intensity at the new distance is only one fourth the original intensity. [1]

1.3. Shielding:

Shielding consists of either fixed protective structural barriers (made of lead, concrete, or both) or protective devices such as mobile shields, lead aprons, gloves, and the like.

1.3.1. Protective Structural Barriers:

Fixed protective barriers are classified as either *primary* or *secondary* barriers. A primary barrier is any wall or other barrier that can be struck by the primary beam and must cover the wall from the floor to a height of at least 7 feet (2.1 m) when the x-ray tube is 5 to 7 feet from the wall in question. The primary beam should not be directed toward secondary barriers, which can only provide protection against secondary radiation (scatter and leakage radiation) **Figure (24)**. This barrier should overlap the primary protective barrier by about ½ inch and must extend to the ceiling. The control booth and the ceiling are usually considered secondary barriers. In this case, x-ray will have scattered at least twice before reaching the radiographer. This reduces the intensity of the beam to one millionth of the original value. [1,5,19]

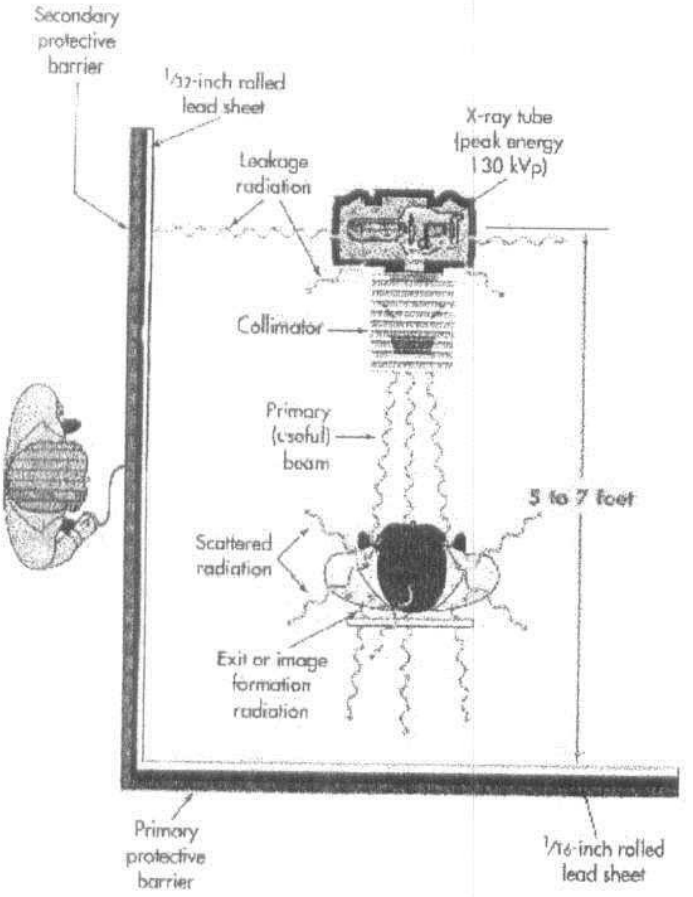


Figure (24): Primary and secondary barriers in an x-ray imaging room. (1)

To ensure maximal protection during radiographic exposures, personnel must remain completely behind the barrier. The radiographer may observe the patient through the lead glass window in the booth **Figure (25)**. This window typically consists of 1.5 mm lead equivalent. For further protection, the exposure cord must be short enough so that the exposure switch can be operated only when the radiographer is completely behind the control booth barrier. (49,51)

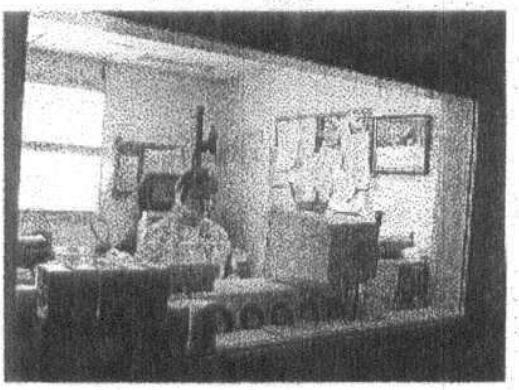


Figure (25): While making a radiographic exposure with a fixed radiographic unit, the radiographer must remain completely within the control-booth barrier for safety. (1)

1.3.2. Protective Device:

Protective device such as lead aprons and gloves should be used whenever the radiographer cannot remain behind a protective lead barrier during an exposure. ***Lead aprons*** are made of powdered lead incorporated in a flexible binder of rubber or vinyl **Figure (26)**. NCRP Report No. 102 stated that attenuation for lead aprons should be 0.5 mm of lead equivalent for fluoroscopy, as they are primary barriers, or 1 mm of lead. The 0.5 mm lead equivalent is the most widely used thickness in diagnostic radiology [1,5]. A 0.5 mm lead equivalent should attenuate 90% of the radiation at 75 kVp. A regular lead apron covers about 75% to 80% of the active bone marrow in the body. [82]

Protective lead gloves of a minimum of 0.25 mm lead equivalent should be worn whenever the hands must be protected from the beam (it is the minimum for fluoroscopy [51]). In addition to regular lead gloves (**Figure (27-A)**), radiation-resistant sterile gloves are also available (**Figure (27-B)**), made of lead-loaded rubber; these gloves are very thin to permit flexibility and dexterity. They lack the attenuation of regular lead gloves.

Figure (26): Lead apron. [5]

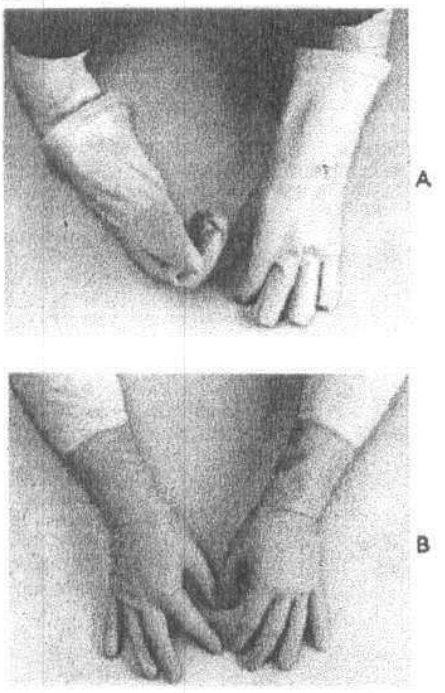


Figure (27): (**A**) Lead gloves, (**B**) Sterile lead gloves. [83]

Mobile shields are devices that can be moved around the room. It is about 0.5 or 1 mm lead equivalent that provides protection from scattered radiation. It may be used during special procedures, in the operating room (**Figure (28)**). [1,5]

Neck and thyroid shield (**Figure (29-A)**) can protect the thyroid area of occupationally exposed people during general fluoroscopy and x-ray special procedures. It should be of 0.5 mm lead equivalent. The second highest dosage to fluoroscopist is to the thyroid. Because radiation-induced thyroid tumors are four times more likely to occur in females than in males as a result of the fluctuating hormonal status of women, women may feel a greater need to wear thyroid shields.

Scatter radiation to the lens of the eyes of radiographer, specially during fluoroscopic procedures, can be substantially reduced by wearing ***protective eyeglasses*** (**Figure (29-B)**) with optically clear lenses that contain a minimal lead equivalent protection of 0.35 mm.

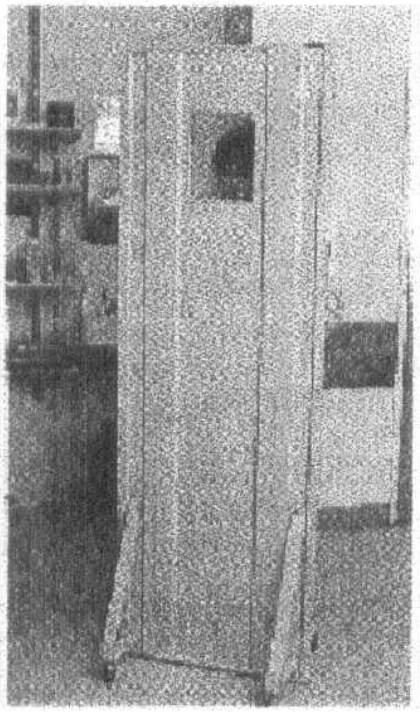


Figure (28): Mobile shield. [1]

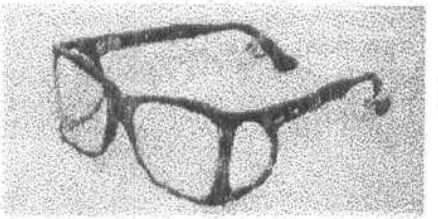


Figure (29): (**A**) The neck and thyroid gland, (**B**) Radiation-shielding eyeglasses. [1]

1.3.3. Proper Care of Lead Apron and Lead Gloves:

The protective devices such as lead aprons and lead gloves must be handled carefully. If the aprons or gloves are continuously folded or piled in a storage area when not in use, they can develop cracks and holes. For this reason, these protective articles should be stored on racks designed for that purpose. In addition, gloves and aprons should be fluoroscoped or radiographed (at a high-kVp technique) at least on an annual basis to check for cracks or holes. [19,38]

1.3.4. Doors to X-ray Rooms:

Radiographic and fluoroscopic exposure should be made only when doors are closed. That door shall be equipped with and interlock device that prevents the operation of the x-ray equipment when the door is open. This practice affords a substantial degree of protection for persons in areas adjacent to the room door because in most facilities room doors provided by a lead equivalent thickness that for attenuation diagnostic energy x-ray. [84]

1.4. Holding Patients (Patient Restraint):

Radiographers should never stand in the primary beam to restrain a patient during a radiographic exposure. Radiographers should not routinely hold patients unable to cooperate during a procedure. Some regulatory agencies require workers to document any holding of patients during procedures. When patient restraint is necessary, mechanical restraining devices should be used to immobilize the patient whenever possible. If mechanical means of restraint are not available, nonoccupationally exposed persons (such as orderlies, relatives, and friends) wearing appropriate protective apparel should perform this function. Any individual holding a patient should remain at right angles to the primary beam [49,51]. Pregnant women or person under the age of 18 years should never be permitted to assist in holding a patient during an exposure because this may result in possible damage to the embryo/ fetus. [85,86]

1.5. The Pregnant Radiographer:

The working habits of pregnant radiographers should be based on previous radiation exposure history and the current work setting. It is usually best to rotate the radiographer out of areas such as fluoroscopy and mobile radiography because of the potential for greater exposure in those areas. It is also recommended the wearing of a lead apron, and that radiographer is double-badged. The radiographer may a film badge at waist level under the lead apron to determine fetal dose. Pregnant radiographers should never hold patients.[5,19,51]

The restriction on dose to the conceptus dose not mean that it is necessary for pregnant women to avoid work with radiation or radioactive materials completely or to be prevented from entering or working in designated areas (controlled and supervised area). It does, however, imply that the exposure conditions of pregnant women should be carefully reviewed by their employer. In particular, their employment should be a type that does not carry a significant probability of high accidental doses and intakes [87]. However, The National Academy or Science has stated that it is uncertain that a dose of less than 1 rad would have any effect at all on the fetus.

2. Protection Patient During Radiology Procedure

The basic principles to minimize radiation dose of patient during radiology procedure are:

1. All unnecessary doses are avoided.
2. All necessary exposures should be justifiable in terms of the benefits to the individual that would not otherwise have been received
3. All doses administered must be the minimum consistent with the medical benefit to the individual. [52]

The limitation of patient dose can be achieved by correctly employing appropriate techniques and devices. [88]

2.1. Filtration:

A filter is a device placed at the x-ray port to absorb low-energy radiation that would not contribute to the diagnostic value of the image since this radiation would be absorbed within the patient. Removing these low-energy photons decreases overall patient skin dose. Total filtration is a sum of that added to the tube and inherent filtration of the tube itself [52,88]. Equipment operating at from 50 to 70 kVp must have 1.5 mm of aluminum (Al) equivalent total filtration. That operating above 70 kVp must have 2.5 mm Al total filtration [89]. Also mammographic equipment must have 0.5 mm Al or 0.3 mm Mo for molybdenum target tubes. [90,91]

Katsuda et al compared radiation exposure levels with and without filters in a number of examinations, measuring the actual depth dose at 5 cm. They found that filters reduced exposure by 29% in skull radiography, by 47% in hepatic angiography, by 80% in lower extremity radiography [92] and by 77% in pelvis radiography. [93]

2.2. Beam Limitation Devices:

Beam limitation devices confine the useful beam before it enters the area of clinical interest, thereby limiting the quantity of body tissue irradiated. This also reduces the amount of scattered radiation in the tissue, preventing unnecessary exposure to tissues not under examination. [52,88]

Most modern equipment is fitted with positive beam limitation (PBL), which automatically collimates or limits the beam to the size of the film. The radiographer must always limit the beam site to just the area of clinical interest. Proper collimation reduced patient exposure and improves image quality. [5,19]

2.3. Radiographic Technique (Exposure Factor):

Radiographic technique not only is important in the production of a quality image but also greatly influences patient dose. The use of higher kilovoltage (kVp) and lower milliamperage and exposure time in seconds (mAs)

reduces patient dose. However, this radiographic technique combination produces a poorer quality radiograph. A balance in radiographic exposure factor must be achieved to ensure the presence of adequate information in the image and minimize patient dose. [52,88]

2.4. Grids:

Grids are placed between the patient and image receptor to absorb secondary scatter radiation. Using a grid requires an increase in exposure factors and thus dose [19]. Thus, care must be taken to ensure that the proper type of grid is being used for a particular examination. [1]

The use of an air-gap technique instead of a grid also provides for slightly lower patient dose than a grid technique. A combination of doubling the SID and using a 6-inch air gap can decrease patient exposure by 70%. [5]

2.5. Gonadal Shielding Devices:

Gonadal shielding devices are used during radiologic procedures to protect the reproductive organs when they are in or within approximately 5 cm of a properly collimated beam. Gonad shielding should be used on all patients of reproductive age whatever they men or women. Gonad shielding will reduce the gonad dose to near zero [52,88]. The correct use of gonadal shielding can result in a decrease of about 50% of the gonadal dose for females, and 90 – 95 % for males. [1,5]

There are three basic types of gonadal shields. *Flat contact shields* are placed directly over the patient's gonads. *Shaped contact shields* are used for male gonadal shielding (**Figure (30)**). They are cup-shaped to provide for maximum protection in a variety of setting. *Shadow shields* cast a "shadow" in the beam and are mounted at the tube or on the tube housing and support structures **(Figure (31))**. [19]

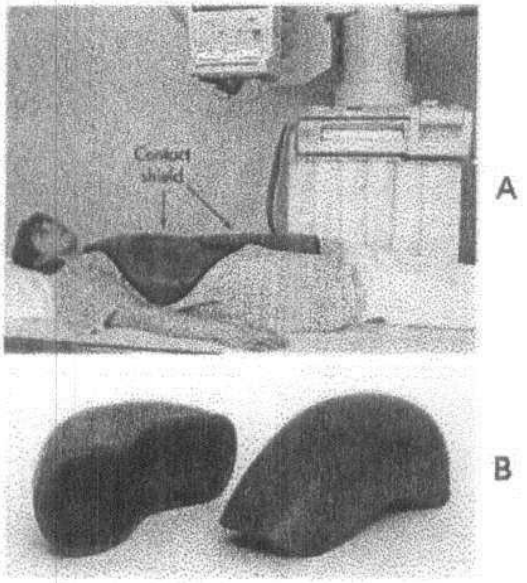


Figure (30): (A) Flat contact shield of lead-impregnated material and **(B)** shaped contact shields (cuplike in shape). (1)

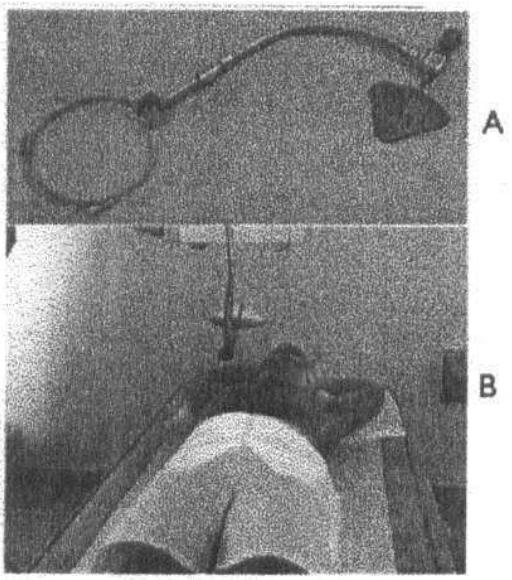


Figure (31): (A) Shadow shield components. **(B)** A shadow shield suspended above the radiographic beam-defining system casts a shadow over the protected body area. (1)

2.6. Immobilization:

Patient movement during radiographic exposure causes blurred image. That will lead to repeat the examination, which results in additional exposure for patient and radiographer. To eliminate the problem of patient movement during radiography, a variety of suitable restraining devices are available to immobilize either the whole body or individual body part to be radiographed. These radiographic aids should be used whenever necessary, especially with pediatric patients. (1,19)

2.7. Position and Projection:

The correct choice of projection can have a considerable influence on the radiation doses received. For example, a posteroanterior (PA) skull examination will reduce the dose to the eyes by as much as 95% compared with the anteroposterior (AP) projection; a PA chest x-ray in females will reduce the breast dose by about 95% compared to the AP projection. This substantially reduces the risk of carcinogenesis. (52)

2.8. Additional Guidelines for Reducing Patient Dose:

The source-skin distance at least 30 cm must be used. By increasing source-skin distance, the entrance dose is reduced and the radiographer maintains a more uniform distribution of exposure throughout the patient. (49,51)

As the high-speed film-screen combination is used, the amount of radiation needed to exposure the film decreases. That will greatly influence patient dose. Fluoroscopic image intensifier tubes incorporate more efficient input phosphors that can reduce patient dose by 25% to 50%. (88)

Radiographic films should not be used beyond the expiration date that to avoid unnecessary exposure to patients. When the film is being expired overexposure is necessary to achieve the proper density. (94,95)

2.9. The Pregnant Patient:

Because some evidence suggests that the developing embryo-fetus is especially radiation sensitive, special care is take in medical radiography to prevent unnecessary exposure of the abdominal area of pregnant females. In 1970 (96) the ICRP proposed a 10- day rule. This rule recommended that women of childbearing age should be exposed to irradiation involving the pelvis or lower abdomen only during the first to days after the start of a normal menstrual period. This rule has not found much favor recently. Instead, based on that the risk to a child, who has been irradiated in utero during the remainder of a four-week period after the menstrual period, is small. In fact, the most important period from the point of view of radiation protection is 8-15 weeks. Now the ICRP revision of the rule which involves no special limitation on exposure in the four weeks following menstruation. (52)

Also some studies of groups have shown that damage to the newborn is unlikely for doses below 20 rad. Because most medical procedures result in fetal exposure of less than 1 rad, the risk of abnormality is small. (89)

Anyway, when radiologic procedures are not considered urgent, they may be regarded as elective examinations and can be booked at an appropriate time to meet patient needs and safety. If the examination is very important to pregnant patient, it should be performed without delay. Under such circumstances, special efforts should be made to minimize the dose of radiation received by the patient's lower abdomen and pelvic region [1,52]

2.10. Protecting Children:

Protecting children is one of the most difficult aspects of radiation protection, but it is very important. Children can be extremely uncooperative, but because of their greater radiosensitivity, a high repeat rate is unacceptable. The radiosensitivity of children to leukemia, for example, has been estimated to be as high as twice that of adults. [97]

In general smaller doses of ionizing radiation suffice to obtain useful image in pediatric radiologic procedures than are necessary for adult. Appropriate radiation protection methods must be used for each procedure [1]. Essentially, the same patient protection methods used to reduce the radiation exposure for adults may be employed to reduce the radiation exposure for children patients. [52]

3. Radiation Protection During Mobile Radiography

Mobile radiography constitutes a potential radiation hazard since, patient rooms and surgical suites are not usually designed for radiation protection. [5,19]

Distance is, as always, the most effective means of protection in mobile radiography for individuals other than the patient, especially when this is combined with appropriate methods of shielding. For the mobile radiographic units, which are not equipped with a remote control exposure device, the cord leading to the exposure switch should be long enough to permit the radiographer to stand at least 2 m (6 feet) from the patient, the x-ray tube, and the useful beam. This permits the radiographer to use the inverse square effect of distance to reduce exposure. [1,5,19]

The radiographer should attempt to stand at right angles (90 degrees) to the x-ray beam scattering object (the patient) line; when the protection factors of distance and shielding have been accounted for, this is the place at which the least amount of scattered radiation is received **Figure (32)**. [1]

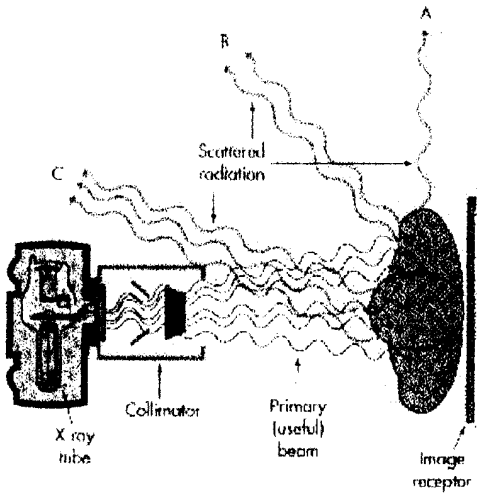


Figure (32): **A** illustrates a relatively low amount of scatter at 90°. **B** and **C** show the amounts of scatter behind the patient. [1]

4. Radiation Protection During Fluoroscopy

The primary use of fluoroscopy is the continuous viewing of dynamic processes in the body. Fluoroscopic unit is equipped with 5-minute reset timers to remind the operator that a certain recommended time limit has elapsed for beam-on time. The required timer is an effort to reduce exposure time to both the patient and attending personnel. Also, a fluoroscopic foot switch known as a deadman switch, is designed to terminate the exposure once the foot is released from the switch. [49,51]

The exposure at tabletop in fluoroscopy cannot exceed 10 R/min and should not exceed 5 R/min [51]. In fluoroscopy, scatter at 90° and just to the front of the patient is greatest; the patient's body filters some of the radiation. Scatter production in fluoroscopy is illustrated in **Figure (33)**. Also the majority of the dose from patient scatter to the radiographer is at the level of the gonads. [19]

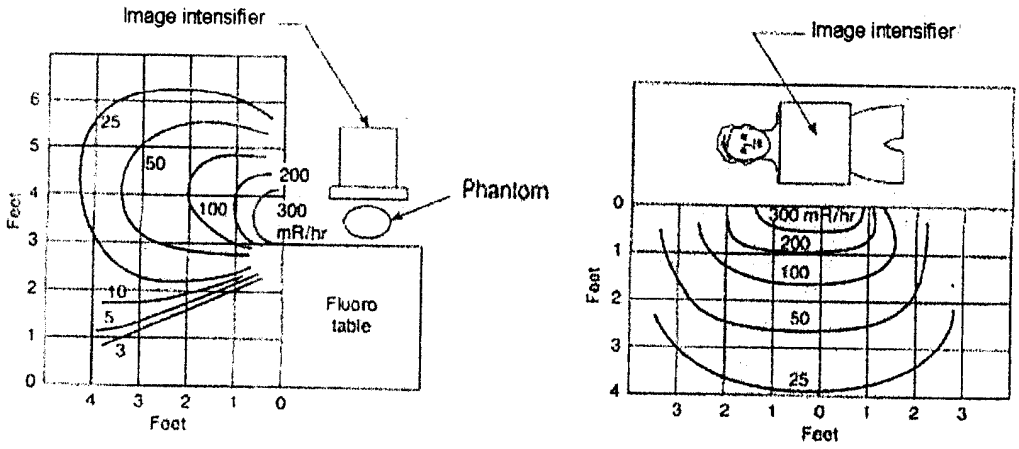


Figure (33): Illustration of scatter (isodose curve) in fluoroscopy. (19)

A ***drape or sliding panel*** (curtain) of at least 0.25 mm of lead equivalent often hangs from the image intensifier to absorb scatter **Figure (34)** (98). This shielding device provides additional protection at the level of the gonads from scatter. Without the protective curtain in place, the exposure rate to the fluoroscopist would exceed 10 mR per hour at a distance of 2 feet (61 cm) from the side of the x-ray table. (1,5)

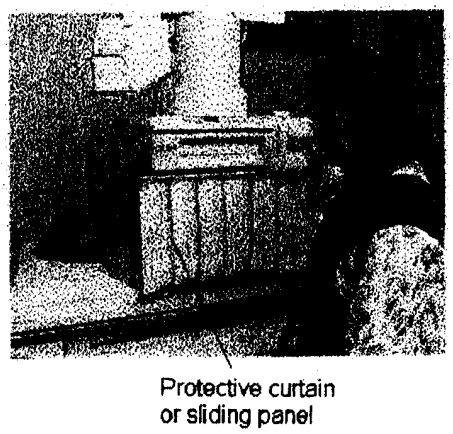


Figure (34): A protective curtain or sliding with a minimum of 0.25 mm lead equivalent. (1)

Occupational exposure of fluoroscopist may be reduced significantly through the use of a fluoroscopic exposure monitor (audible monitor), which "provides an instantaneous audible indication of the intensity of secondary radiation". This device emits "a soft chirping signal, whose frequency varies in direct proportion to the exposure rate" (99). Personnel using this monitor can select best position to stand relative to the source of radiation, thereby achieving the greatest protection. (6)

Fluoroscopic procedures produce the greatest patient radiation exposure rate in diagnostic radiology. If the fluoroscopic procedure is necessary, every precaution must be taken to minimize patient exposure time, include:

1. *The automatic brightness control (ABC)* keeps the exposure at the image intensifier constant, and this decreases the entrance exposure with increasing kilovoltage. Larger fields of view should be used whenever possible to minimize patient exposure. (5)
2. *Grid.* Gray and Swee found that fluoroscopic exposure was reduced by 35% and spot image exposure was reduced by 48% by not using a grid. (101)
3. During C-Arm fluoroscopic procedures, the patient-image intensifier distance should be as short as possible. This reduces patient dose. (1)

4.1. Protection During C-Arm Fluoroscopy:

Safety procedures are particularly important when mobile fluoroscopy (C-arm) systems are used. The dose rate caused by scatter near the entrance surface of patient (the x-ray tube side) exceeds the dose rate caused by scatter near the exit surface of the patient (the image intensifier side) (1). Thus, the operation of an undertable image intensifier which also provides higher doses to the fluoroscopist – up to 10 times higher than conventional overtable intensification units (5). For that, during C-arm fluoroscopy should be positioned the x-ray tube below the patient. Obviously, the radiographer should never encounter the actual useful beam. (6)

5. Radiation Protection During Mammography

In the past, mammography was done in many hospitals with a conventional overhead radiographic tube. However, recent standards for mammographic imaging have emphasized the importance of dedicated equipment and specialized technique. Screen-film mammography should not be performed unless a molybdenum target x-ray tube is used (91). With dedicated

equipment, occupational exposures in mammography are indistinguishable from background, if appropriate radiation protection is used. The x-ray beam energy is low, 50 kVp or less, and the primary beam is limited to the size of the image receptor. The image receptor holder is backed by lead. Consequently, the technologist is exposed only to secondary radiation which is easily controlled by a window-wall type barrier equivalent to approximately 0.2 mm Pb. [33]

Patient dose can be minimized in mammography by observing the following:

1. *High tube output*. A single-phase voltage unit with a high-frequency generator should be used.
2. *Grids*. Exposure is about doubled with a grid. Fatty breasts require less radiation and no grid.
3. *Screen/film combinations and developer time and temperature*. Proper use of screen /film combinations and extended developer time can reduce patient exposure by up to 40%.
4. *Compression*. A device for maintaining firm breast compression *shall* be provided which assures uniform thickness of the compressed breast portion of the radiographed breast [51]. This can reduce dose, on average, by about 20%.
5. Using large cassettes on large-breasted women can reduce the need for two exposures. [5]

6. Radiation Protection in Computed Tomography (CT)

In computed tomography (CT) patient exposures may be high, personnel exposure levels are usually low, because the primary x-ray beam is highly collimated and scattered radiation levels are low. In all such scanners, leakage radiation in the control room of a properly designed facility has been reduced to near zero. Therefore, computed tomography does not represent a significant source of occupational exposure. [33]

In general, CT exposures to the patient are higher than radiographic examinations of the same area. According to Seeram [98], CT dose is dependent on the following:

1. *Slice thickness*. This is an inverse proportion; halving the slice thickness requires a doubling of dose to maintain contrast resolution.
2. *Contrast resolution*. This is a direct proportion to the square of the contrast resolution; thus, to double contrast resolution requires a 4 x increase in dose.
3. *Spatial resolution*. This is an inverse proportion to the square of the cube; thus, to double spatial resolution requires an 8 x increase in dose.

7. Quality assurance

In order to maintain good radiation protection, ***Quality Assurance programs (QA)*** should be carried out to inspect the x-ray equipment and reviews the records of facilities using x-ray equipment. The primary goal of radiology QA program is to enhance accurate diagnosis. However, an associated goal is to reduce radiation dose to patients and occupation persons. QA also optimizes the operation of equipment. [98]

The quality assurance programs shall include main equipment and accessories, radiation source system, imaging and processing systems as appropriate. These QA programs include acceptance tests of new radiological equipment to ensure that such equipment meets applicable performance specifications, as many have been determined by national or local authorities, or by the manufacture. Thereafter, periodic performance tests should be carried out in order to check that conditions are unchanged and they shall be tested regularly at appropriate intervals to minimize the unproductive application of radiation. All QA tests should be documented in records. These tests are often conducted by a medical physicist trained in quality assurance. [49,51]

VII- Protection in Radiation Therapy

The three cardinal principle of radiation protection are time, distance, and shielding. Each of these can be practiced during both teletherapy and brachytherapy to minimize exposure to operators, other health care workers, and patients. [102]

1. Teletherapy

Technologists, physicians and physicists may be exposed to radiation from various external beam units. Cobalt-60 teletherapy units (**Figure (35)**) can expose personal to head leakage radiation while the source is in the "off" position. The types of exposure from linear accelerators (**Figure (36)**) depend upon the beam modality (photon or electron) and the beam energy. For photons and electrons below 10 MeV, the only radiations are primary, scattered, and leakage x-rays that penetrate the protective barrier. [33]

Above 10 MeV, photonuclear reactions can result in the production of both neutrons and radioactive nuclides (activation products). Neutrons can penetrate the protective barrier and expose personal when the unit is on. Relatively long-lived radionuclides produced by photoactivation can expose personal who enter the treatment room immediately after the treatment has been delivered. Neutrons and photoactivation radionuclides usually don't contribute a significant fraction of the exposure to technologists except for units operated at very high energy ($\geq$ 25 MV x-ray). [75,103-105]

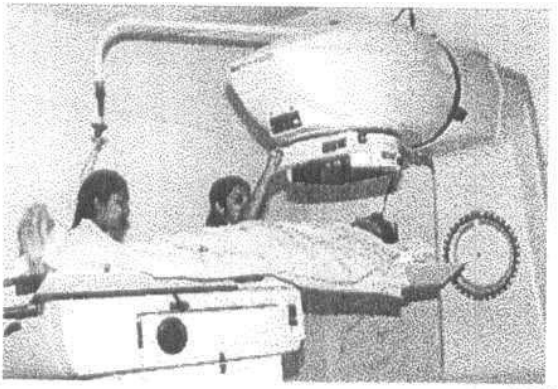


Figure (35): Cobalt-60 teletherapy unit. [106]

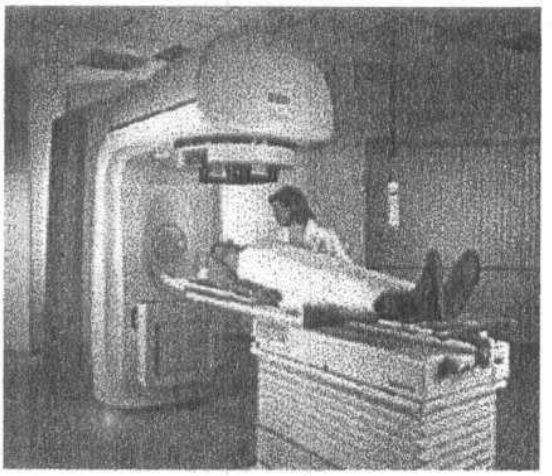


Figure (36): Linear accelerator machine, which delivers high energy x-rays directly to the tumor. [107]

1.1. Time:

With the source always emitting radiation or continually active, the levels of radiation in the treatment room are always higher than background radiation [108]. Radiation therapists should therefore limit their time in the treatment room, especially the amount of time close to the source [109]. For machines emit high-energy radiation above (10 MeV), the therapists should wait some time before entering the treatment room to avoid exposing to activation products.

1.2. Distance:

As a radiation therapist and other worker move away from the source of radiation, it is natural to expect to receive less radiation. Especially, they should stay away from the source housing. [15]

1.3. Shielding:

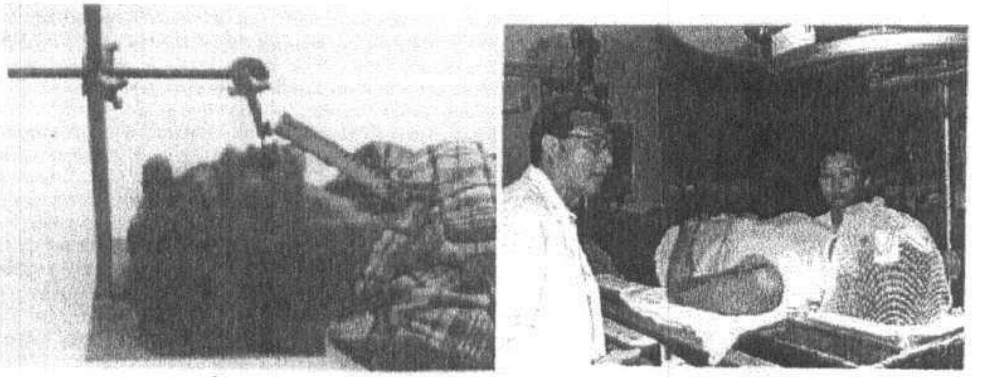
Barriers in therapy are designed in a manner similar to those in diagnostic radiology, but of course are much thicker because of the greater energy of the beam. These walls are commonly in excess of 3 feet (about 1m) thick that depending on the energy of the beam. Concrete is often used instead of lead, which reduces the shielding costs. [102]

The control panel shall be locked outside of the treatment room for all therapy equipment. Both the control panel and the patient shall be observed

during treatments. Persons other than the patient shall not be present in the treatment room when radiation is delivered. [51]

1.4. Protecting patients:

Patients must be positioned exactly the same way with each treatment. Patient-positioning aids include custom mouthpieces known as bite blocks for the head and neck, face masks using plastic material as in **Figure (37)**, and cast Styrofoam materials for the thorax should be used when necessary [102]. Other auxiliary patient positioning devices such as back pointer, wall and ceiling-mounted light sources and patient immobilizers should be available. [51]



A B

Figure (37): A, Bite block system for head and neck immobilization [110]. **B**, Patient faces mask immobilization. [111]

In radiotherapy, it is necessary to differentiate between the dose to the target tissue and the dose to other part of the body. In therapy, the protection of tissue outside the target volume is an integral part of dose planning, which can be regarded an including the same aims as the optimization of protection. [112]

Shaping blocks made of cerobend (an alloy of lead, tin, bismuth, and cadmium) are used to "shape" the beam. This reduces intensity to about 3% of original value. Another means of beam shaping is the use of multileaf collimators.

Additional skin sparing is often achieved through the use of compensating filters. A compensating filter must be inserted a sufficient distance (at least 15 cm) from the patient to ensure that electrons generated by the interaction of megavoltage beam with the filter do not strike the patient. [102]

1.5. Other safety procedures:

For therapy equipment emitting high-energy radiation, door interlocks shall be provided that cause the machine to go to the "off" condition if the door is opened. After such a "shut off", it shall be necessary to "reset" and "restart" the machine at the control panel before irradiation can be continued. It shall be impossible for the machine to go to the "ON" condition when the door is open.

Warning lights indicating when the radiation therapy device is in the "ON" or the "off" condition shall be provided for all installations using radiation therapy devices. These warning lights shall be present at the treatment room door. An easily visible or audible device which indicates whether radiation is or is not being produced, or emitted shall also be provided in the treatment room. It shall not be possible to switch the beam-control mechanism to the "ON" position from inside the treatment room. (51)

1.5.1. Special Consideration for Linear Accelerator:

Special consideration shall be given to the safety design and microprocessor operating software of x-ray machines with electron beam extraction capability (e.g., to insure that the electron mode cannot be employed inadvertently when the x-ray mode is intended or vice versa). The design shall provide electron or photon mode selection at the control panel. (51)

For the safety of the patient the accelerator shall be provided with two independent dose monitoring systems. The separation shall be such that any failure or malfunction in one system does not influence the function of the other system. The detectors of the two systems shall be provided inside the radiation head. Both systems shall be so constructed that they are able independently to terminate irradiation.

Due to the complexity of accelerators and the possibility of changing the parameters, all efforts should be made by systems of interlocks to prevent mistakes being made in the selection of types and energy of radiation wedge filters, scattering foils, etc. (49)

1.5.2. Calibration and Leakage for Co-60:

A qualified radiation physicist must perform full calibration testing for radioactive ^{60}Co units annually. Full calibration may be done more frequency if (1) the source is replaced, (2) a 5% deviation is noticed during a spot check, and (3) a major repair requiring the removal or restoration of major components is done. A monthly output calibration should be done for a set of standard daily operating conditions. Measurements taken during a full calibration include the following: (113)

1. Radiation and light field coincidence.
2. Timer accuracy.
3. Exposure rate or dose rate to an accuracy of ± 3% for various field sizes.
4. Accuracy of distance-measuring devices used for treatment.
5. Uniformity of the radiation field and its dependence of the orientation of the useful beam.

A wipe test (or leak test) must be done twice a year on the sealed ^{60}Co source. If a source's seal is broken and leaking, it may have radiation contamination on the interleaf collimators. A wipe test is done, using long forceps, wiping the collimator edges with a filter paper, cloth pad, or cotton swab moistened with alcohol. A background radiation reading is done by using a survey meter calibrated with the same type material as the one being tested. A reading is then taken of the wipe to determine its activity, with the acceptable level of activity less than 0.005 μCi. If the activity is higher, radiation contamination or leakage may have occurred and the unit must be removed from service until decontamination and repair can be completed. (109)

1.5.3. Radiation Monitoring and Light System:

Because it is a radioactive source that emits ionizing radiation, ^{60}Co requires not only a light system to show when the machine is on and off, but also a monitoring system to detect radiation. The machine on-and-off indicator lights must be on the console, at the head of the machine, and at the entrance to the treatment room. A radiation detector must be located in the treatment room.

The detector is wired to a light outside the room near the console and door. The light must be blinking red if radiation is present and must be in view of the radiation therapist. Before entering the room, the therapist must be sure the off light is green and the blinking red light has stopped. [109]

1.6. Quality Assurance Programs:

Quality assurance programs (QAP) are usually administered by a radiation physicist. Some tests can be performed only by a physicist, but many tests are also performed by therapists on a daily basis (**Table (15)**).

The goal of a quality assurance program is to ensure that the radiation dose delivered is as low as is reasonably achievable while increasing the therapeutic efficacy of procedures. Properly QA program can improve patients' care and minimize their doses. [102,114,115]

Table (15) Quality assurance tests performed by physicists and therapists. [116]

Test	Range of acceptance
Daily tests	
Interlocks, lamp	Working
Patient audiovisual	Working
Output constancy of arc	± 3%
Radiation monitor	± 3%
Radiation warning lights	Working
Laser localization lights	± 3 mm
Optical distance indicator	± 3 mm
Weekly and monthly tests	
Congruence of radiation and light field	± 3 mm
Cross-hair alignment	± 2 mm
Radiation output	± 3%
Beam energy	± 1% TMR
Mechanical inspection	Shows no loose wires, covers, screws, or other items
Emergency off switches	Working
Annual tests	
Mechanical and digital indicators	± 2 mm or 1 degree
Machine isocenter	± 1 mm
Isocentricity of couch and sag	± 3 mm
Radiation beam symmetry	± 2%
Radiation beam flatness	± 3%
Monitor chamber linearity and end effect	± 1%
Beam stability at gantry angles of 0, 90, 180, and 270 °	± 1%

2. Brachytherapy

The most significant source of radiation exposure to radiation oncology personnel is the use of sealed radionuclide sources in brachytherapy. The most commonly used isotopes are ^{137}Cs, ^{192}Ir, ^{226}Ra and ^{125}I, although ^{60}Co, ^{90}Sr and ^{198}Au. Physicists and technologists may be exposed during the receipt and preparation of brachytherapy sources. Physicians, anesthetists and operating room nurses may be exposed during the loading and unloading of sources. During the course of treatment, nurses will be occupationally exposed. (33)

2.1. Time:

Nurses should be encouraged to minimize their time of exposure. It is generally wise to recommend that each provider limit the time of exposure to 30 minutes while the source is in place, although this is a broad recommendation that will vary based on circumstances.

2.2. Distance:

In all cases, individuals caring for the patient should stay as far as possible from the radiation source. If possible, caregivers should be encouraged to stand at either the head or foot of the bed, depending on the site, for intercavitary implants, as well as behind lead shield, as much as possible. For head and neck implants, the caregiver should stand at the side of the bed farthest from the implant. When possible, communication with the patient should be performed at a distance.

2.3. Shielding:

If properly used, lead shielding can sometimes provide additional safety from radiation exposure from brachytherapy patients. In most cases, however, shielding such as lead aprons is not of value, and nurses caring for brachytherapy patient should instead be counseled to limit their time of exposure. There are rolling lead shields that can be placed beside the patient's bed to reduce exposure to caregivers and family members. (102)

2.4. Additional Guidelines for Workers and Patients:

Guidelines for patient care should be contained within the patient's chart, based on prescriptions of the radiation oncologist and radiation safety officer. The following guidelines for nurses are based on these developed by Hassey:[117]

- A "Caution: Radioactive Material" sign is placed on the patient's door.
- Nurses caring for brachytherapy patients should wear dosimeters.
- Pregnant women and children under 16 years should not enter the room.
- Visitors should stand at 6 feet and limit their visits to 30 minutes per day.
- A dislodged source should be picked up with long-handled tongs deposited in a shielded container in the patient's room.
- The patient should be assigned to a private room with private bath. To avoid oppressive isolation of patients, access to treatment room will often be through a gated maze rather than an interlocked door. [112]
- Dressing and bed linens from patients receiving treatment with sealed sources should not be destroyed until it has been checked that they do not contain any sources. [49]

2.5. Protection Against Radiation From Brachytherapy sources:

2.5.1. Storage:

Lead-lined safes with lead-filled drawers are commercially available for storing brachytherapy sources. In choosing a particular safe, consideration should be given to the adequacy of shielding, distribution of sources, and time required for personnel to remove sources from, and return sources to, the safe.

The storage area for radium should be ventilated by a direct filtered exhaust to the outdoors, because of the possibility of radon leaks. Similar arrangement also is recommended for encapsulated powdered sources or sources containing microspheres. This precaution is taken so that if a source ruptures, the radionuclide is not drawn into the general ventilation system of the building.

The storage rooms are usually provided with a sink of cleaning source applicators. The sink should be provided with a filter or trap to prevent loss of source. [118]

2.5.2. Source Preparation:

A separate room or designated area with adequate ventilation and filtration of the exhaust air should be provided for preparation of sources and applicators.

A source preparation bench should be provided close to the safe. The preparation and dismantling of source applicators should be carried out behind a suitable barrier to shield the operator adequately. Many facilities are equipped with a protective "L-block", usually constructed of lead. A lead glass viewing window provides some protection by providing shielding as well as a suitable distance between the face of the operator and the sources (**Figure (38)**).

Brachytherapy sources must never be touched with the hands. Suitably long forceps should be used to provide as much distance as practical between sources and the operator. During such preparation only those persons engaged in the work shall be allowed in the area; eating, smoking and drinking and the application of cosmetics should be prohibited (avoided). [118]

Figure (38): L-block with viewing glass window. [119]

2.5.3. Source Transportation:

The sources can be transported in lead containers or leaded carts. The thickness of lead required will depend on the type of source and the amount of radioactive material to be transported. The transport of the sources should be carried out in such a manner that all individuals are adequately protected.

2.5.4. Leak Testing:

Various methods of leak testing of a sealed source are available. Periodic leak testing of radium is usually specified by state regulation. A source is considered to be leaking if a presence of 0.005 μCi or more of removable contamination is measured. The leaking source should be returned to suitable agency that is authorized for the disposal of radioactive materials. [118]

VIII- Protection in Nuclear Medicine

In nuclear medicine clinical information is derived from observing the distribution of a pharmaceutical administered to the patient. Measurements can be made of the distribution of this radiopharmaceutical by noting the amount of radioactivity present. Gamma camera offers the potential, unique among imaging techniques, of demonstration function rather than simply anatomy. [102]

1. Production of Radionuclides:

Radionuclides can be produced from three sources: the nuclear reactor, the cyclotron, or a generator. Obviously in most instances radionuclides produced by the first two routed will be shipped to the hospital from a central manufacturing site. This creates a problem, since short-lived radionuclides will decay significantly during transportation. Fortunately the third mode of production, the generator, provides an answer, at least for certain radionuclides. The generator depends upon the existence of a long-lived radionuclide which decays into the required short-lived radionuclide. This generator is the source of the radionuclide most commonly used in nuclear medicine, technetium-99m, and the parent material in this case being molybdenum-99. [102]

2. Characteristics of Radionuclide:

A number of points must be considered when selecting the radionuclide label:

1. The chemical properties of the nuclide must be such that it will combine to form a wide range of chemical compounds without altering its biological behavior, each of which must be non-toxic and compatible with the physiology of the patient. It also should be taken up rapidly and completely in the biological system of interest and it should localize only in the area of interest.
2. The specific activity of the radionuclide must be high enough to ensure that only small quantities of the preparation need be administered.
3. The half-life should be long enough to allow for complete preparation of the radiopharmaceutical and imaging but short enough not to give high radiation dose to the patient and personnel. Therefore, it should be similar to the length of the test.
4. The emissions from the radionuclide must be of a suitable type, i.e., gamma rays of sufficiently high energy to escape from the patient without undue attenuation, but not so high that the detection of the gamma rays becomes unreliable. The energy of the gamma rays should be between 50 and 300 keV. There should preferably be no alpha or beta emissions because these given an unwanted dose to the tissues of the patient.
5. The photon abundance should be high in order to obtain good counting statistics.
6. The radionuclide should be readily available and inexpensive. The radiopharmaceutical should be simple to prepare.
7. Biologic behavior. Any administered radiopharmaceutical that is not extracted by the target organ/tissue should be eliminated not only from

circulation but also completely from the body. The amount of radioactivity in the body is determined by the effective half-life according to the equation given below:

$$T_e = T_p\, T_b / T_p + T_b \qquad (29)$$

Where T_e is the effective half-life, T_p is the physical half-life and T_b is the biological half-life. [20,120,121]

The radionuclide **technetium-99m** (^{99m}Tc) is the popular choice for most imaging applications because it satisfies all the criteria listed above. It is chemically versatile and can be labeled on to a range of compounds. It is conveniently available from a technetium generator, which is immediately usable. It emits only gamma photons, and at an energy (140 keV) which is ideal for imaging purposes. Its decay rate ($T_{1/2}$ = 6 hours) gives the minimum radiation dose to the patient consistent with providing and adequate time to complete the imaging study [20]. **Table (16)** shows the most common of the radionuclides used in nuclear medicine.

3. Design of Facilities:

The layout, construction, and finish of the building housing the nuclear medicine department are all influenced by radiation protection considerations.

All rooms where radioactivity is present must show the familiar radiation warning sign. A system of designation of areas with restrictions on who may enter will usually be a legal requirement. The largest activities are handled during the preparation of the radiopharmaceuticals. **Figure (39)** shows schematic plan of hot lab and nuclear medicine department [124]. It is basically aimed at protecting personnel and environment from radiation, and protecting the product from contamination. Essentially, the individual room is designated according to its function. Only relevant personnel should have access to the facility, with minimal entry by the maintenance staff.

Table (16): The most common radionuclides are used in nuclear medicine. [4,15,20,120,122,123]

Radionuclides	Half-life	Mode of production	Mode of decay [a]	Gamma photon energy (keV)	Medical use	Administered activity
Technetium (^{99m}Tc)	6 hr	Generator	IT	140	Diagnostic study (whole body imaging).	3 – 20 mCi
Iodine (^{123}I)	13 hr	Cyclotron	EC	160	Thyroid imaging.	—
Iodine (^{125}I)	60 days	—	EC	35	Medical research: determination of hormone and drug levels.	< 10 μCi
Iodine (^{131}I)	8 days	Reactor	β, γ	280 – 640	Cancer therapy; thyroid and kidney studies.	0.05 mCi
Gallium (^{67}Ga)	78 hr	Cyclotron	EC	92 – 390	Gallium imaging (Abscess).	4 mCi
Xenon (^{133}Xe)	5.3 days	Reactor	β	81	Lung imaging (ventilation).	10 – 20 mCi
Thallium (^{201}Tl)	73 hr	Cyclotron	EC	167, (68 –80) [b]	Heart imaging.	0.04 mCi
Indium (^{111}In)	2.8 days	Cyclotron	EC	173, 247	Use in Abscess and Thrombi.	—
Krypton (^{81m}Kr)	13 s	Generator	IT	191	Lung imaging	—

[a] EC, electron capture; IT, isometric transition.
[b] Characteristic x-rays.

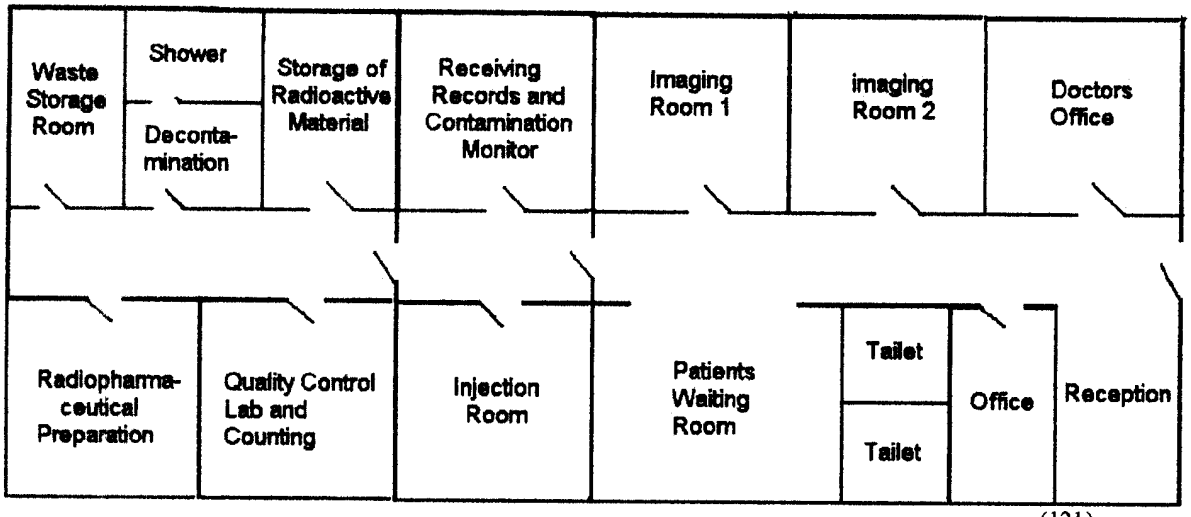


Figure (39): Suggested plan of a hot lab and nuclear medicine department. [121]

Separate rooms should be assigned to receiving and unpacking shipments, preparing radiopharmaceuticals, quality control tests, storage and radioactive waste products. The storage room should have sufficient shielding. Separate rooms should be provided for offices, decontamination and showering. [121]

Also separate areas for the administration of radiopharmaceuticals and the performance of in vivo tests (imaging rooms and other patient counting facilities. Waiting areas with designated toilets should be provided for radioactive patients. Careful consideration should be given to layout in order to reduce the movement of radioactivity within the department. All materials used should allow for easy decontamination. The use of radioactive gases or aerosols presents an additional hazard, and suitable extraction or forced ventilation should be provided. Hand washing facilities must be provided in areas where unsealed radioactive materials are handled. [124]

Equipment for the safe handling and monitoring of unsealed radioactive materials should be provided, and staff properly trained in its use. Any nuclear medicine department needs a method of measuring activity accurately before radiopharmaceuticals are administered. The principal instrument used is a well-type ionizing chamber [125]. Also the most essential pieces of equipment in nuclear medicine department include a radiation area monitor, survey meter, and

is a way to use distance for radiation protection. Also forceps and handling tools should be used to carry boxes. Straight forceps are not very convenient for holding small bottles or vials; shaping the tips makes handling easier and safer. The volume of radioactivity in a syringe should not normally exceed 50% of the syringe capacity; the use of a large syringe size increases the source-to-finger distance.

Unobtrusive methods can be used to ensure an adequate distance between radioactive patients and other people. Discretion should be used in maintaining distance from radioactive patients without alarming or upsetting them. [122,124]

4.3. Shielding:

One of the most effective means of decreasing radiation exposure is to absorb most of the radiation through the use of shielding around the radioactive source. The syringes should be shielded during radiopharmaceutical kit preparation and administration to the patient. Also all vials containing radiopharmaceuticals must be shielded.

Specially designed lead shields that fit around radionuclide generators are necessary because a generator's internal shielding is intended only to meet the regulation for shipment of radioactive materials. Additional shielding is required once the generator is set up for operation in the nuclear medicine department. Thus the generators should be stored behind lead walls. Lead bricks can also be used to provide extra shielding around generators and other areas where radioactive materials are stored.

The bench surface should be shielded to avoid exposure to the lower body. An L-block shield should be used during the preparation of radiopharmaceutical kits and unit doses (**Figure (42)**). The leaded glass window permits the technologist to see the manipulation of the equipment while affording some protection to the eyes and torso. [122]

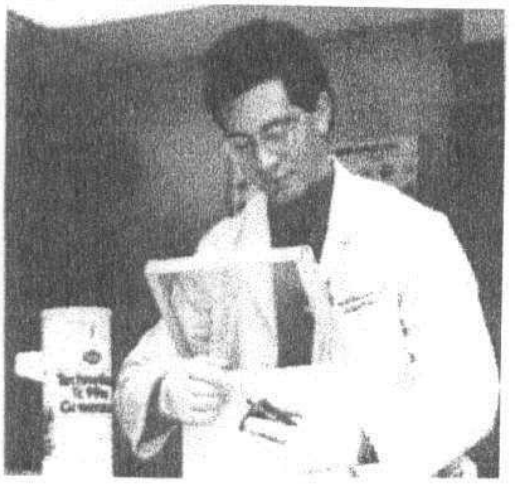


Figure (42): A nuclear medicine technologist using L-block shielding during dose preparation. (122)

4.4. Radiation Contamination:

When unsealed radioactive materials are used it is necessary to protect against both external radiation and the possibility of internal contamination. Worker can receive internal radiation exposure by inhaling or ingesting radioactivity or by absorbing it through the skin or wounds. This type of contamination may be avoided by abstaining from eating, drinking, smoking, or applying cosmetics in areas where radioactive materials are used. Food should not be kept in the same refrigerators where radioactive materials are stored. Also, pipetting of radioactive solutions by mouth must be strictly prohibited. Chewing of pens and licking of labels should be discouraged. Gloves and protective clothing should be worn. For some procedures a plastic apron is advisable. All working areas should be clear and uncluttered, and paper work kept away from radioactive areas. At the end of any procedure involving unsealed sources the hands should be washed and monitored. (122,124)

Additional safety recommendation are listed below for radiation worker:

- Work in a ventilated fume hood while working with volatile radioactive material such as radioiodine solutions. (127)
- Cover the trays and workbench with absorbent paper.
- Identify all radionuclides and note calibration and expiration dates.

- Wear a film badge while working in the radiation laboratory.
- Do not hang laboratory coats with a film badge in a radiation laboratory.
- Survey work areas for contamination as frequently as possible. [4,121]

4.5. Radioactive Spills and Decontamination:

Spills of radioactive materials should be cleaned up promptly and thoroughly to prevent the spread of contamination to other areas or to personnel. Minor spills, involving only a small area or low level of radioactivity, can be handled as outlined here:

1. Inform other people working in the area that spill has occurred and clear that area. Post warning signs to inform others of the contamination and notify the radiation safety officer about the spill.
2. Put on protective clothing, such as gloves and shoe covers, before attempting to clean the spill.
3. Confine the spill as small as area as possible. Placing absorbent paper over a liquid spill will soak up the spill as well as contain it in the absorbent material.
4. If personnel are contaminated, they should be decontaminated as soon as possible to prevent absorption of inhalation of the radioactivity. Decontamination may involve simply the removal of contaminated clothing or washing affected areas of the skin with mild soap and warm water. Harsh or abrasive cleaners and brushes should not be used because they may cause beaks in the skin, promoting internal absorption of the radioactive material or infection. Serious injuries should be treated before decontamination begins.
5. When decontamination is finished, remove all protective wear and discard with other contaminated material. Monitor personal clothing, remove any that is contaminated, and place it in storage until the contamination has decayed to background levels. [122,124]

4.6. Pregnant Workers (Technologist):

Determining and limiting radiation dose to the fetus become important considerations for the pregnant and potentially pregnant technologist.

Also by surveying the workplace, sources of radiation that may contribute to radiation exposure more significantly than other sources can be identified. For example, hot lab duties such as eluting the radionuclide generator and assisting in the administration of radioiodine therapy may produce more radiation exposure than routine imaging procedures. Also, more stringent precautions against the inhalation, ingestion, or absorption of radioactivity should be implemented to prevent possible incorporation of radioactive material into a developing fetus.

Thermoluminescent badges rather than film badges are recommended for monitoring radiation exposure, as TLDs provide a more accurate reading. Double badging – placing one TLD at the waist and the other at the collar – is one way to record the dose to the fetus. [122]

5. Protecting Patients in Nuclear Medicine:

To provide radiation protection for patients that by ensuring they receive the minimum amount of radioactivity necessary to complete a test and by deriving the maximum benefit from the small amount of radiation received [38]. It is important not to give them more activity than necessary, or too little. Also, good quality radiopharmaceuticals are needed, and their activity must be assayed accurately. Sensitive and will-maintained equipment should be used [124]. Furthermore, greater care is required in the use of radionuclide investigations in children because of the increased risk of carcinogenesis.

The medical record of every patient for whom a nuclear medicine test is ordered should be reviewed before any part of the test begins. That for avoiding any patient's misadministration, which can be achieved by implementing strict procedures:

- Physician orders must be verified.
- Mode of administration must be verified.
- Quantity of radioactive material should be assayed in a dose calibrator.
- Type of radioactive material must be verified. [6]

5.1. Immobilization of Patient:

Immobilization devices and techniques are one method of using distance to reduce radiation exposure to the technologist from a radioactive patient. Also, they benefit the uncooperative patient by preventing motion that could lengthen imaging time or compromise image quality. Immobilization has become increasingly important with the growth of tomographic imaging. Also, immobilization may be necessary to immobilize or sedate children so that the examination can be completed successfully. [123]

5.2. Pregnant Patient:

At low radiation doses, below 1 rem (0.01 Sv), the risk to a fetus is thought to be minimal and outweighed by the medical benefit of the procedure to the mother; however, most nuclear medicine procedures exceed this radiation dose. So, radiopharmaceuticals are not normally administered to pregnant women, however under extraordinary circumstances one may be given. Prior to administering a radiopharmaceutical to a woman of childbearing age ascertain whether or not she is pregnant. In the event it is later discovered that a women injected with a radiopharmaceutical is pregnant [121]. The NCRP has stated that this risk is considered to be negligible at 5 rad or less when compared with the other risks of pregnancy, and the risk of malformations is significantly increased above control levels only at doses above 15 rad. Therefore, the radiation dose from a diagnostic examination seldom justifies the termination of pregnancy. [89]

5.3. Women who are Breast Feeding:

Since many radiopharmaceuticals are secreted in breast milk, it is safest to assume that, some radioactive compounds will be found in the breast milk when

a radiopharmaceutical is administered to a lactating female (Nursing mother). If the procedure is performed, the child should not be breast-fed until the radiopharmaceutical is no longer secreted in an amount estimated to give an unacceptable absorbed dose to the child. [123]

The ICRP recommendation action for women who are breast feeding are modified and summarized in **Table (17)**. [42]

Table (17): Modified ICRP recommended actions for breast feeding.

Group I
Stop breast feeding for at least 3 weeks (all ^{131}I radiopharmaceuticals except hippuran, ^{67}Ga citrate and ^{201}Tl)
Group II
Stop breast feeding for at least 12 h ($^{123/131}I$-hippuran, all ^{99m}Tc radiopharmaceuticals except RBCs, phosphorus complexes and renal agents)
Group III
Stop breast feeding for at least 4 h (^{99m}Tc-RBCs, phosphorus complexes and renal agents)

5.4. Other People Contacts:

Family at home, visitors in hospital and other patients are not at risk following the administration of diagnostic radiopharmaceuticals to patients. Due to the short effective half-life of most diagnostic radiopharmaceuticals and their sporadic use, there is usually very little radiation hazard to the patients family [123]. Doses to these groups are unlikely to exceed 2–3 % of any dose limit for members of the public.

The "worst case" dose that any other person might receive is the close contact dose to a frequently cuddled child of the patient will not exceed 1 mSv for most procedures involving diagnostic quantities of radionuclides. Nevertheless, cross-irradiation of patients should be minimized by scheduling of test or treatment (separation in time), by segregation in waiting areas, and if necessary by the use of screens (shielding). Restrictions will be necessary following therapeutic amount of ^{131}I. [31,128,129]

6. Receiving and Monitoring of Radioactive Package:

Monitoring of packages is required if the packages are labeled as containing radioactive material or if the packages are damaged or leaking. A radioactive shipment must be monitored as soon as possible after receipt but no later 3 hr after delivery if the delivery takes place during normal hours, or not later than 3 hr from the beginning of the next working day if it is received after working hours. Two types of monitoring are performed; survey for external exposure and wipe test for contamination on the surface of the package resulting from leakage of liquid. The survey reading of external exposure should not exceed 2 mSv/hr on the surface of the container or 100 μSv/hr at 1 m from the surface of the container. The wipe test should show less than 22,000 dpm or 370 Bq/100 cm^2. If the readings exceed these limits, the final delivering carrier must be notified. Advice should be sought from these authorities as to whether the shipment should be retuned. After all surveys are completed, the data must be entered into a receipt book. (4)

7. Transport of Radioactive Materials:

During the transport of radioactive materials, members of the public who are not specially trained in handling radionuclides may come into relatively close contact with them. It is therefore most important to ensure that such persons are neither unnecessarily exposed to radiation nor likely to become contaminated. (130)

General principles relating to the transport of the material within an institution are as follows:

1. The material must be transported in a suitable container. It should be doubly contained with a rigid outer container designed to prevent leakage should the primary container break. The container should be lined with absorbent material to soak up any spill that dose occur and must also provide adequate shielding from external radiation.

2. Whilst being transported a container of radioactive material must not be left unattended in areas accessible to the public or staff not concerned with its use.

3. Containers should suitably labeled. The label should give details of the radionuclide being transported. Care should be taken to ensure that labels are removed from empty containers.

4. The local rules should take into account the possibility of any hazardous situation that is likely to arise during transport. Procedures should also be such that they minimize the possibility of losing a source during transit and all actions should be taken when source is lost. [131-133]

8. Radioactive Waste Disposal:

8.1. Decay in Storage:

This is the more practical method of disposing of radioactive materials. Radionuclides with half-lives less than 65 days usually are disposed of by this method. These radionuclides are allowed to decay in storage for a minimum of 10 half-lives. The radioactive waste should be monitored and show less than 0.05 mR/hr exposure rate at the surface. If the radioactivity of the waste cannot be distinguished from background, it can be disposed of in the normal trash after removal or defacing of all radiation labels. This method is most appropriate for short-lived radionuclides such as ^{99m}Tc, ^{123}I, ^{201}Tl, and ^{111}In. also for wasting such as syringes, needles, vials containing residual activities and contaminated papers, tissues, and liners. Radioactivities should be stored separately according to half-lives for convenience of timely disposal of each radionuclide. [134]

8.2. Transfer to Authorized Recipient:

This method of transfer to an authorized recipient is adopted for long-lived radionuclides and usually involves transfer of radioactive wastes to authorized commercial firms that bury or incinerate at approved sites or facilities. For example, the columns of the $^{99}Mo - ^{99m}Tc$ generators normally, it is picked up by the authorized carrier when a new one is delivered. [135]

AIM OF THE WORK

The aim of this study is to establish and provide comprehensive guidelines and regulations for radiation protection program of ionizing radiation. It is also summarized recommendations of some national and international organizations to apply good practical radiation protection program.

These guidelines are addressed to physicians, physicists and technologists directly engaged in medical radiology, nuclear medicine and/or radiotherapy. They are also intended for those responsible for management of institutions operating in these fields, as well as advisory bodies concerned with radiation protection. These guidelines are used in planning and designing for any unit regarding nuclear medicine, radiodiagnosis, and/or radiotherapy.

It is aimed to be good reference for whom concerned with radiation protection in medical field.

MATERIAL AND METHOD

The materials of this study are tools and equipments that measure and detect radiation exposures and its levels. While the method is how to use these equipments and in which situations and ways should be used for radiation protection monitoring purpose.

I- Personnel Radiation Monitoring

In order to ensure that a worker will not be exposed throughout the year to an accumulative radiation dose exceeding the annual limit, the personnel monitoring must be used in controlled areas for occupationally exposed individuals.

Exposure monitoring of personnel is required whenever radiation workers are likely to receive 10% or more of the annual effective dose equivalent limit. In general three basic types of personnel monitors are used namely: film badges, thermoluminescent dosimeters (TLDs), and pocket ionization chambers. [2,14]

1. Film Badges:

Film badges (**Figure (43)**) are the most common type of personnel monitor and are most often used to measure whole-body irradiation accumulated at a low rate over a long period of time. Their use are based on the fact that the more radiation to which the badge is exposed, the darker the film when it is processed. If the film badge is worn in an appropriate location during working hours, it will then provide an accurate estimate of the occupational radiation exposure to the individual during the time period that

the badge wads worn. After processing, the degree of blackening of the individual's badge is compared to other similar films exposed to known amounts of radiation (calibrated badge films). These comparisons are used to estimate the radiation dose to the individual.

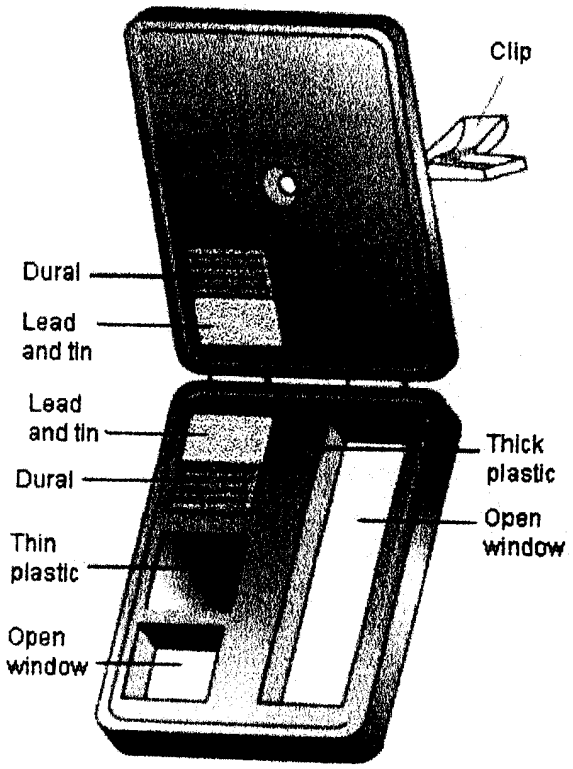


Figure (43): Film badge. [5]

A film badge is typically consists of a piece of film sealed in a light-tight packet. The film packet fits inside a plastic holder which can be clipped to the individual's clothing. Various types of filters (e.g., lead, copper, aluminum) can be positioned inside the holder to shield certain sections of the film. Any darkening of the film in these areas can then be used to determine the energy of the radiation to which the individual has been exposed. This type of information can be used to evaluate the radiation dose as shallow (non-penetrating) or deep (penetrating).

The traditional length of time before changing the film in a badge is 1 month, since they can fog easily as a result of temperature and humidity changes. Recently, dosimetry services have been giving institutions the option of changing film badges every 3 months. Film badges are sensitive to doses ranging from as low as 0.1 mSv (10 mrem) to as high as 500 mSv (500 rem). They are most sensitive to photons having energy of 50 keV; above and below this energy range, dosimetry film sensitivity decreases. (5)

The dosimeter should be worn at the collar level outside the lead apron; if it is worn. An additional monitoring device should also be used when performing some procedure that requires the hands to be near the source of radiation exposure. In this situation, employees may wear a ring dosimeter to monitor the dose equivalent to the hands. (136)

The advantage of film badge dosimeter is considered reasonably economical, and it provides both an integral dose and a permanent record. The main disadvantage of the film badge is the long waiting period before the exposed personnel know about their exposure. The film badge also tends to develop fog resulting from heat and humidity, particularly during storage for a long time, and this may obscure the actual exposure reading. (4)

Film badges characteristics:

Advantages	**Disadvantages**
▪ In use for many years	▪ Must wait for reading
▪ In expensive	▪ Accurate only at 10 mrem and higher
▪ Wide range of sensitivity	▪ Limited accuracy, especially when compared to TLDs
▪ Permanent record of exposure	
▪ Easy to process	▪ Fogging due to humidity, temperature, moisture, and lights leaks
▪ Easy to handle	

2. Thermoluminescent Dosimeters:

Thermoluminescent dosimeters (TLDs) are commonly used as finger rings (**Figure (44)**) in order to measure occupational exposure to the hands. This is an important measurement for the radiation therapy and nuclear medicine technologist, since a greater part of their occupational exposure can occur to the hands. For the x-ray technologist, hand exposures can occur on those rare (it is hoped) occasions when a patient must be held during a radiographic procedure. Rather than a piece of film, the TLD contains crystals of lithium fluoride (LiF) or calcium fluoride (CaF_2). When the crystals are exposed to ionizing radiation, energy is stored within the crystal in trapping centers. As the crystal is heated to several hundred degrees (a process known as annealing), it releases the trapped energy in the form of light. The intensity of the emitted light is directly proportional to the radiation dose.

The TLD has several advantages over the film badge. The lithium fluoride (LiF) crystals interact with ionizing radiation as human tissue does; hence this monitor determines dose more accurately and more sensitive than film badges. Exposure as low as (5 mrem or 0.05 mSv) can be measured precisely. Humidity, pressure, and normal temperature changes do not affect the TLD. Unlike the film badge, which can fog if worn for more than 1 month, the TLD may be worn up to 3 months. After annealing and obtaining the TLD reading, the crystals can be reused. This makes the device somewhat cost-effective, even though the initial cost is high (approximately twice the cost of a film badge).

TLDs have some disadvantages other than their high cost. A TLD can be read only once. The readout process destroys the stored information; the TLD may be reused, but once the crystal is heated, the record of any previous exposure is gone. [1]

TLDs characteristics:

Advantages

- Are tissue equivalent
- Can be worn for 3 months
- Can be reused
- Are highly accurate (sensitive)
- Do not affected by small temperature

Disadvantages

- Potentially higher cost
- Provide no permanent record

Figure (44): Thermoluminescent dosimeters (TLD) badge containing the sensitive material lithium fluoride. (1)

Figure (44): Extremity dosimeter (TLD ring badge) can be used to monitor the dose equivalent to the hands. (1)

3. Pocket Ionization Chambers (Pocket Dosimeters):

Pocket dosimeters are the most sensitive personnel dosimeters. However, the use of these monitors in medical field is not commonly. This simple dose-measuring device is mounted in a pen-type holder, as shown in **Figure (45)**, which can be readily clipped on an individual's clothing.

A pocket dosimeter is similar to other ion chambers and consists of two electrodes in an air-filled chamber. One electrode is stationary; the other, a thin quartz wire called a hair or fiber, is movable. The electrodes are charged positively prior to operation, which causes them to repel each other. When totally charged, the fiber aligns with the zero point on a reading scale. As air in the chamber is ionized by radiation, the liberated electrons neutralize the positive charge on the electrodes, which allows the fiber of the dosimeter to move closer to the other electrode. More exposure caused the creation of more ions, causing greater movement of the fiber, which in turn shows a higher exposure on the reading scale.

The primary advantage of pocket ionization chambers is that they provide immediate exposure readout for radiation workers who work in high exposure areas. Furthermore, pocket dosimeters are compact units that are easy to carry and convenient to use. Also they are reasonably accurate and sensitive and are considered ideal monitoring devices for procedures that last for relatively short periods of time.

Some disadvantages are associated with the use of pocket ionization chambers. They are fairly expensive. If not read each day; the dosimeter may give an inaccurate reading because the electric charge tends to escape (i.e., the fiber indicator drifts with time; thus a false reading might be obtained from a dosimeter read too late). Pocket dosimeters can also discharge if subjected to mechanical shock, which again would result in a false reading. [19]

Pocket dosimeter characteristics:

Advantages	Disadvantages
▪ Can be used for short periods.	▪ The charge can leak on the dosimeter, causing a false reading.
▪ Can give immediate reading.	▪ Mechanical trauma can change the reading.
▪ Useful for monitoring personnel who are not normally monitored.	▪ Easy to misread.

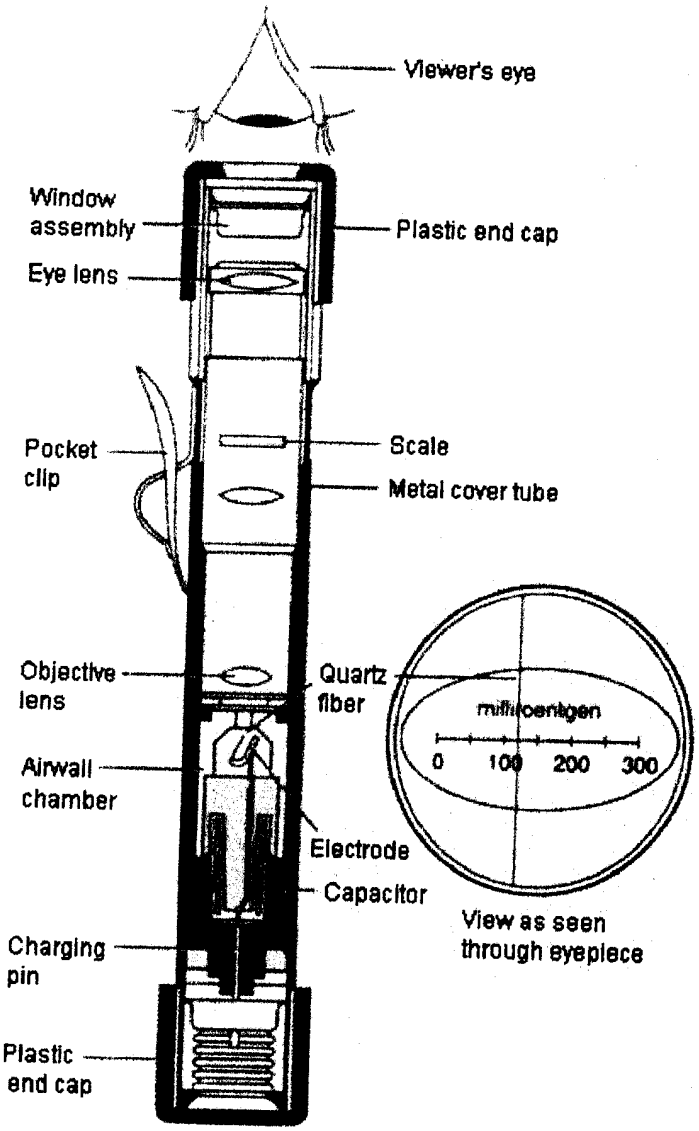


Figure (45): Schematic drawing of a pocket dosimeter. (19)

4. Proper Care of Personnel Dosimeters:

Regardless of the type of personnel dosimetry device assigned, it is the wearer's responsibility to assure that it is cared for properly. For the device to give an accurate estimate of the wearer's occupational exposure, the following precautions must be observed:

- Dosimetry devices must be worn only by the persons to whom they are assigned and for the period designated.
- Film badges should be worn at collar level or if a lead apron is worn, at collar level outside the lead apron.
- Dosimetry devices should not be worn when having personal medical or dental x-ray procedures, since this is not occupational exposure.
- When not in use, dosimetry devices should be stored in a location away from heat, humidity, and sources of stray radiation.
- If the badge or other dosimetry device is lost or any thing happens to it that could lead to a false reading, the supervisor or the person in charge should be notified.

Great care should always be taken with any personnel dosimetry device, since this provides the wearer's radiation exposure history and is the only way to assure that the wearer does not exceed maximum occupational exposure limits. [5,19]

5. Personnel Monitoring Report:

Results from personnel monitoring programs must be recorded accurately and maintained for review to meet the regulations. To comply with such requirements, institutions frequently use established dosimetry services. These monitoring services process film badges and other types of personnel

dosimeters and prepare a written personnel monitoring report for the health care facility. Such report lists the deep and shallow occupational exposure of each person in the institution by the exposed monitors. *Deep* refers primarily to penetrating radiation such as x-radiation and gamma radiation, *shallow* refers to non-penetration radiation such as beta and very low-energy x-radiation and gamma radiation. Information on the report (**Table (18)**) is arranged in a series of columns. These columns include the following:

1. Personal data; listing each participant's identification number, name, sex and birth date.
2. Type of dosimeter; such as film badge or finger badge.
3. Radiation quality; e.g., x-ray, beta particle, neutron, combined radiation exposure.
4. Dose equivalent data; including current deep and shallow recorded dose equivalents (millirems) for the time indicated on the report (e.g., from the first day of a given month to the last day of that month).
5. Cumulative dose equivalents; for deep and shallow radiation exposures for the calendar quarter (3 months), the year to date, and lifetime radiation.

These reports are required to be posted where workers can review their occupational exposures. The information contained in these reports should be transferred whenever change of employment site so that the occupational exposure records are always up to date. The dosimetry report is a permanent record that should be kept on file indefinitely. [1,5,19]

Table (18): Sample file badge report. [5]

RADIATION DOSIMETRY REPORT			
FOR EXPOSURE PERIOD TO	REPORT DATE	DOSIMETER RECEIVED	PAGE No.

Participant ID Number	Name	Sex	Birth date	Note	Dosimeter type	Radiation quality	Exposure to badge (Millirems) for period(s) indicated below		Cumulative totals (Millirems)					
									Calendar Quarter		Year to date		Permanent	
							Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow

II- Workplace Monitoring

Radiation monitoring of the working environment and the surrounding areas is an essential part of any effective radiation protection program. This is to ensure that neither the operating personnel nor the general population receives radiation doses in excess of permissible limits. The type and extent of the environmental monitoring program for a particular radiation installation largely depends on the individual circumstances. Some typical guiding factors are the types of facilities and their inventories, the nature of work with radiations and radioactive materials, the types and quantities of radionuclides handled, and the possible routes and rates of release of radioactivity into the environment. A continuing assessment of the radiation situation in the working environment is necessary to ensure safe working conditions. This procedure is an essential adjunct to the personnel monitoring system which measures the radiation doses received by operating personnel. [28]

1. Radiation Surveys for External Radiation:

Radiation surveys should be conducted in areas where the potential exists for exposure to external radiation field in order to:

1. Characterize the radiation field so that it can be properly posted and controlled.
2. Provide the information required for planning work activities to maintain the external radiation exposures at ALARA levels.
3. Ensure the prompt discovery of changed radiation fields caused by changing conditions.

Routine radiation surveys are conducted at fixed intervals and at fixed locations to document the field and to determine whether there have been any unexpected changes in the external radiation field levels. Non-routine surveys

should be performed to evaluate radiation fields. That have not been previously measured and when there is an expected change in the radiation field, for example: [84]

1. During the initial operations of newly installed radiation-producing equipment or radiation sources.
2. Following the modification of radiation-producing equipment or radiation sources.
3. Following any modification of the shielding around a source of external radiation.
4. Following an incident in which an elevated external radiation exposure is suspected or has occurred.

The instrumentation that is used to perform radiation surveys should be capable of measuring accurately the types of radiation, at the dose rates and under the environmental conditions that may be encountered. The radiation survey result should be documented according to established procedures. [51,84]

All radiation measuring devices must be calibrated, and some simple method of checking constancy should be employed.

Records of monitoring of workplaces and individual monitoring of workers shall be kept. The purpose of record keeping is influenced by the evaluation of trends in exposure, the evaluation of collective or average dose equivalents, and the use of records for medical and legal purposes. [49]

2. Installed Area Monitoring:

Fixed area monitors are typically used to monitor ambient radiation levels in potentially occupied areas. They are particularly useful when the potential exists for a significant increase in the ambient radiation levels. These monitors provide a continuous "radiation survey" at their

predetermined and fixed locations and normally activate an alarm when a predetermined radiation dose or dose rate is exceeded. They can also be used to supplement or replace personal dosimeters, especially in areas where the annual external effective dose is expected to be less than 1 mSv. [28,84]

3. Radiation Surveys for Surface Contamination:

The principal objective of monitoring programme for surface contamination is to assist in preventing the spread of contamination. [87]

Contamination surveys are conducted to establish the extent to which radioactive material is present on surfaces of equipment and in facilities and the extent to which that material may be transferable. Any transfer or resuspension of the material can lead to internal deposition through ingestion or inhalation. [84]

In the direct monitoring method, the probe of the conventional contamination monitor is used to scan the area, which is suspected of contamination, and the reading so obtained provides a direct measure of the degree of contamination. Where the surface areas involved are very large, it may not be practicable to monitor the entire surface and in such cases it will be sufficient to monitor representative areas. Where such direct measurements are impossible, a swab technique should be used. This involves rubbing a filter paper lightly over the contaminated surface, usually covering an area of up to 100 cm^2. This filter paper is then assessed for activity, using the contamination monitor. [28]

4. Radiation Surveys for Air Contamination:

Monitoring of airborne radioactive materials is important because inhalation is usually the most significant route of intake of radioactive material by workers. The principal objective monitoring programme for airborne contamination is to assist in the control of internal exposure of

workers resulting from inhalation and to provide early detection of abnormal conditions, thereby allowing appropriate protective actions. Monitoring for air contamination is likely to be needed only in installations handling significant amounts of unsealed radioactive material. [87]

There should be an airborne monitoring program in those areas where there is a significant potential for airborne contamination. Surveys for airborne radioactive material should be performed on a regular basis in these areas where the potential for airborne radioactive material exists. The frequency of these surveys should be commensurate with the potential for the existence of, or changes in airborne radioactivity levels. Special surveys for airborne radioactivity should be preformed to evaluate conditions that have not been previously measured and when there is an expectation that airborne radioactivity will be present or that airborne radioactivity levels may have changed, for example, immediately following the discovery of a significant spill or spread of radioactive materials. Continuously operating samplers equipped with continuous air monitors should be used to detect unexpected airborne contamination and to give a warning of any sudden change in concentration of airborne radioactive material. These monitors should be located in areas in which the potential for internal exposure is high and near systems that have a potential for causing rapid increases in airborne radionuclides. Continuous air monitors can be equipped with an alarm system that will indicate an abrupt change or an increase in radioactivity above a preset level. [28, 84]

III- Radiation Protection Survey Instruments

Radiation protection survey instruments are area monitoring devices that detect and measure radiation. The detection system indicates the presence or absence of radiation, whereas the dosimeter system measures only

cumulative radiation intensity [1]. The choice of a particular radiation detector dosimeter depends on the type of measurement required. In radiation protection surveys, low levels of radiation are measured and, therefore, the instrument must be sensitive enough to measure such low levels. [14]

1. Requirements of Radiation Survey Instrument:

Radiation survey instruments for area monitoring should meet certain requirements as follows:

1. These devices must be easy to carry so that one person can operate the device in an efficient manner for a period of time.
2. Survey instruments must be durable enough to withstand normal use, including routine handling that occurs during standard operating procedures.
3. Area monitors must be reliable; only in such a case can radiation exposure or exposure rate in a given area be accurately assessed.
4. Area monitoring devices should interact with ionizing radiation in a manner similar to the way human tissue reacts. This permits dose to be determined more accurately.
5. A radiation survey instrument should be able to detect all common types of ionizing radiation. Such a capability increases the usefulness of an area monitoring device.
6. The energy of the radiation should not affect the response of the detector, and the direction of the incident radiation should not affect the performance of the unit. Such characteristics ensure consistency in unit operation among individual users.
7. Survey equipment should be cost-effective. The initial cost and subsequent maintenance charges should be as low as possible. [1,84]

2. Gas-Filled Radiation Survey Instruments:

2.1. Principles of Gas-Filled Detectors:

The operation of a gas-filled detector is shown in a schematic diagram in **Figure (46)**. When an ionizing radiation beam passes through the gas, it causes ionization of the gas molecules and ion pairs are produced depending on the type and pressure of the gas. When a voltage is applied between the two electrodes, the negative electrons move to the anode and the positive ions to the cathode, thus producing a current that can be measured on a meter. The measured current is proportional to the applied voltage and the amount of radiation. The different regions characterizing these instruments are as follows:

1. At very low voltages, the ion pairs do not receive enough acceleration to reach the electrodes and therefore may combine together to form the original molecule instead of being collected by the electrodes. This region is called the *region of recombination* (**Figure (47)**).

2. As the applied voltage gradually increases, a *region of saturation* is encountered, where the current measured remains almost the same over the range of applied voltages. In this region, only the primary ion pairs formed by the initial radiations are collected. Individual events cannot be detected; only the total current passing through the chamber is measured. Because specific ionization differs for α-, β-, and γ-radiations, the amount of current produced by these radiations differs in this region. The applied voltage in this region is in the range of 50 – 300 V. Ionization chambers such as Cutie Pie surveys are operated in this region.

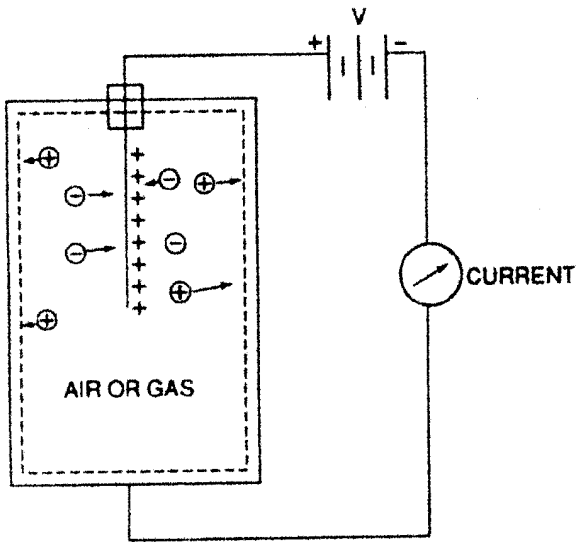


Figure (46): A schematic diagram of a gas-filled detector illustrating the principles of operation. (4)

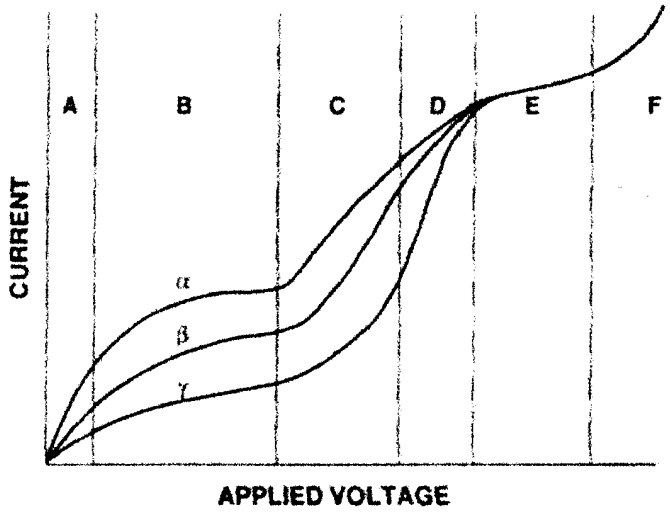


Figure (47): A composite curve illustrating the current output as a result of increasing voltages for different radiations. (A) Region of recombination, (B) region of saturation, (C) proportional region, (D) region of limited proportionality, (E) Geiger region, and (F) region of continuous discharge. (4)

3. When the applied voltage is further increased, the electrons and positive ions gain high velocities and energies during their acceleration toward the electrodes to cause secondary ionization. The latter increases the measured current. This process is referred to as the *gas amplification*. This factor can be as high as 10^6 per individual primary event depending on the design of the gas detector and the applied voltage. In this region, the total current measured is equal to the number of ionizations caused by the primary radiation multiplied by the gas amplification factor. In this region, the current increases with the applied voltage in proportion to the initial number of ion pairs produced by the incident radiation. Therefore, as in the case of the saturation region, the current amplification is relatively depends on the type of radiation i.e., α-, β-, and γ-radiations. This region is referred to as the *proportional region* (Fig. (47)).

4. As the applied voltage increases further, the current produced by different types of radiation tends to become identical. The voltage range over which the current tends to converge is referred to as the *region of limited proportionality*. This region is not practically used for detecting any radiation.

5. With additional increase in voltage beyond the region of limited proportionality, the current becomes identical, regardless of how many ion pairs are produced by the incident radiations. This region is referred to as the *Geiger region*. In the Geiger voltage region, the current is produced by an avalanche of interactions.

6. As the applied voltage is increased beyond the Geiger region, a single ionizing event produces a series of repetitive discharges leading to what is called *spontaneous discharge*. This region is called the *region of continuous discharge*. Operation of a detector in this region may cause damage to the detector.

Three types of gas-filled radiation survey instruments exist: the ionization chamber survey meter (Cutie Pie), the proportional counter, and the Geiger-Muller detector. These instruments measure either the total quantity of electrical charge resulting from the ionization of the gas or the rate at which the electrical charge is produced. These devices, when properly calibrated, give a reasonably accurate measurement of the exposure. Each of these instruments has its own special use, and they are not all equally sensitive in the detection of ionizing radiation. [4, 15]

2.2. Ionization Chamber Survey Meter (Cutie Pie):

Ionization chambers are operated at voltages in the saturation region that spans 50 – 300 V. The portable survey meter (Cutie Pie) is made of an outer metallic cylindrical electrode and a central wire. In this meter air is used for ionization and is operated with a battery (**Figure (48)**). [4,11,15]

Ionization chambers are widely used in measuring either dose (total amount of radiation) or the exposure rate per hour. They are primarily used for measuring high-intensity radiation such as x-rays, gamma rays, and high-energy beta radiation (if equipped with a suitable window). [1,4,5,28]

In the rate mode the ionization chamber can measure radiation intensity ranging from 1 mR/hr to several thousand R/hr and in integrate mode or cumulative mode can sum exposures from as little as 0.1 mR to 1 R [28]. This device can be used to monitor diagnostic x-ray installations when exposure times of a second or more are chosen and to measure fluoroscopic scatter radiation exposure rate, exposure rate from patients containing therapeutic doses of radioactive materials, exposure rate in radioisotope storage facilities, and the cumulative exposures received outside protective barriers.

The advantage of using the ionization chamber is that it can measure a wide range of radiation exposures within a few seconds. The delicate construction and relatively large size of the unit, however, may be considered a disadvantage. [1]

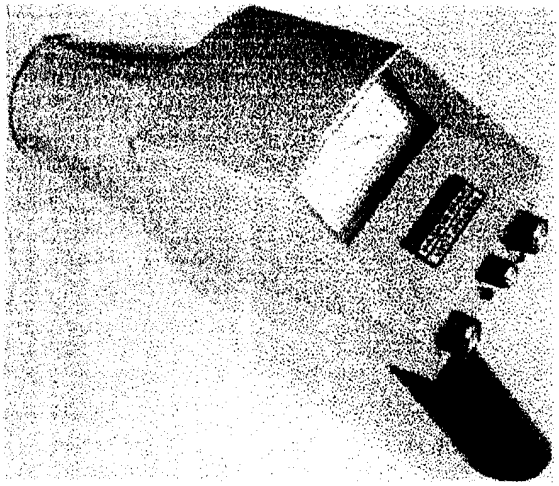


Figure (48): Ionization chamber survey meter, or "cutie pie". [1]

2.3. Proportional Counters:

Proportional counters are usually filled with 90 % argon and 10 % methane at atmospheric pressure. These counters can be used to count individual counts and to discriminate radiations of different energies such as α- and β- particles. These counters, however, are not commonly used for γ- and x-ray counting because of poor counting efficiency (< 1 %) [4,15]. They are generally used in a laboratory setting to detect alpha and beta radiation and small amounts of other types of low-level radioactive contamination. [1,28]

2.4. Geiger–Muller (G-M) Counter:

The Geiger-Muller (G-M) counter operates in the Geiger region of the voltage, as shown in **Figure (47)**. The G-M counter consists essentially of a cylindrical cathode with a fine wire stretched along the axis of the cylinder. This cylinder tube or probe is filled with a special mixture of gases (such as

helium, argon, methane, or neon) at a pressure of about 100 mmHg (**Figure (49)**). This probe has a very thin window that allows the detection of alpha and beta radiation [5,14,28]. Some GM probes are provided with a metal cover that stops all β particles and low-energy γ-radiations so that only high-energy photons are detected. The GM counter is usually battery operated at a voltage of 1000 – 1200 V. The meter connected to the GM probe gives reading in mR/hr or counts per minute. Some counters are equipped with audible alarms or flashing light alarms that are triggered by radiation above a preset intensity. The latter kind is often used to monitor the radiation level in different work areas and is called an *area monitor.* [4]

The G-M survey meter is much more sensitive than the ionization chamber. For example, the Geiger counter can detect individual photons or individual particles that could never be observed in an ionization chamber. However, this detector is not a dose-measuring device, it just registers counts for whatever incident radiation happens to produce an ionization n the sensitive volume. Although G-M counters are most useful in the detection (rather than measurement) the presence of radiation sources and low-level intensity radiation. These counters are almost 100 % efficient for counting alpha and beta particles but have only 1 % to 2 % efficiency for counting γ- and x-rays. [11,14]

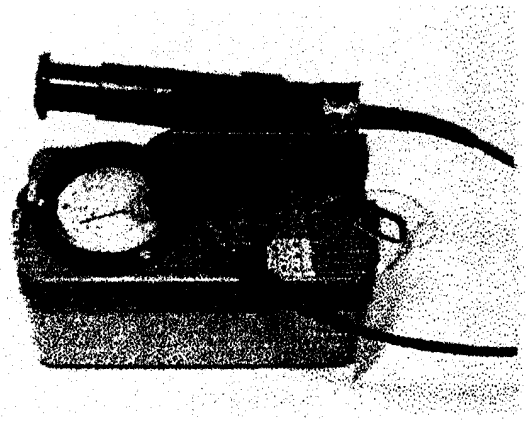


Figure (49): Geiger-Muller detector. [1]

The G-M counter serves as primary radiation survey instrument for area monitoring in nuclear medicine facilities. Hence it can easily detect any area contaminated by radioactive material, and also it can be used to locate a lost radioactive source or low-level radioactive contamination. (1)

3. Scintillation Detectors:

To improve counting efficiency for γ- and x-rays, scintillation detectors with high density are used. As in the ionization chamber, the scintillation detectors are dose-rate measuring devices. They are the most sensitive detector of x- and γ-rays, and are also useful in the detection and subsequent location of lost radiation sources. (11)

These detectors have the unique property of emitting scintillations of flashes of light after absorbing γ- or x-radiations. The sensitive part in these counter (**Figure (50)**) is sodium iodide or cesium iodide crystal that produces scintillations upon exposure to radiation. This light is detected after that by a photomultiplier tube, which converts the flashes of light into electric impulses, which is directly proportional to the exposure and can be measured or recorded. (5)

As the scintillation counter is the most expensive of all radiation detectors, however, a number of factors have led to its being developed as a versatile measuring device, these are:

a) The detector volume can easily be made tissue-equivalent.

b) The detection efficiency is extremely high, and this makes the instrument particularly valuable for low- counting level.

c) The detector volume can be made as large or as small as necessary.

d) A high degree of discrimination between radiations of different energies is possible and this makes the instrument particularly valuable for use in mixed radiation fields. (28)

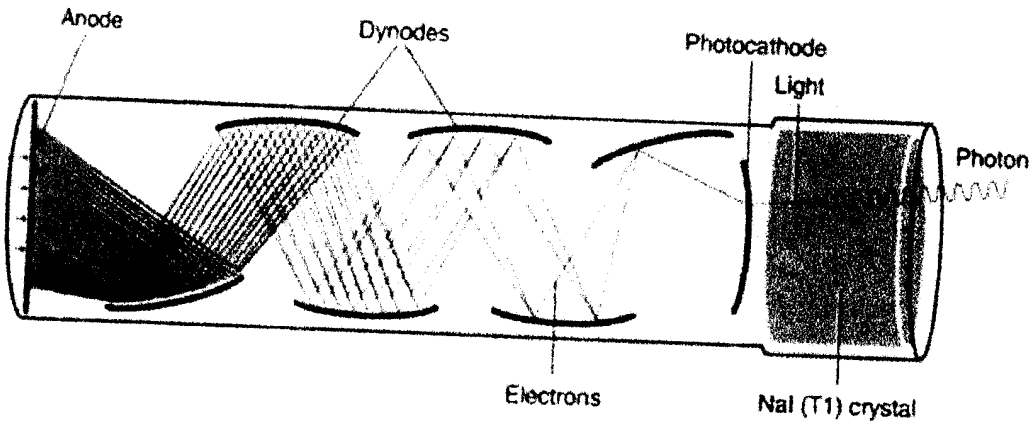


Figure (50): Scintillation counter. (137)

4. Calibration of Survey Meter:

All radiation survey instruments should be carefully calibrated as soon as they are received for use. In addition, they should be subjected to both mechanical and electrical inspection, and further, all environmental factors that could lead to any malfunction of the instruments should be carefully considered. Survey meters should be stored in dust-free atmospheres and should not be subjected to extreme changes of environmental conditions such as temperature and humidity. In case of battery-operated instruments where the batteries are not leak-proof, it is important to ensure that the batteries are *removed*. These steps will generally ensure trouble-free performance of such instruments. Another important factor involved in the use of radiation survey instruments is the need for regular calibration of these instruments at carefully predetermined intervals.

The main objectives of calibration procedures are:

a) To ensure sound functioning of the instrument.

b) To ensure that the measurements of the instrument are reliable and accurate in all ranges and for all energies in which the instrument is expected to provide energy-independent response.

c) To ensure further that the instrument functions reliably in the specified dose-rate range.

d) To confirm the performance of the instrument under extremes of environmental conditions in which it is certified to perform satisfactorily. [28,84]

IV- Work Area Definitions

An unrestricted area is one where radiation levels are essentially the same as background radiation. Such areas do not require monitoring, posting, or control requirements, which access is not limited. *A restricted area* is an area which access is limited for the purpose of protecting individuals against undue risk from radiation exposure. Within a medical facility, restricted areas include rooms in which radiographic procedures are performed, nuclear medicine departments, and rooms in which radioactive materials are used or stored.

Regulations require that restricted areas be properly **posted** with **signs and labels** to warn individuals entering such areas of potential for radiation exposure or the possibility of radioactive contamination or both. The radiation symbol, a magenta or black tri-blade on a yellow background, is the internationally recognized symbol of radiation. However, signs indicating various levels of radiation hazard may be found in medical facility. The requirements for each type of signs shown in **Figure (51)** are given below:

- *Caution – Radioactive Materials.* Required to be posted at the entrance to rooms where radioactive materials are used, stored, or both, indicating the presence of radioactive materials and the possibility of radioactive contamination.

- *Caution – Radiation Area.* Required to be posted at the entrance to room in which radiation levels could result in a person's receiving a dose equivalent in excess of 5 mrem (0.05 mSv) in one hour at 30 cm from the source or any surface that the radiation penetrates.

- *Caution – High-radiation Area.* Required to be posted at the entrance to rooms in which radiation levels can result in a dose equivalent in excess of 100 mrem (1 mSv) in one hour at 30 cm from the source or any surface that the radiation penetrates.

- *Grave Danger – Very High Radiation Area.* Required to be posted at the entrance to rooms in which radiation levels could result in an absorbed dose of 500 rads (5 Gy) in one hour measured at a distance of 1 m from the radiation source. [5,19]

Access to all areas in which exposure to radiation and to radionuclides could occur must be controlled not only in respect of the personal who may be permitted to enter such areas but also in respect of the type of clothing they should wear and the precautions they should take. In the administration of such control measure, **the classification of radiation areas** that are given in **Table (19)**, based either on the presence of ionizing radiations or on the presence of radioactive contamination or on both, is of great assistance. [28]

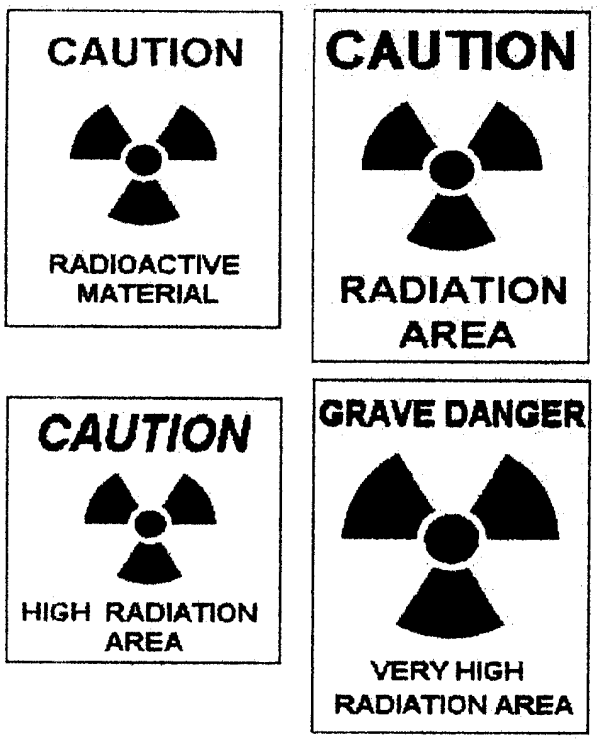


Figure (51): Radiation warning signs. [19]

Table (19): CLASSIFICATION OF WORKING AREAS. [28]

Area type	Definition	Control of access	Typical examples
4	Areas within the confines of a radiation facility where the external radiation levels are negligible and where radioactive contamination is also not present.	Unrestricted	Administration block
3	Areas in which the average external radiation level is not greater than 0.1 R/week. Contamination is negligible and no special operating instructions are required.	Access limited to radiation workers, no special clothing necessary.	Working areas in the immediate vicinity of radiography operations, such as control rooms, etc.
2	Areas in which external radiation levels could exist and in which the possibility of contamination necessitates special operating instructions.	Access limited to radiation workers in appropriate clothing and foot-wear.	Luminizing factories and other equivalent installations.
1	Areas in which the external radiation exposure levels and/or radioactive contamination levels could be high.	Controlled access to radiation workers only, under strictly controlled working conditions and with appropriate clothing.	Hot laboratories and similar facilities. Highly contaminated areas.

RESULTS & DISCUSSION

RESULTS AND DISCUSSION

I - Types of Exposures

1. Occupational Exposure:

There are a wide variety of situations in which persons at work are exposed to ionizing radiations, ranging from work involving small amounts of radioactive material, such as tracer work, through work with radiation generating or gauging equipment, to work in a nuclear fuel cycle facility. There are also situations where the exposure of workers to natural sources of radiation is sufficiently high to warrant its management and control as an occupational hazard. [87]

The conventional definition of occupational exposure to any hazardous agent includes all exposures incurred at work, regardless of their source. However, because of the ubiquity of radiation of natural origin, the direct application of this definition to radiation would mean that all workers should be subject to a regime of radiological protection. Therefore, it is limited its application of the phrase "occupational exposure (to radiation)" to exposures incurred at work as the result of situations that can reasonably be regarded as being the responsibility of the operating management.

Any exposure at work (excluding any medical exposure at work) as a result of artificial sources in, or associated with, the workplace should be included in occupational exposure, unless the sources have formally been excluded from regulatory control or exempted from the relevant aspects of regulatory control by the regulatory agency. [34,87]

2. Medical Exposure:

Medical exposure is confined to exposures incurred by individuals as part of their own medical diagnosis or treatment (including screening and medico – legal purposes, all these individuals are called patients herein) and to exposures (other than occupational) incurred knowingly and willingly by individuals helping in the support and comfort of patients undergoing diagnosis or treatment. Exposure of an individual to other sources, such as stray radiation from the diagnosis or treatment of other persons and any occupational exposure of staff, is not included in medical exposure. [34,112]

3. Public Exposure:

Public exposure encompasses all exposures other than occupational and medical exposures. The component of public exposure due to natural sources is by far the largest, but this provides no justification for reducing the attention paid to smaller, but more readily controlled, exposures to artificial sources. [34,112]

II- Limitation of Exposure and Risk Estimation to Ionizing Radiation

Occupational and nonoccupational dose limits have changed over the years in step with evolving information about the biological effects of radiation and with change in the conceptual framework within which recommended dose limits are developed and applied. [37]

Early in the twentieth century radiation dose limits were called tolerance doses. From approximately 1940 to 1990, radiation dose limits were known as maximum permissible dose (MPD). Currently radiation dose limits are referred to simply as recommended dose limits. [6,138]. **Table (20)** shows the evolution of occupational dose limits and **Figure (52)** represents the evolution of the dose limits.

Table (20): Evolution of occupational exposure limits. [38]

Time period	Limit	Authority
1896 to early 1900s	Erythema dose.	Generally accepted guideline.
1902	Fogging of a photographic plate.	Rollins
1920s – 1940s	Tolerance dose.	Generally accepted guideline.
1925	1/100 erythema dose. 1/10 erythema dose.	Mutscheller Sievert
1931	0.2 R/day (about 40 rem/y)	Advisory Committee on X-Ray and Radium Protection
1936	0.1 R/day (about 20 rem/y)	Advisory Committee on X-Ray and Radium Protection
1959	5 rem/y Cumulative dose 5 (N-18)	NCRP
1987	5 rem/y Cumulative dose = age in rem	NCRP
1991	2 rem/y	ICRP

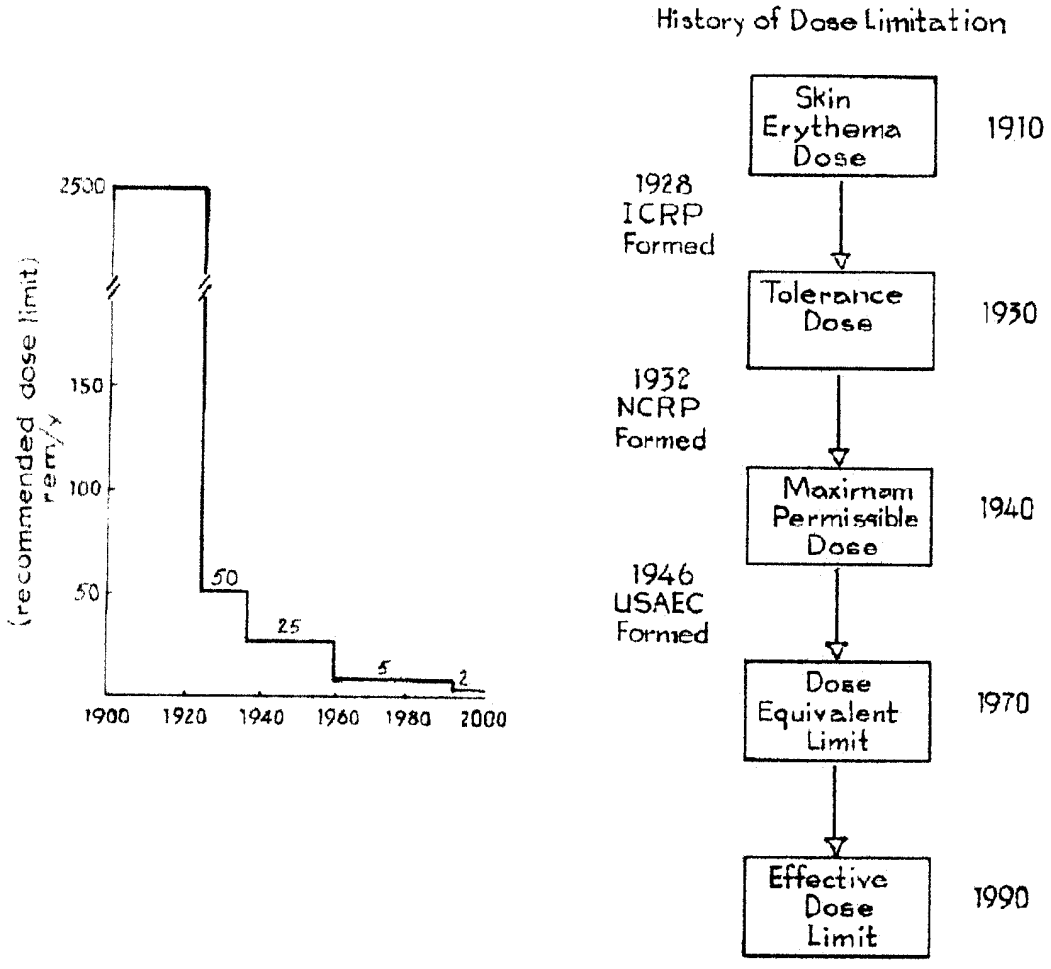


Figure (52): History of Dose limitation. [6]

1. Annual Effective Dose Limits:

Effective dose limit concerns the upper boundary dose of ionizing radiation that results in a negligible risk of bodily injury or genetic damage. The sum of both external and internal whole-body exposure is considered when effective dose limits are established. These upper limits are designed to minimize the risk to humans in terms of non-stochastic (deterministic) and stochastic (probabilistic) effects. [20, 31]

For occupational exposure, ALARA principle should be followed, for which the risks are kept as low as reasonably achievable, taking into account social and economic factors. In any case, radiation exposure limits are designed to ensure that the risk to an individual of a fatal cancer from exposure to radiation should be no greater than that of fatal accidents by employees in other safe industries. [14,37]

1.1. Occupational Dose Limits:

Table (21) gives occupational and public dose limits as recommended by the NCRP and ICRP. These limits do not include exposure received from medical procedures or the natural background [14]. An annual effective dose equivalent limit for whole-body occupational exposure has been set at a maximum of 50 mSv (5 rem) by the NCRP. [37]

The ICRP published new recommendations proposing the need to restrict the whole body radiation dose for occupationally exposed persons to an effective dose equivalent of 20 mSv per year, with the flexibility to go to 50 mSv in a single year provided that the total effective dose in 5 consecutive years does not exceed 100 mSv, an average annual dose of 20 mSv. [2,34,87,112]

Table (21): Summary of NCRP recommendations specifying limits for radiation exposure. [a] (37,84)

A. Occupational exposures [b]		
1. Effective dose limits:		
a. Annual [c]	50 mSv	5 rem
b. Cumulative	10 mSv x age	1 rem
2. Equivalent dose limits for tissues and organs (annual):		
a. Lens of eye	150 mSv	15 rem
b. Skin, hands and feet	500 mSv	50 rem
B. Public exposures (annual)		
1. Effective dose limit, continuous or frequent exposure [b]	1 mSv	0.1 rem
2. Effective dose limit, infrequent exposure [b]	5 mSv	0.5 rem
3. Equivalent dose limits for tissues and organs: [b]		
a. Lens of eye	15 mSv	1.5 rem
b. Skin, hands and feet	50 mSv	5 rem
4. Remedial action for natural sources:		
a. Effective dose (excluding radon)	>5 mSv	>0.5 rem
b. Exposure to radon decay products	>7x 10^{-3} Jhm^{-3}	>2 WLM
C. Education and training exposures (annual) [b]		
1. Effective dose limit	1 mSv	0.1 rem
2. Equivalent dose limits for tissues and organs:		
a. Lens of eye	15 mSv	1.5 rem
b. Skin, hands and feet	50 mSv	5 rem
D. Embryo-fetus exposures (monthly) [b, d]		
1. Equivalent dose limit	0.5 mSv	0.05 rem
E. Negligible individual dose per source or practice (annual) [b]	0.01 mSv	0.001rem

[a] Excluding medical exposures.
[b] Sum of internal and external exposures but excluding doses from natural sources.
[c] the ICRP recommended annual dose limit for occupational is 20 mSv.
[d] the ICRP recommended dose limit to embryo-fetus below 1 mSv during the pregnancy.

Non-stochastic (deterministic) limits for tissues and organs have been set to prevent excessive doses to specific regions of the body. They include the following: 150 mSv (15 rem) to the lens of the eyes and 500 mSv (50 rem) to all other tissues and organs, including the red bone marrow, breast, lung, reproductive cells, and localized areas of skin. [34,37,112]

It may be noted that the NCRP has discontinued its previous recommendation of the age-proration formula for the cumulative limit, i.e., (age – 18) x 5 rem. The new guidance is that the lifetime total effective dose in mSv should not exceed 10 times the occupationally exposed person's age in years. A radiation worker's lifetime effective dose must be limited to his or her age in years times 10 mSv (years x 1 rem). Adhering to this limit ensures that the lifetime risk for these workers remains acceptable. [1,14,37]

The NCRP recommends that all new facilities and the introduction of all new practices should be designed to limit annual effective dose to workers to a fraction of the 10 mSv per year implied by the lifetime dose limit (cumulative dose limit). [37]

1.2. Dose Limits for Public at Large:

A limit also has been set for individual members of the general public not occupationally exposed. The recommended annual limit is 1 mSv (0.1 rem) effective dose for continuous or frequent exposure and an annual limit of 5 mSv effective dose for infrequent exposure (not including medical or background exposure in either case). [34,37,112]

Also an annual equivalent dose limit of 50 mSv is recommended for the hands, feet and skin and 15 mSv is recommended for the lens of eye.

The recommendation of remedial action levels for the public is 5 mSv annual average effective dose for exposure from natural sources excluding

radon and an annual average of 7 x 10^{-3} jh m^{-3} for total exposure to radon and its decay products.

Students under the age of 18 who may be exposed to radiation as a result of their educational or training activities should not receive more than 1 mSv (0.1 rem) per year. [37]

1.3. Dose Limits For Pregnant Women:

The pregnant woman who is a radiation worker can be considered as an occupationally exposed individual, but the fetus cannot [14]. The NCRP recommends a monthly equivalent dose limit not exceeding 0.5 mSv to the embryo-fetus after declaration of the pregnancy. With this recommendation, there is no need for a limit on the total equivalent dose received by the embryo-fetus [37]. This limit excludes both medical and natural background radiation and is designed to restrict significantly the total lifetime risk of leukemia and other malignancies. Deterministic effects are expected to be negligible if the dose limits remain below the established limit. [1]

The ICRP has also recommended a supplementary dose limit for pregnant workers, which is intended to keep the dose to the embryo-fetus below 1 mSv during the remainder of the pregnancy. It also recommends that the equivalent dose to the surface of the maternal abdomen (lower trunk) should not exceed 2 mSv. The maternal intake of radionuclides should not exceed about 1/20 of the limit allowed for radiation workers. [31,34,87,112]

1.4. Negligible Individual Risk Level (Dose):

The concept of a Negligible Individual Risk Level (NIRL) was introduced in 1987 by NCRP [39] and was defined as "the level of average annual excess risk of fatal health effects attributable to radiation, below which efforts to reduce radiation exposure to the individual is unwarranted.

The NCRP also states that "the NIRL is regarded as trivial compared to the risk of fatality associated with ordinary, normal societal activities and can, therefore, be dismissed from consideration." [39]

In the NCRP Report No. 116 [37], it defines an annual Negligible Individual Dose (NID) which establishes a boundary below which the dose can be dismissed from consideration and sets the NID at 0.01 mSv effective dose. Thus, activities that result in an exposure of 0.01 mSv do not warrant further efforts to reduce dose. This NID is not a yearly exposure to an individual but is exposure from an activity or a source of radiation. [38]

1.5. Annual Limits on Intake:

The Annual Limits on Intake (ALI) is restricted by the basic requirements for stochastic and non-stochastic effects [27]. The ALI given by ICRP is based on limiting the committed effective dose from an intake in a single year to 20 mSv. This approach will take adequate account of any non-uniform distributions of dose within organs such as those due to hot particles. The estimated intakes may be averaged over a period of 5 years to provide some flexibility. The restriction of intakes (averaged over 5 years) to the annual limit on intake will, in practice, ensure that the lifetime equivalent dose (not committed equivalent dose) in any single organ will not be such as to result in deterministic effects. [34]

NCRP Report No. 116, [37] it introduces Annual Reference Levels of Intake (ARLI) at the same effective dose level as recommended by the ICRP for annual limits on intake (ALI) of 20 mSv for workers. Whereas, the NCRP recommends the use of the ICRP values as reference value rather than limits since intakes up to 2.5 times the ALI would be in compliance with the effective dose limit of 50 mSv.

1.6. Derived Air Concentrations:

The ALI that only gives the annual intake limit; it does not deal with the rate of intake or with environmental concentrations of a radionuclide that lead to the intake. For engineering design purposes and for control of routine operations, it is useful to know the environmental concentrations of the radionuclides with which we are dealing. To this end, the Derived Air Concentrating (DAC) or Derived Reference Air Concentration (DRAC) is introduced for airborne contaminants [27]. The DAC is that concentration of a radionuclide that would result in an intake of one ALI in breathed by reference man, inspiring 0.02 m^3 per minute for a working year. Thus, the DAC is determined by dividing the ALI by 40 h/week, 50 weeks/y, 60 min/h and 0.02 m^3/min:

$$DAC = \frac{ALI}{2400} \quad Bq/m^3 \qquad (30)$$

The purpose of the DAC is to provide a method for controlling exposure in the workplace to the ALI. Since the values of DAC apply to individual radionuclides, they should be reduced appropriately for each radionuclide when one or more radionuclides are involved. [37]

2. Risk Estimates for Radiation Protection:

For many purposes in radiation protection, it is necessary to make estimates of the consequences of an exposure to radiation. That is called risk estimates 'nominal'. Radiation risks estimates should be derived from the complete injury caused by radiation exposure. The risk of terminal cancer, genetic imperfections induced by reproductive cell mutations, relative span of life lost, and contribution of nonterminal cancer to a poorer quality of life must be taken into account. [1]

It is important to compare radiation risks with the risks in other industries when setting radiation protection standards. The predicted risk for stochastic effects should not be greater than the average risk of accidental death among workers in safe industries. Safe industries are defined as "those having an associated annual fatality accident rate of 1 or less per 10,000 workers, i.e., an average annual risk of 1×10^{-4} y^{-1} [37,39]. The annual risk for radiation workers is unlikely to exceed this rate, where the available data for radiation industries show average fatal accident rate of less than 0.3×10^{-4} [139]. From this perspective, the radiation industries compare favorably with the safe industries. For radiation protection purposes, the total risk coefficient is assumed to be 1×10^{-2} Sv^{-1} (1×10^{-4} rem^{-1}). [14]

The ICRP and NCRP made estimates of total detriment, which included fatal cancer risks, nonfatal cancer risks and the risks of sever genetic effects for workers and population of both sexes and all ages, modified by an adjustment according to the relative length of life lost. The risk estimates coefficients given in **Table (22)**, use the concept of detriment due to stochastic effects. [34,48,112]

Table (22): Risk estimates probability coefficients for stochastic effects. [34,48]

Exposed population	Detriment			
	Fatal Cancer [a] (10^{-2} Sv^{-1}) [b]	Nonfatal Cancer (10^{-2} Sv^{-1}) [b]	Severe genetic Effects (10^{-2} Sv^{-1}) [b]	Total Detriment (10^{-2} Sv^{-1}) [b]
Adult workers	4.0	0.8	0.8	5.6
Whole population	5.0	1.0	1.3	7.3

[a] For fatal cancer, the detriment coefficient and the probability coefficient are equal since the total detriment is that resulting from the fatal cancer only.

[b] Rounded values.

Figure (53) illustrates the risk comparisons between a numbers of activities that have potential risks. From this Figure, it is clear that for actual number of deaths, x-radiation is ranked 9th and nuclear power 20th as risk respectively. (140)

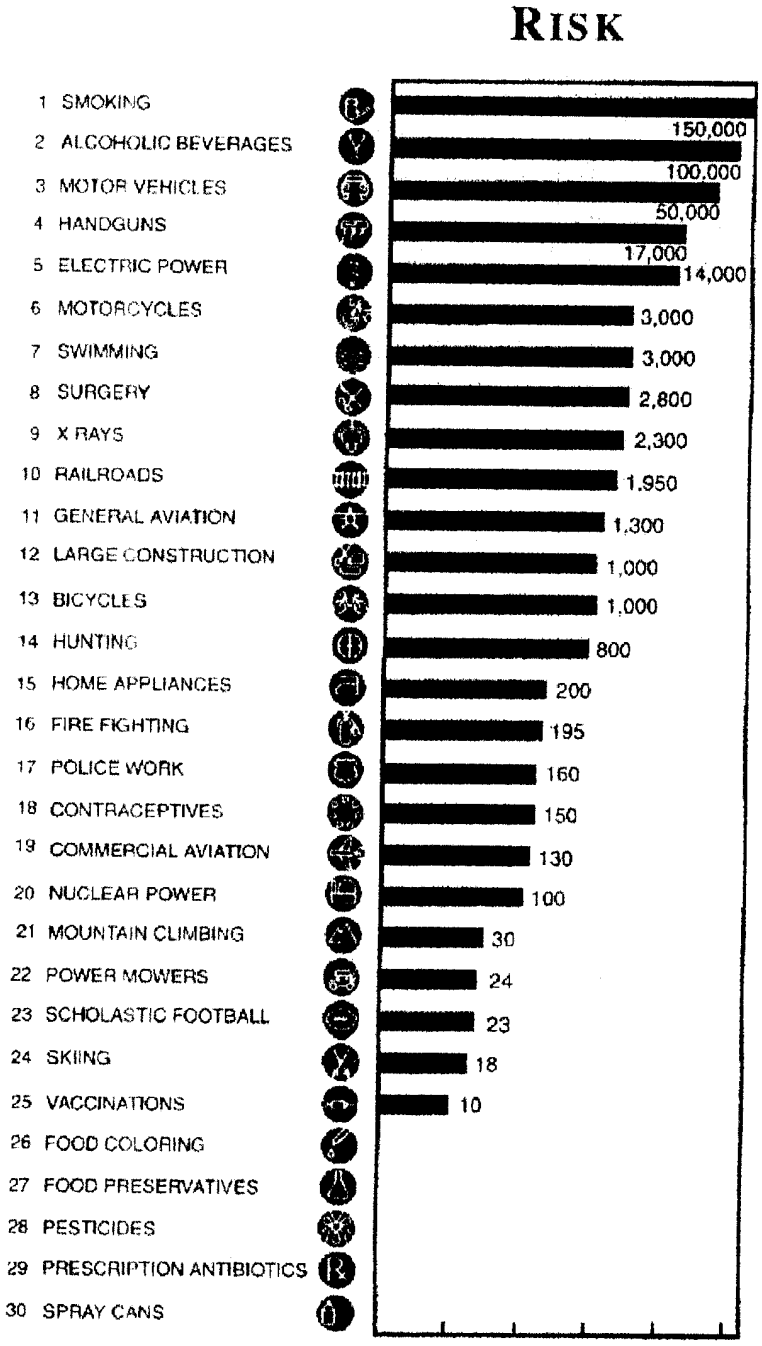


Figure (53): Perception of risks. (140)

III - Occupational Exposure in Medicine

1. Exposures of Workers in Diagnostic Radiology:

During the course of normal x-ray examinations, the technologist receives at least 95% of occupational exposure during **fluoroscopy**.

Adjacent to the examination table exposure rates may approach 500 mR/hr. The protective curtain draping the image intensifier tower usually reduces the exposure to less than 5 mR/hr. The technologist exposure can be estimated by assuming a position near the table and determining the x-ray beam on time. For example, if a barium enema requires 3 minutes of x-ray tube on-time and the technologist is positioned in a 100 mR/hr field, then the occupational exposure to the unshielded part of the technologist would be as follows:

$$100 \text{ mR/hr} \times 3/60 \text{ hr} = 5 \text{ mR}$$

Protective apparel usually provides an exposure reduction factor of at least one tenth, so that in the above example the exposure to the trunk of the body of the technologist would be less than 1 mR. [88]

Unlike conventional fluoroscopic procedures, the **mobile C-arm** fluoroscope is often impossible to use protective drapes to shield personnel from scattered radiation. Air kerma rates at the location of operating personnel have been reported to range from 0.5 to 2 mGy/hr at a distance of approximately 50 cm from the patient using a technique of 110 kVp, 2.5 mA for orthopedic procedures [141]. Miller et al reported dose equivalent from various orthopedic procedures. Forehead and thyroid dose equivalent ranged from 10 μSv to 1.44 mSv while fluoroscopic beam time ranged from 0.2 to 23 minutes. The forehead and thyroid dose equivalent averaged approximately 50 μSv per minute of fluoroscopic "on" time. [141]

Bush et al. [142,143] measured dose equivalent levels associated with C-arm of renal calculus removal. The average dose equivalent per procedure at the collar level was 100 μSv to the physician and 40 μSv to the radiologic technologist, for an average fluoroscopy time of 25 minute.

During **fixed radiography** the technologist will stand in a control booth that is typically shielded as a secondary barrier against x-ray tube head leakage and scattered radiation from the patient. Depending on room size and barrier thickness, the dose equivalent to a technologist in the control booth area is typically less than 1 μSv for a single film taken with a technique of 80 kVp and 40 mAs. [33]

Since **mobile radiography units** operate in unshielded environments they are often a cause for concern. Studies of scattered radiation from mobile units indicate that air kerma at a distance of one meter from the patient may range from 0.4 to 1 μGy per film for technique of 80 kVp and mAs. [144,145]

During **Computed Tomography (CT)**, the personnel who are located in the control room of a properly designed facility, it does not represent a significant source of occupational exposure. Only if an individual is required to remain in the room with the patient during the examination a measurable exposure may be expected. Depending on technique factors, air kerma levels of 5 to 20 μGy per slice have been measured near the gantry opening. [146,147]

Jacobson and Kelly [146] found a maximum dose equivalent outside of protective apparel of 0.4 mSv/procedure occurred during contrast injection for a whole body CT procedure.

In 1980, the mean annual dose equivalent for radiologic technologist was ranged between 0.5 and 2 mSv. [33]

Finally, radiation workers such as radiographers receive actual annual dose levels around from 0.1 mSv to 0.5 mSv. It is only 0.5% of the recommended limit (20 mSv) or 0.2% of legal limit (50 mSv). [6,148]

2. Exposures of Workers in Radiation Therapy:

Personnel whose duties most often involve external beam **teletherapy** are primarily technologists and, less often, physicians and physicists. Typical exposure patterns for this subcategory of workers depend on the type of teletherapy equipment, facility design and workload [33]. Hughes et al. [149] reported that the average dose to therapy technologists is approximately 1 mSv/y. the personnel in this study operated all types of external beam equipment.

Hoffman and Nath [103] have estimated that exposure to leakage radiation from the source head in the treatment room may result in 1 to 2 mSv/y average dose equivalent to technologists working solely with ^{60}Co teletherapy units.

The same study noted that technologists working solely with 4 MV and 6 MV linear accelerators never received measurable monthly film badge exposure, but that those working on a 25 MV linear accelerator did receive measurable exposures. The exposure from the high energy linac was due primarily to radioisotopes produced by photoactivation of air and accelerator components. The authors calculated that, for their equipment, the maximum yearly individual dose equivalent was 1 mSv/y. The average annual exposure to technologists operating with both low and high energy linear accelerators was 0.33 mSv/y [103]. For high workloads in high energy accelerators therapy, the dose to radiation therapists from activation are estimated to be in the range 3 – 4 mSv/y. [150]

The magnitude and distribution of exposure among persons involved with **brachytherapy** depend on individual institutional practices [33]. From personnel monitoring records Cobb and Svensson [151] determined that the mean annual dose equivalent to radiation therapy personnel in the years 1981

to 1984 was 0.51 mSv for nursing personnel and 1.66 mSv for physicians, residents and implant technologists.

Stanton and colleagues [116], indicated that therapists can receive a whole-body equivalent dose of about 0.2 mSv (20 mrem) per month and as much as 1.5 mSv (150 mrem) to the extremities from these sources.

3. Exposures of Workers in Nuclear Medicine:

3.1. Nuclear Medicine Staff:

By far the greater part of the radiation dose to staff comes from **external exposure** rather than contamination. Much of this is due to patient handling, which depends on the workload. A weighted average of 1.5 μSv per procedure has been estimated for typical work patterns and workloads as shown in **Table (23)**. Accordingly, a nuclear medicine technologist performing eight varying procedures per day would receive, on average, a dose of 12 μSv per day, corresponding to about 2.9 mSv per year. This estimate agrees with the reported value of a typical monitoring program [152]. Some Positron Emission Tomography (PET) examinations can result in quite high exposure to stuff; values of between 17 μSv and 50 μSv per procedure have been reported by MeCormack & Miklos [153]. **Table (24)** shows absorbed dose rates at various times and at various distances from individuals who have received diagnostic levels of various radiopharmaceuticals. [123]

Internal exposure may result from personal contamination, which is most likely to occur during the preparation and administration of radiopharmaceuticals. Small body burdens of ^{99m}Tc have been found in nuclear medicine staff, mostly acquired during lung ventilation procedures, but the effective dose from this source was only 0.01 – 0.1 mSv/year [154]. Skin or eye contamination by beta-emitting radionuclides or solutions of very high radioactive concentration, such as ^{99m}Tc generator eluate, could result in high localized doses. [155]

Table (23): Radiation doses to nuclear medicine technologists from various procedures, based on typical UK work pattern and workload. [156]

Procedure	Radiopharmaceutical [a]	Administered activity (MBq)	Average dose to technologist (μSv)
Bone	Tc-99m MDP	500	1.0
Brain	Tc-99m	500	5.3
Lung	Tc-99m MAA	100	1.3
Liver	Tc-99m colloid	70	0.3
Gated RBC cardiac	Tl-201 or Tc-99m	800	3.5
Renal: DTPA	Tc-99m	100	0.8
Renal: MAG3	Tc-99m	200	0.8
GI bleed		200	3.0
Thyroid scan [b]	Tc-99m	74	0.5
Thyroid uptake [c]	I-131	0.05 mCi	0.01 mR
Average			**1.5 per procedure**

[a] Data from [31,157]
[b] Data from [158]
[c] Data from [157]

Table (24): Illustration of absorbed dose rates at various distances and times from a typical adult patient after administration of a radiopharmaceutical. [123]

Study	Radiopharmaceutical	Typical range of administered activity (MBq)	Absorbed dose rate (nGy/hr per MBq)					
			Immediately after			After 2 hr		
			Close*	0.3m	1m	Close*	0.3m	1m
Bone scintigraphy	^{99m}Tc MDP	150-600	27	13	4	13	7	2
Liver scintigraphy	^{99m}Tc colloid	10-250	27	13	4	20	10	3
Blood pool determination	^{99m}Tc RBC	550-740	27	13	4	20	10	3
Myocardial scintigraphy	^{201}Tl	50-110	36	18	6	36	18	6

* At the body surface over the relevant tissue.

3.2. Nursing Staff:

The dose to nursing staff from patients returning to the ward after a nuclear medicine procedure depends on the radiopharmaceuticals administered, its activity and the degree of care required by the patient. In caring for a bone scan patient, for example, to whom 550 MBq ^{99m}Tc- MDP has been administered, nursing staff would receive a maximum of 114 μSv if the patient is totally helpless, but only 2.4 μSv if the patient is largely self-caring. At most, for nurses spending long periods of time near helpless patients, the maximum dose has been estimated at around 150 μSv per shift [159]. Fortunately, many nuclear medicine patients need little nursing care and doses are at the lower end of the above range, usually less than 20 μSv per patient. [128]

Jankowski [160] studied radiation exposure to critical care nurses over a 3-year period from portable x-ray machines, fluoroscopic units, and patients injected with radiopharmaceuticals. She concluded that radiation is not a significant occupational hazard for critical care nurses, since no cumulative exposures measured over the period exceeded 0.8 mSv.

Because of nursing rosters and the relatively small number of nuclear medicine patients in wards, most members of the nursing staff will encounter only a small number of nuclear medicine patient in any one year, and the average annual radiation dose to nursing staff in the ward should be quit small. Nevertheless, administrative procedures should be set in place to make nursing staff aware of patients to whom radioactive materials have been administered and procedures which can be used to minimize exposure. [161]

IV - Medical (Patient) Exposures

1. Dose Limit in Medical Exposure:

No specific dose limit was recommended by ICRP for medical exposure. However, it recommend that only necessary exposure should be made, that these exposures should be justifiable on the basis of benefits that would not otherwise have been received. The doses actually administered should be limited to the minimum dose consistent with the medical benefit to the patient. (27,34)

For medical exposure of pregnant women, exposure of the embryo-fetus in the first three weeks following conception is not likely to result in deterministic of stochastic effects in the liveborn child. However, diagnostic and therapeutic procedures causing exposures of the abdomen to women likely to be pregnant should be avoided unless there are strong clinical indications. (34)

The doses from diagnostic or therapeutic procedures should apart from general compliance with the ALARA principle and a requirement that risk-benefit factors be considered. (162,163)

2. Patient Dose in Diagnostic Radiology:

Because of the large variety of radiologic equipment, differences in radiologic procedures, and individual radiologist or radiographer technical skills, patient close for each examination varies according to the institution [10]. Patient dose from diagnostic radiologic procedures may be specified in three ways: Entrance Skin Exposure (ESE), organ dose (bone marrow and gonadal dose), and fetal dose. Each has a specific application in assessing the risk to the patient, but skin exposure is the easiest to estimate. **Tables (25)** to **(28)** indicate permissible patient ESE, bone marrow, gonadal, and fetal doses for several different radiologic examinations. (88)

Table (25): Permissible Entrance Skin Exposures (ESE) for various radiographic examinations. [88]

Examination	Skin exposure (mR per projection)
Chest (posteroanterior PA)	12 to 26
Skull (lateral)	105 to 240
Abdomen (anteroposterior AP)	375 to 698
Retrograde pyelogram	475 to 829
Cervical spine (AP)	35 to 165
Thoracic spine (AP)	295 to 485
Limb	8 to 327
Dental (bite wing and periapical)	227 to 425

Table (26): Typical bone marrow doses for various radiographic examinations. [88]

X-ray examination	Mean marrow dose (mrad)
Skull	10
Cervical	20
Chest	2
Stomach and upper gastrointestinal	100
Gallbladder	80
Lumbar spine	60
Intravenous urography	25
Abdomen	30
Pelvis	20
Extremity	2

Table (27): Typical fetal dose factors as a function of skin entrance exposure.[88]

X-ray examination	Fetal dose factor (mrad/R)
Skull	< 0.01
Cervical	< 0.01
Full- mouth dental	< 0.01
Chest	2
Stomach and upper gastrointestinal	25
Gallbladder	3
Lumbar spine	250
Intravenous urography	265
Abdomen	265
Pelvis	295
Limb	< 0.01

Table (28): Typical gonad doses from various radiographic examinations. [88]

	Gonad dose (mrad)*	
X-ray examination	**Male**	**Female**
Skull	< 1	< 1
Cervical spine	< 1	< 1
Full-mouth dental	< 1	< 1
Chest	< 1	< 1
Stomach and upper gastrointestinal	2	40
Gallbladder	1	20
Lumbar spine	175	400
Intravenous urography	150	300
Abdomen	100	200
Pelvis	300	150
Upper limb	< 1	< 1
Lower limb	< 1	< 1

* For some radiologic examinations the female gonad dose is greater than the dose received by the male because the female reproductive organs are located within the pelvic cavity, unlike the male reproductive organs, which are located outside and below the pelvic cavity. The distribution of biologic tissue overlying the ovaries also affects the dose received for a given radiologic examination.

Federal regulations for FDA certification of screening mammography facilities state that the maximal dose to the glandular tissue of a 4.5-cm film compressed breast using a screen-film mammography system should not exceed 3 mGy (300 mrad) per view [164]. Studies have shown that well-calibrated mammographic systems are capable of providing optimal imaging performance with an average glandular dose of less than 2 mGy (200 mrad) as shown in **Table (29)**. [165]

Table (29): Typical skin exposure and mean tissue glandular dose for screen/film mammography examinations. [88]

Examination	Skin exposure per projection (mR)	Approximate mean glandular dose per projection (mrad)
Screen/film	200 to 1000	75 – 200*

* (165)

The radiation doses associated with CT can be compared with those received from other types of diagnostic radiology examinations by using effective dose. The effective dose from various types of examinations was calculated using frequently data and effective doses published in the literature [166,167,168–171]. The results are shown in **Table (30)**. The data reveal that CT scanning represents 11% of radiology procedures but is the major contributor to diagnostic radiology dose and account for 67% of the total effective dose from all diagnostic radiology procedures. [172]

Bushong [82] identifies averages skin dose ranges from scans of the cranial region to be from 1 to 3 cGy (1 to 3 rad) and dose ranges for scans of the body to be from 2 to 6 cGy (2 to 6 rad).

Table (30): Contribution of various types of diagnostic procedures to total effective dose. [172]

Procedure	Effective dose (mSv) per procedure	Percentage
Radiography		
Head and neck	0.22	3.3
C-spine	0.20	1.0
T-spine	0.80	2.4
L-spine	1.27	4.8
Chest	0.08	4.1
Abdomen	0.56	4.3
Upper GI and SB	2.44	4.6
Barium enema	4.06	1.7
Kidney/bladder	1.58	2.1
Pelvis	0.44	1.7
Hip	0.83	2.1
Extremities	0.01	0.4
Mammography	0.10‡	0.7
CT		
Head	1.50	13.9
Chest	5.40	8.6
Abdomen/pelvis	3.10	36.3
Other (neck, spine etc)	3.00‡	8.0

‡ Estimated

3. Patient Dose in Nuclear Medicine:

When radiopharmaceuticals are administered to a patient, many organs of the body are irradiated, not only the organ being imaged. Effective doses in diagnostic nuclear medicine test are low. With the exception of tests involving longer-lived nuclides like ^{75}Se, ^{67}Ga or ^{131}I, effective doses are usually a few mSv or less [43,44]. **Table (31)** presents absorbed doses from various radiopharmaceuticals to different organs in adults.

In many instances, the critical organ, the organ receiving the greatest radiation exposure, is not the organ being imaged. However, the radiation dose to the critical organ strongly governs the recommended range of radioactivity to be administered for a particular agent. For this reason, it is important only the prescribed amount of radioactivity be given to minimize the radiation dose to the critical organ as well as other target organ. [31,122]

Table (31): Absorbed doses and effective dose from various radiopharmaceuticals.

Radio pharmaceutical	Activity* (MBq)	Absorbed dose† (mGy)						Eff. dose‡ (mSv)
		Red marrow	Breast	Uterus	Thyroid	Ovaries	Testes	
^{51}Cr red cells	4	0.6	0.4	0.3	0.5	0.3	0.3	1.3
^{67}Ga citrate	150	28.5	9.3	11.9	8.4	12.3	8.6	16.5
^{99m}Tc colloid	80 (static)	0.9	0.2	0.2	0.06	0.2	0.05	0.7
	200 (SPECT)	2.2	0.5	0.4	0.2	0.4	0.1	1.8
^{99m}Tc-DMSA	80	0.5	0.1	0.4	0.09	0.3	0.1	0.7
^{99m}Tc-DTPA	300	0.8	0.3	2.4	0.2	1.3	0.8	1.6
^{99m}Tc-HIDA	150	1.1	0.09	2.0	0.02	3.0	0.2	2.3
^{99m}Tc-HMPAO	500 (SPECT)	1.7	1.0	3.3	13.0	3.3	1.2	4.6
^{99m}Tc-HAS	40	0.3	0.2	0.2	0.2	0.2	0.1	0.4
^{99m}Tc-MAA	100	0.4	0.6	0.2	0.2	0.2	0.1	1.1
^{99m}Tc-pertechnetaate§	500 (static)	2.3	1.3	3.3	1.1	2.4	1.6	6.0
	800 (SPECT)	3.6	2.0	5.3	1.7	3.8	2.6	9.6
^{99m}Tc phosphonate	600	5.8	0.5	3.7	0.6	2.1	1.4	3.5
^{111}In platelets	20	7.2	2.0	1.9	1.6	2.0	0.9	1.0
^{111}In white cells	40	27.6	3.6	4.8	2.4	4.8	1.8	1.9
^{123}I-MIBG§	400	3.7	2.5	4.4	1.7	3.2	2.2	5.6
^{131}I-MIBG§	20	1.3	1.4	1.6	1.0	1.3	1.2	2.8
^{201}Tl chloride	80	14.4	2.2	4.0	20.0	9.6	44.8	18.4

* Maximum usual activity per test, as recommended by ARSAC. (173)
† Data from ICRP. (43,44)
‡ Data from Johansson et al. (174)
§ With blocking agent.

Tables above show that there are large variations in the patient dose (effective dose) for different examinations. This is to be expected since different organs of different radiosensitivities are involved. However, there are also large variations for the same procedure between hospitals and between countries. This reflects the use of different equipment and, to some extent, different techniques, but also the poor use of equipment (either through default or through misplaced priorities), lack of quality assurance (QA) and a basic misunderstanding of quality versus dose and a failure to adopt dose saving measures. (52)

V- Natural Background Exposure

Natural sources of ionizing radiation have always been a part of the human environment. All individuals are exposed to low levels of ionizing radiation from this natural sources such as the following:

1) Terrestrial radiation varies over the earth because of differences in the concentrations of naturally occurring elements in the earth's surface such as thorium (^{232}Th), uranium (^{238}U) and their decay products (daughters) and potassium (^{40}K) [2,52]. The concentrations depend on the composition of the soil or rocks in that geographic area. In addition, building materials may incorporate naturally occurring radioactive materials. Many buildings may have elevated levels of ***radon*** emitted by naturally occurring uranium-238 in soil. It is by far the largest contributor to background radiation [14]. **Table (32)** gives the average annual effective doses of the background radiation.

2) Cosmic radiation enters the atmosphere of the earth from outer space. The resulting radiation doses vary with height above sea level and may also at different points on the earth's surface. The earth's atmosphere and magnetic field help shield it from cosmic rays. The shielding is diminished at higher elevations, where less atmosphere separates the earth from cosmic rays. The average exposure dose from cosmic rays is shown in **Table (32)**.[1,20]

3) Internal radiation arises from natural radioactive nuclides inherent in body composition. The tissues of the human body contain many naturally existing radioactive nuclides that have been ingested in minute quantities from various foods or inhaled as particles in air. Potassium (^{40}K), Carbon (^{14}C), Hydrogen (^{3}H; tritium), Strontium (^{90}Sr), and decay products of Polonium (^{210}Po), are examples of internal radiation sources that exist within

the body (**Table (32)**). The most internal radiation arises from ^{40}K, which emits β and γ rays and decay with half-life of 1.3×10^9 years. [2,14]

Table (32): Average Annual effective dose equivalent.

Sources of radiation	Dose (mrem)	Percentage of dose (%)
	[a] – [b]	[a] – [b]
Natural		
Radon	198 – 126	55 – 45
Cosmic rays	29 – 36.5	8 – 13
Terrestrial	29 – 42	8 – 15
Internal	39 – 36.5	11 – 13
	295 – 240	82 – 86
Manmade		
Medical x-rays	40 – 28	10
Nuclear medicine	14 – 11	4
	54 – 40	14
Other [a]		
Occupational	1.1	0.3
Fallout	< 1.1	< 0.3
Nuclear fuel cycle	0.4	0.1
Consumer products [c]	0.4	0.1
Miscellaneous	0.4	0.1
	3.0	< 1

[a] Data from [175]
[b] Data from [31]
[c] Data from [176]
The variation in dose values is according to the difference between the countries.

VI - Manmade Radiation

Ionizing radiation created by humans for various uses is classified as manmade, or artificial radiation. Manmade ionizing radiation sources include the following:

*1) **Medical radiation*** exposure results from the use of diagnostic x-ray machines and radiopharmaceuticals in medicine. Diagnostic medical x-ray and nuclear medicine procedures are the two largest sources of artificial radiation that account for about 14 – 18 % of the average annual individual dose equivalent of ionizing radiation. **Table (32)** also shows the average annual individual dose from medical radiation. [1,31]

*2) **Consumer products.*** A number of consumer products available on the market contain small trace of radioactive material. Examples of such products include airport surveillance systems; smoke detector alarms; and some watches with luminous dials and numbers contain promethium-147, radium-226, and tritium [1,20]. Moreover, the cathode-ray tubes in television sets and computer monitors generate small amounts of x-radiation [177]. These products contribute a small fraction of the total average annual dose to each member of the general population. The dose from such products contributes about 0.1% of the total average annual effective dose as can be seen from **Table (32)**. [176]

*3) **Radioactive fallout***. Testing of nuclear weapons above ground discharge radioactive products into the atmosphere. These airborne radioactive materials are dispersed around the globe by the wind, and eventually settle or are washed out of the atmosphere by rain, onto the ground or into the sea. Some nuclear reactor accidents, such as those at Windscale (now Sellafield) in England (1957), at ThreeMile Island in USA (1979) and at Chernobyl in the Ukraine (1986), also resulted in the release and dispersal of radioactive material into atmosphere. The annual dose to the public from fallout peaked in the early 1960s, but has since declined as atmospheric testing of nuclear weapons becomes less frequent. Fallout from nuclear weapons tests and other environmental sources contributes less than 0.3% annually to the dose equivalent of each person. [20]

4) Nuclear fuel for generation of power. Nuclear power plants that produce nuclear fuel for the generation of power do not contribute significantly to the annual dose equivalent. The nuclear fuel cycle contributes approximately 0.3% to the total annual effective dose. [1]

5) Environmental pollution. Some industries, research establishments and hospitals discharge radioactive waste into the environment. Such discharges are rigorously controlled and produce an average annual dose about 0.1% of the total average annual effective dose. [20]

6) Occupational exposure. Some individuals may be exposed to ionizing radiation from both artificial and natural sources due to the nature of their work. Occupationally exposed workers include for example, aircraft pilots and crew; medical and dental staff; industrial radiographers; workers in the nuclear industry; and those who work in areas of high radon gas concentration. Accordingly, the annual dose to individuals from occupational exposure varies according to the nature of their work [148]. It is contributed about 0.3% of the total average annual effective dose [175]. **Figure (54)** shows a breakdown of the effective doses from various sources.

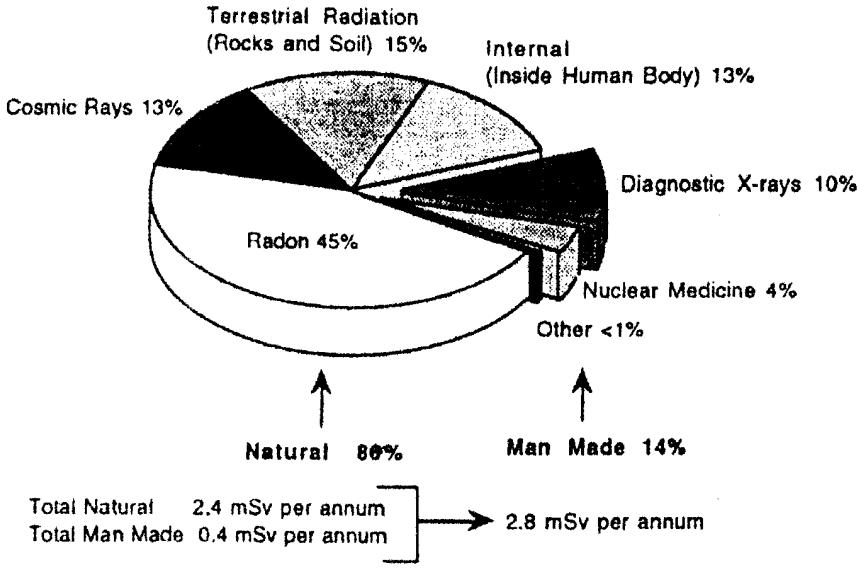


Figure (54): Annual effective dose received by an average member of the world population.[31]

A large proportion of the average annual effective dose received by the population results from environmental radiation. Typically, environmental radiation amounts to around 2 - 3 mSv/year, or in range of 82% - 86% of the global per capita radiation dose [175,178,179]. Each member of the world population is exposed, on average, to 2.4 - 2.95 mSv of unavoidable ionizing radiation every year [175]. The large component arising from radon gas in homes and workplaces has only come to light comparatively recently. [180]

An additional 14% - 18% (0.4 mSv – 0.65 mSv) of the average annual exposure is man-made, this is highly variable depending on local practice, [162,175,181] and a small amount from miscellaneous sources (less than < 1%).

Therefore, the total average annual effective dose from man-made and natural radiation is about 2.8 mSv – 3.6 mSv (280 – 360 mrem) [31,175]. Although the amount of natural background radiation remains fairly constant from year to year, the frequency of exposure to manmade radiation in medical applications is rapidly increasing among all age group. This increase in frequency of radiation exposure in medicine must be counterbalanced by limiting the amount of patient exposure in individual procedures. This can best be accomplished through application of appropriate radiation protection measures and techniques on the part of the radiographer. [1]

From previous tables and from the observed exposures of workers and patients it can be concluded that all exposure within the range of recommended limits. Nevertheless, all procedures and precautions should be taken into account to minimize the exposures of workers. In normal circumstance, good and effective radiation protection program should by applied, which included the most effective factors, i.e. time, distance and shielding.

It is important to establish radiation monitoring program that including radiation survey of places and personal monitoring for workers. The regular

radiation survey is very important to note the levels of radiation in work areas to ensure the level of radiation within the acceptable permissible dose limits. The regular personal monitoring report of workers measure the exposures they received during work time. That reports enable the radiation safety officer controlling and knowing every exposure of workers and taking appropriate procedures if one of them had overexposure. All the readings of radiation survey and personal monitoring should be documented to be reference in cases of overexposure or accidents.

Modern radiation protection practice requires that exposures be kept at levels which are as low as reasonably achievable (ALARA), economic and social factors being taken into account. The implementation of an operational radiation safety program depends not only upon codified recommendations and regulations but also upon the judgments and perceptions of qualified radiation safety personnel. This reliance on qualitative insight is, at present, the preferred method for providing a level of radiation exposure that is as low as reasonably achievable (ALARA) while dealing with uncertainties in the precise nature of low level radiation risks and in the protective measures is best suited to a particular situation. [33]

Therefore, implementation of ALARA concept for medical workers is very important to minimize their exposures. For that it might be improved ALARA practices in medicine which can be achieved by set the concept of the Individual Reference Range (IRR).

The **IRR** is defined as that range of individual dose equivalent values that, if exceeded, automatically triggers optimization activity. Hence, all individual dose equivalents above the IRR must be reviewed and actions should be taken to reduce the exposure from the identified procedure to as low as reasonably achievable. The IRR is not a dose limitation because in certain instances an exposure exceeding the IRR may already be optimal and

hence should not be modified. However, it is desirable to concentrate effort on those measures that affect exposures exceeding the IRR. Each institution should set its own IRR depending upon its experience and radiation protection philosophy. As a general guideline, the upper bound of the IRR should be greater than the average dose, but not set so high that it is rarely exceeded. A properly set upper bound would be expected to be exceeded by a few percent of workers during the course of several review periods. The lower bound of the IRR defines the individual exposure below which no optimization activity need be initiated. (33)

To illustrate the use of normative patterns in setting reference levels, it may be of value to consider the following hypothetical situation. A **radiology department** performs 40,000 procedures per year, including 4,000 fluoroscopic and special procedures, with a staff of 35 monitored personnel. Technologists are rotated every three months through all areas. A review of monitoring records indicates that 23 personnel receive some doses such that the average annual dose equivalent of measurably exposed workers is about 1.9 mSv and that 95 percent of measurably exposed personnel receive less than 8 mSv. A review of quarterly records reveals an average dose equivalent for measurably exposed workers of approximately 0.5 mSv with 95 percent of personnel receiving less than 2.5 mSv. The quarterly records show a greater variability of dose equivalent, due to the manner in which personnel are rotated through the various duties. The reference ranges would be an IRR of 0.5 to 2.5 mSv/qtr. Other institutions, facing different individual situations, would establish difference ranges.

It may also be of value to consider the following situation of a **nuclear medicine** section that is staffed by four technologists and performs 5,000 procedures per year. From a review of their past several years of quarterly film badge totals, it was determined that less than five percent of quarterly individual doses exceeded 2.5 mSv while the average measurable quarterly

dose was 0.9 mSv. Radiation protection surveys were also reviewed and typical, as well as maximal, quarterly doses were calculated based on workload and staffing patterns. From this review it was determined that, most of the time, personnel should be able to carry out their normal duties without exceeding a quarterly individual dose of 2.5 mSv. Based upon these considerations the quarterly individual reference range (IRR) was set at 0.9 mSv to 2.5 mSv.

Also, for a small **radiotherapy** center with a single 6 MV linear accelerator and five technologists treating 35 patients per day. A review of their past several years of quarterly total radiation monitoring records revealed that less than five percent of quarterly individual dose equivalent exceeded 0.8 mSv while the average measurable quarterly dose equivalent was 0.25 mSv. Radiation protection surveys were also reviewed, and typical as well as maximal quarterly exposures were calculated based on workload and staffing patterns. From this review it was concluded that, most of the time, personnel should be able to carry out their normal duties without exceeding a quarterly individual dose equivalent of 0.8 mSv. Based upon these considerations the IRR ranged from 0.25 to 0.8 mSv. [33]

The health of the worker is essential to the effective functioning of the radiation protection program. Therefore, a good occupational health program should be provided [84]. Thus, it is important to make regular blood count test for workers involving with the use of ionizing radiation in medicine. That test is very important in radiation protection, which is considered a good indicator for workers who affected by radiation after receiving high dose (overexposure). Due to the high radiosensitivity of the blood cells their counts are reduced after exposure to ionizing radiation.

So, it is recommended to do regular blood count test every three months and compare the results of blood count with the radiation exposures

reports of the workers. In addition any diseases affecting the blood count of the worker should be exclude.

Full medical examination for workers are required every 6 months that based on the three main objectives of occupational medicine:

1. To assess the health of the workers,
2. To determine the fitness of the worker for tasks expected to be undertaken under the specific working conditions, and
3. To provide a baseline of information useful in the case of accidental exposure to a particular hazardous agent or occupational disease. (87)

Special health evaluation and monitoring may also be needed for occupationally exposed individuals working in special circumstances, e.g., assignment to an unfamiliar job, a necessity to receive more radiation exposure than usual, exposure to unfamiliar conditions that involve sources of radiation and pregnancy. Special health services should be available to provide care to workers accidentally exposed to high radiation doses or to high internal or skin contamination. (84)

➢ *Excess in Exposure of The Occupational Dose Limits:*

The annual dose limits are intended to control the maximum lifetime risk incurred by an individual in any year and normally exposures should be well below the limit. Nevertheless, slightly exceeding the annual effective dose limit in a given year has little biological significance for the individual since the lifetime risk can be readily offset by a history of exposure below the dose limits in past years or reduced exposure in future years. The importance of such occurrences is that they call attention to what may be an inadequate system of radiation control. This would suggest that the decision on permitting individuals who have exceeded annual dose limits to return to worker status depends more upon the improvement and corrections in the

control of radiation exposure in the workplace than on in depth analysis of the worker's health status.

Because there are individuals who, under the previous recommendations of the NCRP, were permitted to accumulate exposures in excess of the new age-related limit, the NCRP recommends that individuals whose cumulative effective dose exceeds the age related limit should be restricted in their exposures to no more than 10 mSv per year until the age related lifetime limit is met. [37]

➢ *Guidance for Emergency Occupational Exposure:*

Normally, only actions involving life saving justify acute exposures that are significantly in excess of the annual effective dose limit. The use of volunteers for exposures during emergency actions is desirable. Older workers with low lifetime accumulated effective doses should be chosen from among the volunteers, whenever possible. Exposures during emergency actions that do not involve life saving should, to the extent possible, be controlled to the occupational dose limits. Where this cannot be accomplished, it is recommended that a limit of 0.5 Sv effective dose and an equivalent dose of 5 Sv to the skin be applied, which is consistent with ICRP recommendations.

When, for life saving or equivalent purposes the equivalent dose may approach or exceed 0.5 Sv to a large portion of the body in a short time, the workers need to understand not only the potential for acute effects but they should also have an appreciation of the substantial increase in their lifetime risk of cancer. If internally deposited radionuclide exposures are also possible, these should be taken into account. [34,37,87]

SUMMARY & CONCLUSION

SUMMARY AND CONCLUSION

Since the discovery of radioactivity and x-rays, the uses of radionuclides and x-rays for various purposes increased, [4] especially in the medical field. For example, the x-rays are used in diagnostic radiology and radiation therapy. The radioactive materials are also used in teletherapy, brachytherapy and nuclear medicine.

In the years immediately after discovery of x-rays and radioactivity, many of the workers were seriously affected by exposure to radiation because they were not aware of the potential dangers of radiation and they were not know the levels of radiation were likely to cause damage [20]. In addition, with the increase of the uses of ionizing radiation, the radiation hazards and the exposure to radiation sources have also increased [6]. Therefore, the needing to radiation protection program is considered necessary when using ionizing radiation in medical fields.

The field of radiation protection has gained an important value to use the ionizing radiation in medicine safely. Protection proceeding consists of tools and techniques employed to protect workers, patients, and public from hazards of ionizing radiation. It also limits the radiation exposure to minimize the risk of harmful biologic effects. [10]

The biological effects of radiation can be grouped into two categories: deterministic (non-stochastic) and probabilistic (stochastic). Radiation effects that are produced after a certain threshold dose of radiations are called deterministic effects. Those effects that may occur without a threshold dose are called stochastic effects. [40]

The radiation protection program is therefore to limit exposure so as to prevent the occurrence of deterministic effects, by keeping dose below the relevant threshold. The possibility of stochastic effect cannot be totally eliminated, so that to avoid unnecessary sources of exposure and to take all reasonable steps to reduce the dose from those sources of that are necessary or cannot be avoided. (112)

The aim of radiation protection is to provide an appropriate standard of protection of humans against ionizing radiation without unduly limiting the beneficial practices giving rise to radiation exposure. (34)

Each radiation protection program has standards and guidelines for handling of radiation. These guidelines and standards set by international and national organizations. Thus, the organizations make reports or recommendations that lead to standards for practice or laws regulating the use of equipment and set the levels of dose limits in radiation protection field. (38)

The following are some international agencies that are concerned with the subject of ionizing radiation protection as one of their duties: The International Commission on Radiological Protection (ICRP) in UK, The National Council on Radiation Protection (NCRP) in USA, The International Commission on Radiation Units and measurement (ICRU) in USA, The International Atomic Energy Agency (IAEA) in Vienna, Austria, and in each country there is national commity to apply the international rules.

For the purpose of protecting workers from occupational exposure, they must employ all appropriate methods of protection against ionizing radiation (1). In general, the three important and most effective principles of radiation protection are (1) minimize time of exposure; (2) maximize distance from the source of radiation; and (3) maximize amount of shielding. They should stand behind protective barriers or wearing protective lead apron. Each of these

principles can be practiced during diagnostic radiology, radiation therapy and nuclear medicine to minimize exposure to operator and other health care workers [102,51]. In addition the workers in nuclear medicine and/or brachytherapy should be careful when dealing with radioactive materials to avoid contamination and ingestion by these materials.

To provide radiation protection for patients that by ensuring they receive the minimum amount of radioactivity or radiation exposure necessary to complete the test and by deriving the maximum benefit from the small amount of radiation received (in diagnostic radiology and nuclear medicine) [122,52]. In radiotherapy, the correct dose should be given to patient with differentiating between the dose to the target tissue and the dose to other normal tissue. [112]

The limitation of patient dose can be achieved by correctly employing appropriate techniques and devices. Patient exposure may be also limited by proper immobilization, use of appropriate beam limitation devices, correct filtration, use of gonadal or other specific area shielding (shaping blocks), avoid any dose misadministration and regular quality assurance of equipments. [1,88]

Radiation monitoring for places and personnel is considered the main aim of radiation protection. The radiation survey of areas is very important to be sure that all the surrounding areas are safe and the level of radiation is in a normal condition [51]. Personnel monitoring device may be used to ensure that none of the workers reaches the maximum permissible dose (dose limit), which is internationally or nationally accepted. [87]

Shielding design of radiation protection is necessary to protect the surrounding adjacent areas from unnecessary exposure to ionizing radiation. It is used many kind of materials as shielding and it is determined the

thickness of these materials used for shielding (in walls, doors, floors, and ceiling). [5]

For the protection of radiation workers, and the population as a whole, dose limits gave been established as guides. Dose limit concerns the upper boundary dose of ionizing radiation that results in a negligible risk of bodily injury or genetic effect. The sum of both external and internal whole-body exposure is considered when dose limits are established. These limits are designed to minimize the harmful biologic effects to humans in terms of non-stochastic (deterministic) and stochastic (probabilistic) effects [20,31]. Thus, dose limits should be applied on any individuals exposed to radiation as the result of their works.

The radiation exposures or absorbed doses for occupational exposed personnel and patients during medical procedures in diagnostic radiology, radiation therapy and nuclear medicine are illustrated. Also the natural exposures that are a part of the human environment are shown. The total average annual effective dose from man-made and natural radiation is about 2.8 – 3.6 mSv [31,175]. A large proportion of the average annual effective dose received by the population results from natural radiation about 82% – 86% of the total dose [175,178,179]. The man-made exposure is contributed about 14% – 18% of the total average annual dose, which this is highly variable depending on local practice. [162,175,181]

Although the amount of natural radiation remains fairly constant from year to year, the frequency of exposure to man-made radiation in medical applications is rapidly increasing among all age group. This increase in frequency of radiation exposure in medicine must be counterbalanced by limiting the amount of patient exposure in individual procedures. [1]

Modern radiation protection practice requires that exposures be kept to levels which are as low as reasonably achievable (ALARA), economic and social factors being taken into account. The ALARA concept should be applied for both occupational and medical exposure [33]. The ALARA concept calls for a reasonable effort to maintain individual and collective radiation exposure as low as possible. Under this concept, techniques, equipment, and procedure are all critically evaluated [4]. This can be achieved through the employment of proper safety procedures performed by qualified personnel. The ALARA concept assumes that linear, nonthreshold relationship exists between radiation dose and biologic effect. Thus, the risk of injury should be overestimated rather than underestimated.

A radiation safety officer (RSO) is a person such as medical physicist or health physicist designated by an institution and approved by the concerning local agencies to ensure that internationally accepted guidelines for radiation protection are followed by the institution. The RSO is responsible for developing an appropriate radiation safety program for the institution and maintaining radiation monitoring records for all personal. [1]

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I- LIST OF ABBREVIATIONS

ALARA	:	As Low As Reasonable Achievable
ALI	:	Annual Limits on Intake
ARLI	:	Annual Reference Levels of Intake
Bq	:	Becquerel
Ci	:	Curie
CT	:	Computed Tomography
D	:	Absorbed Dose
DAC	:	Derived Air Concentrating
DRAC	:	Derived Reference Air Concentration
ESE	:	Entrance Skin Exposure
FDA	:	Food and Drug Administration
G-M	:	Geiger-Muller
Gy	:	Gray
H	:	Dose equivalent
H_E	:	Effective Dose Equivalent
H_T	:	Equivalent dose of symbol
HVL	:	Half-Value Layer
IAEA	:	International Atomic Energy Agency
ICRP	:	International Commission on Radiological Protection
ICRU	:	International Commission on Radiation Units and Measurement
IRR	:	Individual Reference Range
ISL	:	Inverse square law
K	:	Kerma
KeV	:	Kilo electron volt
LET	:	Linear Energy Transfer
Linac	:	Linear accelerator

mAs : Milliampere second
MeV : Mega electron volt
MPD : Maximum permissible dose
NCRP : National Council on Radiation Protection and Measurements
NID : Negligible Individual Dose
NIRL : Negligible Individual Risk Level
OER : Oxygen enhancement ratio
PET : Positron Emission Tomography
Q : Quality factor
QA : Quality assurance
R : Particle Range
R : Roentgen
RBE : Relative biological effectiveness
Rem : Roentgen Equivalent Man
RSO : Radiation safety officer
S : Linear stopping power
SI : Specific ionization
SI Units : International System of units (standing for systeme Internationale)
SID : Source image distance
SSD : Source skin distance
STP : Standard pressure and temperature
Sv : Sievert
T : Occupancy Factor
$T_{1/2}$: Half-Life
T_a : Mean Life
TLDs : Thermoluminescent dosimeters
TVL : Tenth-Value Layer
U : Use Factor
UNSCEAR : United Nations Scientific Committee on the Effects of Atomic Radiation
W : Workload
W_R : Radiation weighting factor
W_T : Weighting factors of tissue
X : Exposure

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ARABIC SUMMARY

الملخص العربي

الملخص العربى

أدى اكتشاف عنصر الراديوم المشع و الإشعاع المؤين مثل أشعة ألفا وبيتا و جاما و كذلك الأشعة السينية و النيوترونات و الديوترونات على يد نخبة من العلماء الأفذاذ، مدام كوري و بيير كوري، هنري بيكريل، وليام كونراد رونتجن و شادويك و غيرهم الى ظهور فروع جديدة من العلم متمثلة فى علوم الإشعاع و أثاره و تأثيراته البيولوجية و تبع ذلك إنشاء أقسام فى كليات الطب و المستشفيات لم تكن معروفة من قبل فى مجال استخدام الأشعة السينية فى كل من التشخيص و العلاج كذلك استخدام النظائر المشعة مثل عناصر الراديوم و الاسترنشيوم و اليود المشع فيما يسمى بالطب النووي.

ومع التوسع المستمر فى استخدام المصادر الإشعاعية المختلفة سواء المصادر المغلقة أو المصادر المفتوحة أو الأشعة السينية ازدادت مخاطر تعرض الإنسان الى الآثار البيولوجية للإشعاع بوجه عام. و يمكن تقسيم الآثار البيولوجية للإشعاع الى قسمين رئيسيين:

١. الآثار الحتمية أو الحادة وهى التى تحدث نتيجة التعرض لجرعة إشعاعية تتجاوز حد معين تعرف بعتبة الجرعة الإشعاعية.

٢. الآثار الاحتمالية حيث لا يوجد لحدوثها حد أو عتبة للجرعة و لذلك فهى أثار احتمالية قد تحدث أو لا تحدث عند التعرض للإشعاع بجرعة أو جرعات قليلة.

ونتيجة لذلك دعت الحاجة الى ظهور فرع أخر من فروع علوم الإشعاع وهو علم الوقاية من الإشعاع وهذا الفرع يختص بتحديد المستويات المطلوبة للإشعاع للتقليل بقدر الإمكان وفى حدود المعلومات و النتائج المتاحة من الآثار البيولوجية للإشعاع.

لذلك فلقد أوردنا فى هذه الرسالة المفاهيم و القواعد الأساسية اللازمة لإنشاء نظام وقاية من الإشعاع و كذلك وضحنا كل الطرق و الإجراءات التى يمكن تطبيقها فى هذا المجال للحماية من أثار الإشعاع الضارة.

و يعتبر نظام الوقاية من الإشعاع ذو أهمية خاصة فى الطب لضمان استخدام الأشعة المؤينة بطريقة آمنة، فى هذا النظام يتم استخدام كل الأدوات و التقنيات التى توفر الحماية للعاملين و المرضى و العامة من أخطار هذه الأشعة المؤينة. وهذا النظام يعنى بأن يحدد أو يقلل من التعرض لهذه الأشعة لتقليل التأثيرات البيولوجية الضارة التى يمكن أن تحدثها الأشعة المؤينة فى الخلايا من ثم أعضاء الجسم المختلفة فى الإنسان.

والغرض الأساسي من الوقاية أن يحد من الإصابة بالآثار الحتمية للإشعاع و ذلك بجعل جرعة التعرض اقل من الحد أو عتبة الجرعة، كذلك يعمل النظام على تجنب التعرض الغير ضروري للإشعاع و اتخاذ كل الإجراءات الممكنة للتقليل من جرعة الإشعاع التى لا مفر منها و ذلك للحد من الإصابة بالآثار الاحتمالية. لذلك يمكن القول إن نظام الوقاية من الإشعاع يهدف الى إنشاء مقاييس و قواعد مناسبة لحماية الإنسان من الأشعة المؤينة بما لا يتعارض أو يحد من الفائدة المكتسبة من استخدام لك الأشعة.

وقد انبثقت عدة مجالس و لجان دولية و إقليمية خاصة بمجال الوقاية من الإشعاع منها: اللجنة العالمية للوقاية الإشعاعية (ICRP)، و المجلس الإقليمي للوقاية من الشعاع (NCRP)، واللجنة الدولية لوحدات الإشعاع والقياس (ICRU)، والوكالة الدولية للطاقة الذرية (IAEA).

ومن مهام هذه المنظمات العالمية و الإقليمية وضع مقاييس و قواعد و شروط استخدام المصادر المشعة وأجهزتها المختلفة. أيضا تصدر هذه المنظمات تقارير و توصيات و توجيهات ينتج عنها قواعد وقوانين تنظم و تحدد فيها طريقة التعامل مع مصادر الأشعة و كذلك حدود و مستويات التعرض لهذه الأشعة و مواصفات و معايير الأجهزة أو المعدات التى تتعامل مع الأشعة المؤينة فى جميع المجالات الطبية التى تستخدم الأشعة المؤينة.

وتبعا لذلك تم تقسيم مبادئ و أسس الوقاية فى هذه الرسالة لكل من التعرض المهنى (العاملين فى مجال الإشعاع) و المرضى و العامة من الناس كالاتى:

لحماية العاملين من التعرض المهنى للإشعاع لابد من تطبيق كافة الإجراءات و الطرق لحمايتهم من أخطار الأشعة المؤينة و أهم هذه الطرق و أفضلها فعالية هى كالأتي: ١) تقليل زمن التعرض للأشعة أو التواجد بالقرب من مصدر الأشعة، ٢) زيادة المسافة و الابتعاد بقدر الإمكان عن مصدر الأشعة ، ٣) زيادة سمك الدرع أو الحاجز الواقى، على العاملين الوقوف خلف الحواجز الوقائية و ارتداء الملابس الواقية المرصصة. وبتطبيق هذه الأساسيات فى أقسام الأشعة التشخيصية أو العلاج بالأشعة أو الطب النووى فانه بالإمكان تقليل نسبة تعرض العاملين بالأشعة، كذلك على العاملين الذين يتعاملون أو يستخدمون مصادر مشعة مفتوحة أن يتوخوا الحذر لتجنب التلوث أو ابتلاع أو استنشاق هذه المواد. و التى يمكن إن تنتج من مخلفات المرضى الذين يتناولون هذه المواد المشعة كالملابس و الشعر و غيره أو عند التعامل المباشر مع هذه المواد أو تحضيرها.

أيضا المرضى الذين يتعرضون للأشعة وذلك خلال الفحوصات المختلفة لابد وان يجروا هذه الفحوصات و الحصول على أقصى فائدة منها بأقل تعرض ممكن للأشعة. و فى العلاج بالأشعة فمن المهم إعطاء المريض الجرعة المناسبة لتدمير الورم دون تعرض الخلايا السلمية الى هذه الأشعة. وهناك طرق كثيرة من شأنها أن تقلل التعرض للمرضى و منها التثبيت الجيد للمرضى إثناء إجراء الفحوصات أو العلاج و كذلك اقتصار دخول الأشعة الى الجزء المحدد فقط للتشخيص أو العلاج باستخدام محددات الأشعة و أيضا استخدام المرشح المناسب للجهاز، بالإضافة الى حماية الأجزاء الحساسة من جسم الإنسان باستخدام الدروع و الملابس الواقية المرصصة.

ولابد إن تكون الأقسام التى تتعامل مع المواد المشعة و الإشعاع أو الأماكن التى يتواجد بها المرضى المتعرضون لهذه المواد إثناء فحوصاتهم أو علاجهم منفصلة و ذلك لحماية الزائرين و العامة المترددين على هذه الأماكن أو المستشفيات من التعرض لمخاطر هذه الأشعة.

أيضا أوضحت هذه الرسالة أهم المواد و الأدوات المستخدمة فى مجال الوقاية من الإشعاع وكذلك بينت الطرق التى تستخدم بها هذه الأدوات و التى تعتبر مرشدا هاما لكل من يعمل فى هذا المجال. ويعتبر الكشف الإشعاعي أو المراقبة الإشعاعية من أهم متطلبات الوقاية من الإشعاع، حيث إن المسح الإشعاعي للاماكن أو المناطق المحيطة بمصادر الإشعاع مهم جدا حيث انه يتأكد من إن مستويات الإشعاع فى معدلاتها الطبيعية. وتوفر أجهزة المراقبة الشخصية رؤية واضحة عن معدلات تعرض العاملين أو الأشخاص للأشعة و إن ما من أحد منهم قد تعرض الى جرعة عالية تفوق الحد الأقصى للتعرض المحدد بواسطة المنظمات العالمية و الإقليمية. ولقد أفردنا فى هذا العمل المواد و الأجهزة المستخدمة فى الكشف الإشعاعي و أنواعها و طرق عملها و كيفية استخدامها.

كذلك تم توضيح كيفية تصميم الدروع و الحواجز الوقائية الذى يعتبر ضروريا فى برنامج الوقاية من الإشعاع حيث انه يوفر الحماية لكل المناطق المجاورة لمصادر الأشعة و يتفادى التعرض الغير ضرورى للأشعة المؤينة، وهنا تستخدم مواد كثيرة كدروع أو حواجز وقائية مع تحديد السمك المناسب لها وكيفية وضعها أو استخدامها فى جدران الحجرة.

وكان من أهم النتائج التى حصلنا عليها هى عند تجميع حدود الجرعات القديمة و الحديثة و المقارنة بينها وقد وضع جدولا بهذه الحدود لجميع الفئات من عاملين و جموع العامة و غيرهم. حيث يعتبر تطبيق نظام حدود الجرعة على العاملين فى مجال الأشعة و جموع العامة أحد متطلبات نظام الوقاية من الإشعاع، أن حد الجرعة يعتبر الحد الأقصى أو الأعلى للتعرض للأشعة المؤينة و الذى قد ينشأ عنها خطر صغير للإصابة أو التأثير الجينى للإنسان. و لقد وضعت هذه الحدود للتقليل من الآثار البيولوجية الضارة على الإنسان عند التعرض للأشعة.

أيضا تم توضيح نماذج لجرعات التعرض للعاملين فى مجال الأشعة للتشخيص و العلاج بالأشعة و الطب النووي، وهناك أيضا جداول للجرعات الممتصة للمرضى عند إجراء الفحوصات بالأشعة مع تبيين الجرعة الممتصة لكل عضو فى الجسم على حده، وكذلك تم توضيح التعرض الطبيعي للإنسان كجزء من حياته و بيئته.

و فى المفهوم الحديث للوقاية من الإشعاع لابد و أن يكون التعرض للأشعة اقل ما يمكن و هو ما يعرف بمبدأ (ألارا – ALARA) ، أي أن التعرض للأشعة لابد و أن يكون فى اقل حد أو مستوى معقول يمكن تحقيقه. لذلك لابد من بذل كل الجهود الممكنة لتقليل التعرض للأفراد واستخدام كل الأجهزة و المعدات التى توفر ذلك.و يمكن تحقيق ذلك إذا طبق نظام حماية جيد

بواسطة أفراد مؤهلين و مدربين تدريباً جيداً على كل الإجراءات الوقائية، وهذا المبدأ لابد و أن يطبق على التعرض المهنى و الطبى على حد السواء.

و نرى من كل ما سبق أن هدف هذا العمل هو وضع أسس و مبادئ نظام وقاية من الإشعاع يطبق فى كل المؤسسات التى تستخدم الإشعاع، و يوضح كل الخطوات و القواعد التى تطبق فى الوقاية فى أقسام الطب التى تستخدم الأشعة موضحا كل الإجراءات العملية فى هذا المجال. لذلك فهى تعتبر مرشدا و مرجعا لكل من يعمل فى مجال الأشعة من أطباء و فيزيائيين و فنيين وكذلك يستفيد منها كل المنوط بهم تطبيق نظام وقاية من الإشعاع أو المسئولين عن مؤسسات تستخدم الأشعة .

المشرفون

الأستاذ الدكتور / محمد فريد نعمان

أستاذ الفيزياء الطبية والوقاية من الأشعة

قسم الأشعة

كلية الطب

جامعة الإسكندرية

الأستاذ الدكتور / متولى على متولى قطب

أستاذ الطبيعة الحيوية والطبية

قسم الطبيعة الحيوية والهندسة الطبية والإحصاء الطبي

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معهد البحوث الطبية

جامعة الإسكندرية

توصيات و حدود التعرض الإشعاعي الإقليمية و العالمية في الطب.

رسالة

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جامعة الإسكندرية
إيفاء جزئيا للحصول على

درجة الماجستير

في

الطبيعة الحيوية و الطبية

من

رشا محمد نوري المغيربي

بكالوريوس العلوم – الفيزياء

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