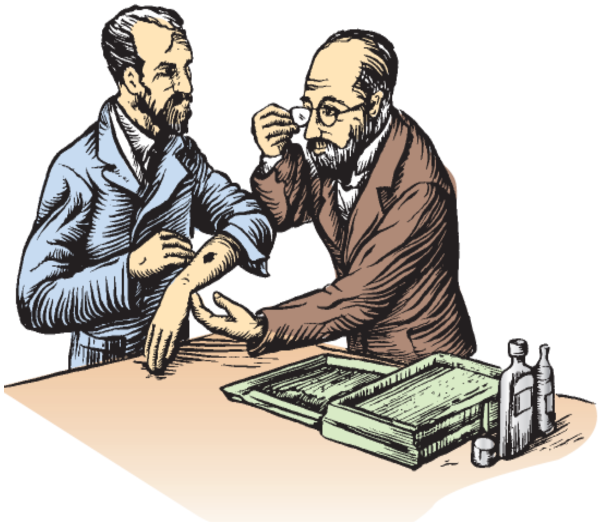
RADIATION PROTECTION

DR ANIL GUPTA

MODERATOR: DR ARUN S OINAM

Introduction

- Scientists were quick to realize the benefits of X-rays, but slower to comprehend the harmful effects of radiation.
- The first recorded biologic effect of radiation was seen by Becquerel, developed erythema subsequently ulceration when radium container was left accidentally in left pocket
- Elihu Thomson demonstrated x ray causes erythema and blisters in 1897



- Thomas Edison’s assistant, Clarence Dally, who had worked extensively with X-rays, died of skin cancer in 1904, first death attributed to radiation effect
- William Herbert Rollins developed leaded tube housings, collimators , and other techniques to limit patient dose during 1896-1904.

- Also demonstrated that exposure of a pregnant guinea pig resulted in killing of the fetus
- He was a true pioneer of x-ray protection

- Rome Vernon Wagner, an x-ray tube manufacturer, had begun to carry a photographic plate in his pocket and to develop the plate each evening to determine if he had been exposed (1907)
- Pioneer for personal monitoring
- Died of cancer in 1908
- Film badge came into effect from 1920

- The first tolerance dose or permissible exposure limit was equivalent to about 0.2 rem per day. Based on this limit on 1/100 of the quantity known to produce a skin erythema per month noting that recovery would occur swiftly enough to obviate any untoward effects. (1925)
- Rolf Sievert also put forth a tolerance dose- 10% of the skin erythema dose - (1925)
- Hermann Muller demonstrated the genetic effects of radiation(1926)
- 2^{nd} International congress of radiation(1928) set up International X-ray and radium protection committee

Effects Of Radiation

- Low level radiation effects
  - genetic effects
  - neoplastic diseases
  - effect on growth and development
  - effect on life span and premature ageing
  - cataracts or opacification of eye lens

- High level radiation effects
  - acute radiation syndrome

Early Chronolgy Of Radiation Protection

- Pioneer Era (1895-1905)- in which recognition of the gross somatic hazard occurred, and relatively simple means devised to cope.

- Dormant Era (1905-1925)- little overt progress was made, but in which great gains were made in technical and biological knowledge which were later applied to protection.

- Era of Progress (1925-1945), which saw the development of radiation protection as a science

Atomic Age...

Atomic Age

ICRP

- International X-ray and radium protection committee remodeled into The International Commission on Radio logical Protection (ICRP) and The International Commission on Radiation Units and Measurements (ICRU)
- The International Commission on Radiological Protection (ICRP) was the primary body created to advance for the public benefit the science of radiological protection
- It is a registered charity, independent non-governmental organisation

- It provides recommendations and guidance on protection against the risks associated with ionising radiation, from artificial sources widely used in medicine, general industry and nuclear enterprises, and from naturally occurring sources

- The first report Publication 1 (ICRP, 1959)--->Publication 26(ICRP, 1977)--->Publication 60(ICRP, 1991b, international Basic Safety Standards)--->Latest is **Publication 103(ICRP, 2007)**

- IAEA (International Atomic Energy Agency) establishes standards of safety and provides for the application of the standards

- National commission on radiation protection and measurement(NCRP) is recommendation body of USA

- In India regulatory and recommendation authority is Atomic Energy Regulatory Board (AERB)

Atomic Energy Regulatory Board(AERB)

- Was constituted in 1983 by government of India

- Carries out certain regulatory and safety functions under the Atomic Energy Act,1962 and Environment Protection Act, 1986, Radiation Protection Rules 2004

- It is the recommendation, research and licensing body in India

Objectives Of AERB

- To ensure that use of Ionising radiations in India does not cause undue risk to health of people and environment
- Develop Safety Codes, Guides and Standards for siting, design, construction, commissioning, operation and decommissioning of different types of nuclear and radiation facilities.
- Shall ensure that radioactive waste generated is disposed in a safe manner
- Shall ensure development of adequate plans and preparedness for responding to emergency situations
- Shall take steps necessary, to keep the public informed on safety issues of radiological safety significance
- Shall provide license and shall revoke license if the concerned setup is not following appropriate safety norms

Terminologies of radiation protection

Unit of Absorbed Dose

- It is defined as the amount of energy absorbed per unit mass of the medium at the point of interest
- Units
  - 1 Rad = 100erg/g
  - Gray (Gy) = 1J/Kg = 100 Rad
- SI Unit is Gray

Unit Of exposure

- The **roentgen** or **röntgen** (**R**) is a unit of measurement for the exposure of X-rays and gamma rays up to several megaelectron volts
- It is a measure of the ionization produced in air by X-rays or gamma rays and it is used because air ionization can be measured directly
- It was last defined by the US National Institute of Standards and technology (NIST) in 1998 as 2.58×10^{-4} C/kg, (i.e. 1 C/kg = 3876 R)
- F-factor is used for conversion of exposure to absorbed dose which depends upon type of radiation and atomic number(Z)
- As a rule of thumb, 1 roentgen is approximately 10 mSv

Organ Dose

- The organ dose (D_T) is defined as the mean dose in a specified tissue or organ of the human body.
- Unit is cGy or joules/kg

$$D_T = \frac{1}{m_T} \int_{m_T} D \, dm = \frac{\varepsilon_T}{m_T}$$

m_T is the mass of the organ or tissue under consideration;
ε_T is the total energy imparted by radiation to that tissue or organ.

Radiation Weighting Factor

- Probability of induction of cancer depends not only on dose but also on type and energy of radiation
- i.e some radiations are biologically more effective for a given dose
- This is taken into account by radiation weighting factor W_R

Radiation Type	Weighting Factor
Photons all energies	1
Electrons all energies	1
Protons, other than fission fragments, energy more than 2 MeV	5
Neutrons energy < 10 KeV	5
10 KeV to 100 KeV	10
100 KeV to 2 MeV	20
> 2 MeV to 20 MeV	10
> 20 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Equivalent Dose

It is defined as:

$H = D \times W_R$

where D is the absorbed dose and W_R is Radiation Weighting Factor

The SI unit for both dose and dose equivalent is joules per kilogram, but the special name for the SI unit of dose equivalent is sievert (Sv).

1 Sv = 1 J/kg

If dose is expressed in units of rad, the special unit for dose equivalent is called the rem.

H(rem) = D(rad)Â·Q

Because Q is a factor and has no units,

1 rem = 10^{-2}, J/kg

Tissue Weighting Factor

Organ	ICRP 26	ICRP 60	ICRP 103
Gonads	0.25	0.2	0.08
Bone marrow	0.12	0.12	0.12
Lung	0.12	0.12	0.12
Breast	0.15	0.05	0.12
Thyroid	0.03	0.05	0.04
Bone Surfaces	0.03	0.01	0.01
Remainder	0.3	0.05	0.12
Colon		0.12	0.12
Stomach		0.12	0.12
Bladder		0.05	0.04
Liver		0.05	0.04
Esophagus		0.05	0.04
Skin		0.01	0.01
Salivary glands			0.01
Brain			0.01

Effective Dose

- The sum of all of the weighted equivalent doses in all the tissues or organs irradiated is called effective dose

  effective dose= Σ absorbed dose × W_R × W_T

- It is useful concept
  - measure the degree of harm from given dose of radiation
  - can be used to compare different types of radiation
  - can be used to compare the dose from various types of exposure
- For the whole body the ICRP recommends the use of Effective doses for defining safety standards eg. Annual dose limits
- For individual organs and extremities, however equivalent doses are used

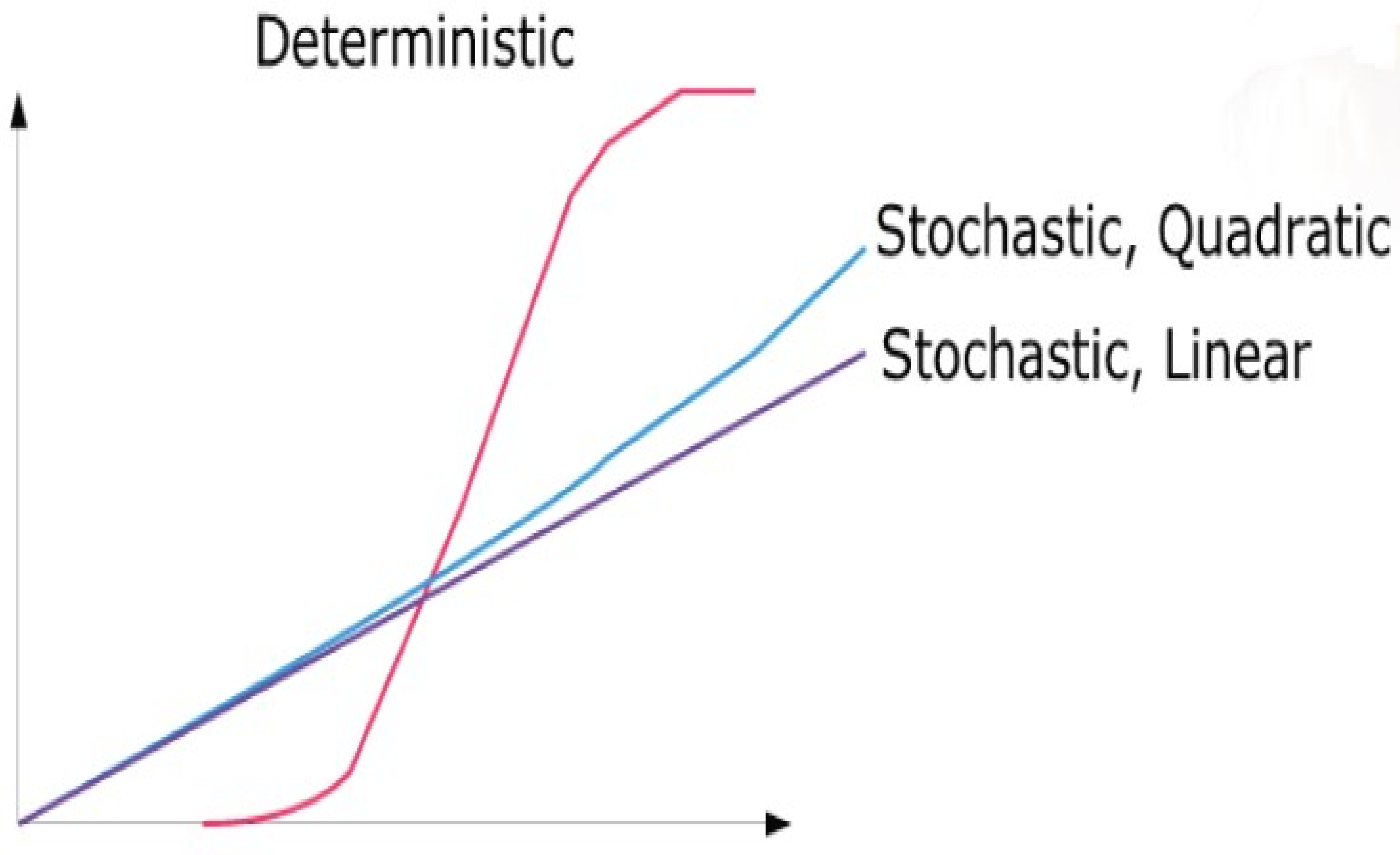
Collective Dose

- The collective dose relates to expose group or population
- Defined as the product of the average mean dose to a population and number of persons exposed
- SI unit is man-sievert
- It is collective equivalent dose when mean dose is average equivalent dose
- And it is collective effective dose when mean dose is average effective dose

Effects Of Radiation Exposure

- **STOCHASTIC EFFECTS/PROBALISTIC EFFECTS**
  - Occurs at level of cells
  - Has no threshold levels of radiation dose
  - The probability of effects is proportional to dose
  - A latent period is seen between the time of exposure and the events to manifest
  - Severity independent of dose received
  - Seen when the cells are modified rather than killed
  - Malignancies,mutations teratogenic effects

- **NON STOCHASTIC EFFECTS/DETERMINISTIC EFFECTS**
  - Occurs at level of tissues
  - Has no threshold levels of radiation dose
  - The probability of effects is proportional to dose
  - A latent period is seen between the time of exposure and the events to manifest
  - Severity may be proportional to the dose received
  - Seen when the cells are killed or loose capability to divide
  - Acute radiation syndromes
  - Sterility, cataract


Deterministic
Stochastic, Quadratic
Stochastic, Linear

Radiation Worker

- A worker is defined by the Commission as any person who is employed, whether full time, part time, or temporarily, by an employer and who has recognised rights and duties in relation to occupational radiological protection
- Workers in medical professions involving radiation are occupationally exposed.

Background radiation

Mainly three sources

- terrestrial radiation; due to naturally occurring radioactive elements on earth's surface, building materials, radon
- cosmic radiation; mainly due to sun, increases with elevation
- radiation from radioactive elements in the body mainly ^{40}K

the estimated total annual exposure is estimated to be 3mSv

TYPES OF RADIATION EXPOSURE

i. Occupational exposure- defined as all exposures of workers incurred in the course of their work

ii. Medical exposure - which is defined as exposure incurred, by patients as part of their own medical or dental diagnosis or Treatment;

iii. Public exposure- which is defined as exposure incurred by members of the public from radiation sources, excluding any normal local natural background radiation but including exposure to authorized sources and practices and from intervention situations.

Exposure Situations

- Planned exposure situations- which are involving the planned introduction and operation of sources.
- Emergency exposure situations- which are unexpected situations such as those that may occur during the operation of a planned situation, or from a malicious act, requiring urgent attention.
- Existing exposure situations - which are exposure situations that already exist when a decision on control has to be taken, such as those caused by natural background radiation

Three Principles Of Radiation Protection

- JUSTIFICATION: Any decision that alters the radiation exposure situation should do more good than harm.
- OPTIMISATION: The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factor
- DOSE LIMITATION: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission

JUSTIFICATION

- A practice involving exposure to radiation should produce sufficient benefit to the exposed individual or to society

1. In the case of patients, the diagnostic or therapeutic benefit should outweigh the risk of detriment
2. In the occupational exposure, the radiation risk must be added and compared with other risks in the workplace
3. In cases in which the individual receives no benefit, the benefit to society must outweigh the risks

OPTIMISATION

- The principle of optimisation is to keep the likelihood of incurring exposures,the number of people exposed, and the magnitude of individual doses as low as reasonably achievable
- Optimisation is always aimed at achieving the best level of protection under the prevailing circumstances through an ongoing, iterative process that involves:

- ➢ evaluation of the exposure situation, including any potential exposures (the framing of the process);
- ➢ selection of an appropriate value for the constraint or reference level;
- ➢ identification of the possible protection options;
- ➢ selection of the best option under the prevailing circumstances; and
- ➢ implementation of the selected option.

ALARA

- As low as reasonable achievable
- In USA, ALARA has cash value of about 1,000$ per 10 mSv
- If the exposure of one person can be avoided by this amount of money, it is considered reasonable
- At higher dose levels, additional exposure may threatened worker's job by exceeding the lifetime dose limit, here reasonable cost is 10,000$

DOSE LIMITATIONS

- In the 1930s, the concept of a tolerance dose was used, a dose to which workers could be exposed continuously without any evident deleterious acute effects such as erythema of skin
- Early 1950s , emphasis shifted to late effects and maximum permissible dose was designed to ensure that probability of injury is so low that the risk would be `easily acceptable to the average person
- This was based on geneticist H.J Muller work who had indicated that the reproductive cells were vulnerable to even smallest doses of radiation

Permissible Dose

- The concept of tolerance dose indicated that there was a level of radiation below which it was safe.
- The concept of stochastic effects of radiation invalidated this dogma
- Most scientists rejected that there was a threshold dose below which exposure to radiation was harmless
- The concept of permissible dose therefore introduced

Maximum Permissible Dose

"There is no safe level of exposure and there is no dose of radiation so low that the risk of a malignancy is zero" — Dr. Karl Z. Morgan, father of Health Physics

Maximum Permissible dose (MPD) is defined as that dose which in the light of present knowledge is not expected to cause appreciable bodily injury to the person at any point during his lifetime

- Advantages

- explicit acknowledgment that doses below MPD have a risk of detrimental effects

- acknowledged danger due to stochastic effects of radiation

- introduced the concept of acceptable risk- probability of the radiation induced injury was to be kept low to be easily acceptable to individual

Recommendations on exposure limits

- At low radiation levels for non stochastic effects are essentially avoided
- The predicted risk for stochastic effects should not be greater than the average risk accidental death among workers in “safe industries”
- As low as reasonably achievable principle should be followed

(“safe” industries are defined as “those having an associated annual fatality accident rate of 1 or less per 10,000 workers i.e. Average annual risk is 10^{-4})

General recommendations on Dose Limitations

- The first general Recommendations were issued in 1928 and concerned the protection of the medical profession through the restriction of working hours with medical sources
- This corresponds to an individual dose of about 1000 millisievert (mSv) per year
- 1956 Recommendations limits on weekly and accumulated doses were set that corresponded to annual dose limits of 50 mSv for workers and 5 mSv for the public

- All the sta made for "reference

- Reference 0 yrs of age, weigh ht, lives in a climat re of 10 to 20°C, he is uropean or north Amer

- Most count t of reference an

- Enables ba n doses

	Indian Adult*	ICRP Reference Man
Body mass (kg)	52	70
Height (cm)	164	170
Adrenals(g)	13	20
Brain(g)	1250	1400
Heart(g)	250	330
Kidneys(g)	220	310
Liver(g)	1150	1800
Lungs(g)	860	1000
Pancreas(g)	100	100
Spleen(g)	140	180
Testes(g)	35	35
Thyroid(g)	19	20

General guidelines Dose limitations

- Individual doses due to combination of exposures from all relevant practices should not exceed specified dose limits for occupational or public exposure
- Different dose limits are specified for the radiation workers as the expected benefit from the work they do while they do while handling radiation will outweigh the small increase in risk
- Pregnant radiation workers have to be protected so that the fetus/embryo is given the same radiation protection as given to public
- Dose limits are not applicable for medical exposure as the benefits gained outweighs the harm
- Does not include natural background or radiation for medical purposes

LIMITS FOR OCCUPATIONAL EXPOSURE

- Stochastic Effects

1. No occupational exposure should be permitted until the age of 18 years
2. The effective dose in any year should not exceed 50mSv(5 rem)
3. The individual worker's lifetime effective dose should not exceed age in years X 10mSv

PROTECTION OF THE EMBRYO/ FETUS

1. NCRP recommends 0.5 mSv to the embryo/ fetus once the pregnancy is declared
2. ICRP recommends a limit of 2 mSv to the surface of woman's abdomen for the remainder of her pregnancy

3 There is a provision that a declared pregnancy can later be “undeclared” if the female worker so desires

EMERGENCY OCCUPATIONAL EXPOSURE

- If possible, older workers with low life time accumulated effective doses should be chosen among the volunteers
- If exposure do not involve saving life should be avoided
- If for lifesaving the exposure may approach 0.5 Sv to a large portion of the body, the worker needs to understand potential for acute effects, but also substantial increase lifetime risk of cancer

EXOSURE OF PUBLIC

- For continuous or frequent exposure, the annual effective dose should not exceed 1 mSv
- Maximum permissible annual equivalent dose is 5 mSv for infrequent dose

Exposure Type		Dose Levels
Occupational Exposure (Annual)		
Whole Body Effective Dose Limits (Stochastic Effects)		50 mSv
Dose Equivalent Limits for organs (Non Stochastic Effects)		
	Lens of Eye	150 mSv
	All others	500 mSv
Public Exposure (annual)		
Effective dose euivalent limit, continous exposure		1 mSv
Effective dose euivalent limit, infrequent exposure		5 mSv
Dose Equivalent Limits for lens, skin and extremities		50 mSv
Embryo Fetus Exposures		
Total dose equivalent limit		5 mSv
Dose Equivalent in a **month**		0.5 mSv
Annual effective **education and training exposure**		1 mSv
Dose Equivalent Limits for lens, skin and extremities		50 mSv

Dose Limits by AERB

- The limits on effective dose apply to the sum of effective doses from external as well as internal sources. The limits exclude the exposures due to natural background radiation and medical exposures.
- Calendar year shall be used for all prescribed dose limits

Occupational exposures

1. An effective dose of 20 mSv/yr averaged over five consecutive years (calculated on a sliding scale of five years);
2. An effective dose of 30 mSv in any year;
3. An equivalent dose to the lens of the eye of 150 mSv in a year;
4. An equivalent dose to the extremities (hands and feet) of 500 mSv in a year and
5. An equivalent dose to the skin of 500 mSv in a year;
6. Limits given above apply to female workers also. However, once pregnancy is declared the equivalent dose limit to embryo/fetus shall be 1 mSv for the remainder of the pregnancy.

Apprentices and Trainees

The occupational exposure of apprentices and trainees between 16 and 18 years of age shall be so controlled that the following limits are not exceeded:

1. An effective dose of 6 mSv in a year;
2. An equivalent dose to the lens of the eye of 50 mSv in a year;
3. An equivalent dose to the extremities (hands and feet) of 150 mSv in a year and
4. An equivalent dose to the skin of 150 mSv in a year.

Dose Limits for Members of the Public

1. An effective dose of 1 mSv in a year;
2. An equivalent dose to the lens of the eye of 15 mSv in a year; and
3. An equivalent dose to the skin of 50 mSv in a year.

STRUCTURAL SHIELDING DESIGN

- NCRP Report No. 49, Structural Shielding Design and Evaluation for Medical Use of X Rays and Gamma Rays of Energies Up to 10 MeV(1976)
- NCRP Report No. 51, Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities(1977)
- NCRP Report No. 79, Neutron Contamination from Medical Electron Accelerators(1984)
- NCRP Report No. 144, Radiation Protection for Particle Accelerator Facilities, in order to account for the higher energies and the associated production of neutrons
- NCRP Report No. 151, Upgrade of report no.49

Basic Principles Of Structural Sheilding Design

- 3 basic parameters influence the exposure that an individual receives in a radiation field;

  - Time- longer the time spent in radiation field longer the exposure
  - Distance- the exposure falls as function of distance from radiation field
  - Shielding- exposure can be reduced due to attenuation of primary beam by shielding

- Design of radiation facility basically deals with shielding for a given set of time and exposure

GENERAL DESIGN GUIDELINES

- Usually located at periphery of hospital complex- avoids the problem of therapy room in high occupancy area
- Ground level is preferred as the problem of shielding floor is less
- Whenever possible the areas around therapy machine should be designated as controlled area
- Mazes should be designed wherever possible as they reduce the need for heavy shielded door

- Doors should be provided at the maze entrance to avoid casual entrance of public
- The control console should be provided with devices for keeping a watch on the patient on all times

- CCTV cameras- 2 cameras are recommended – 15 off and above the gantry rotation axis for optimum patient viewing
- Mirrors and door glass arrangement
- Lead glass for direct viewing – expensive, only for low energy
- Suitable warning signs must be used

Controlled And Noncontrolled Areas

- Controlled area:- under supervision of radiation safety officer

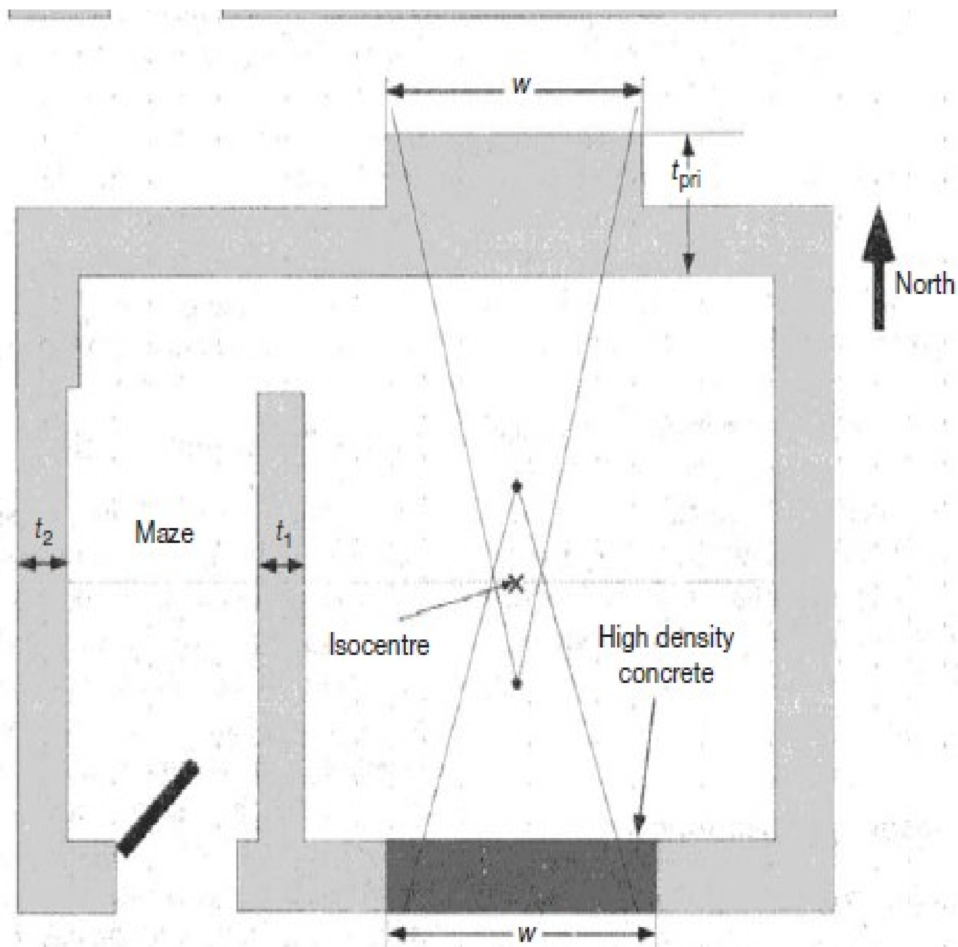
  The dose equivalent limit is assumed to be 0.1 rem/week~ 5 rem/yr

- Non controlled area:- not under supervision of radiation safety officer

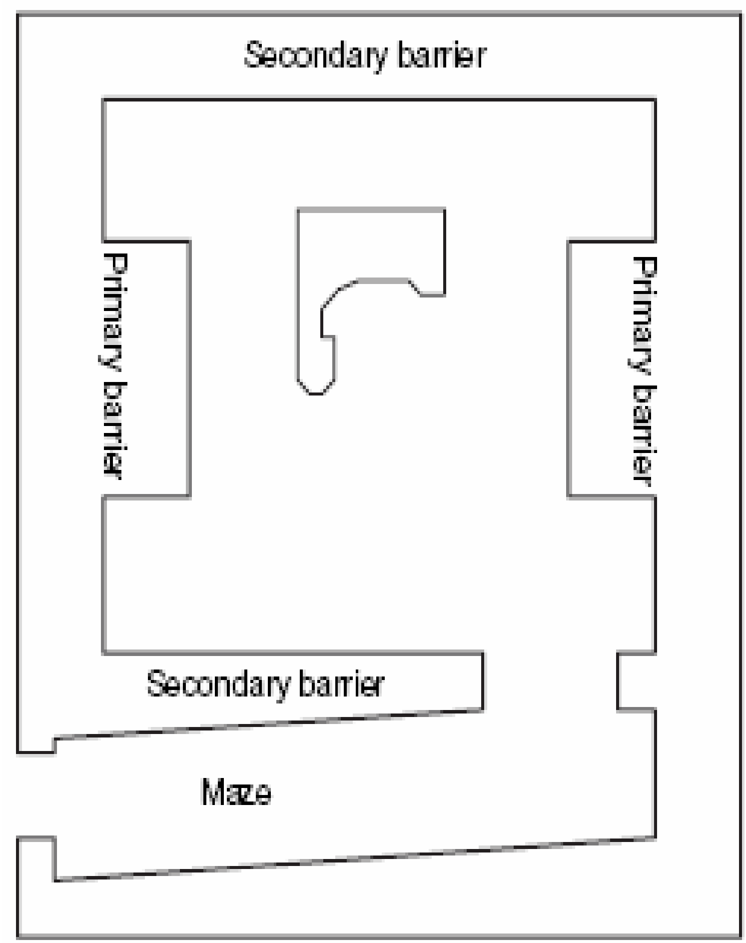
  The dose equivalent limit is assumed to be 0.01 rem/week ~ 0.5 rem/yr

Types Of Barriers

- 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.



w
t_{pri}
North
t_2
Maze
t_1
Isocentre
High density
concrete
w



Secondary barrier
Primary barrier
Primary barrier
Secondary barrier
Maze

- If I_0 is the intensity of the radiation at a point without shielding.
- I is the intensity when a thickness of the material is introduced, then for monoenergetic beam

$$I=I_0e^{-\mu t}$$

- Where μ is called the attenuation coefficient and represent the fraction of the beam remove from the beam by unit thickness of the material.
- t is thickness of shielding material.

μ depend upon → Energy of radiation

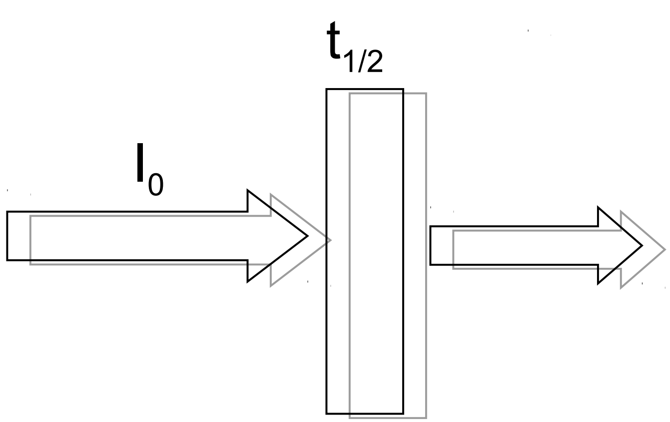
→ Shielding material

Half Value Thickness(HVT)

The thickness of the material which reduce the intensity of the radiation to half of its original value (50 percent) is termed as HVT($t_{1/2}$)

$$I=I_0e^{-\mu t}$$

if intensity is reduced to 1/2 of I then



$$I_0/2=I_0\times e^{-\mu t_{1/2}}$$

$$½= e^{-\mu t_{1/2}}$$

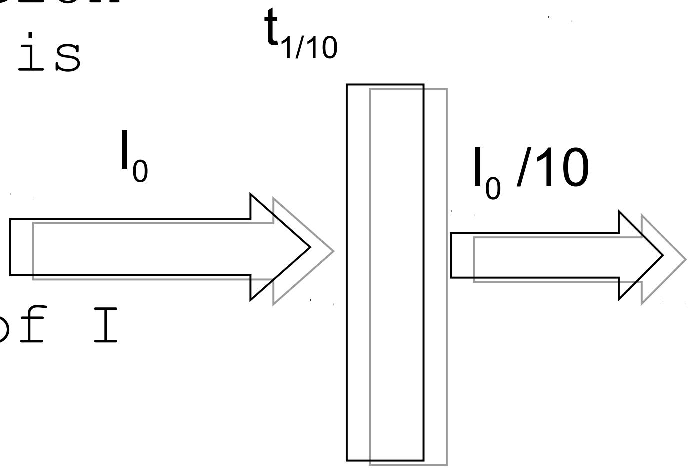
$$e^{\mu t_{1/2}} =2$$

$$\Rightarrow \quad \mu t_{1/2} = \log_e 2 = 0.693$$

$$t_{1/2} = 0.693/\mu$$

Tenth Value Thickness(TVT)

The thickness of the material which reduces the intensity of the radiation to one tenth of its original value is define the TVT($t_{1/10}$)



$$I=I_0 \times e^{-\mu t}$$

if intensity is reduced to 1/10 of I then

$$I_0 /10=I_0 \times e^{-\mu t_{1/10}}$$

$$e^{\mu t_{1/10}} =10$$

$$\mu t_{1/10} =\log_e 10$$

$$\mu t_{1/10} =2.303$$

$$t_{1/10} =2.303/\mu$$

SOURCE	TVT	VALUE
	Lead	Concrete
Co^{60}	4 cm	20.3cm
Cs^{137}	2.2 cm	16.3cm
Ir^{192}	1.9cm	13.5cm
6MV	5.1	34cm
15MV	5.5	42cm

Reduction Factor(R.F)

$$t_{1/2} = 2.303 \times \log_{10} 2 / \mu$$

$$t_{1/2} = 2.303 \times 0.301 / \mu$$

1 HVT = 0.3 TVT

1 TVT = 3.3 HVT

Reduction factor=(Rad^{n} level without shield)/
(Rad^{n} level with shield)

$$R.F = I_0 / I$$

Factors For Barrier Thickness

- WORKLOAD(W):- 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.

- NCRP 49 suggests a workload figure of 1000Gy/week based on dose 4 at 1m per patient, assuming 5 days a week for megavoltage facilities

<u>so 50 patients per day 5 days a week 8 hours in a day is the basis for workload calculation</u>

- USE FACTOR(U):- Fraction of the operating time during which the radiation under consideration is directed toward a particular barrier

VALUES

TABLE 16.6 Typical Use Factor for Primary Protective Barriers

Location	Use Factor (%)
0 degree (down)	31.0
90 and 270 degrees	21.3
180 degrees	26.3

- OCCUPANCY FACTOR:- Fraction of the operating time during which the area of interest is occupied by the individual. If more realistic occupancy factors are not available, following values can be used

TABLE 16.7 Typical Occupancy Factors

Location	Occupancy Factor (T)
Full occupancy areas (areas occupied full-time by an individual), e.g., work offices, treatment planning areas, nurses stations, attended waiting areas, occupied space in nearby building	1
Adjacent treatment room, patient examination room adjacent to shielded vault	1/2
Corridors, employee lounges, staff rest rooms	1/5
Treatment vault doors	1/8
Public toilets, unattended vending rooms, storage areas, outdoor areas with seating, unattended waiting rooms, patient holding areas, attics, janitors' closets	1/20
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), stairways, unattended elevators	1/40

- 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.

Calculation Of Primary Radiation Barrier Thickness

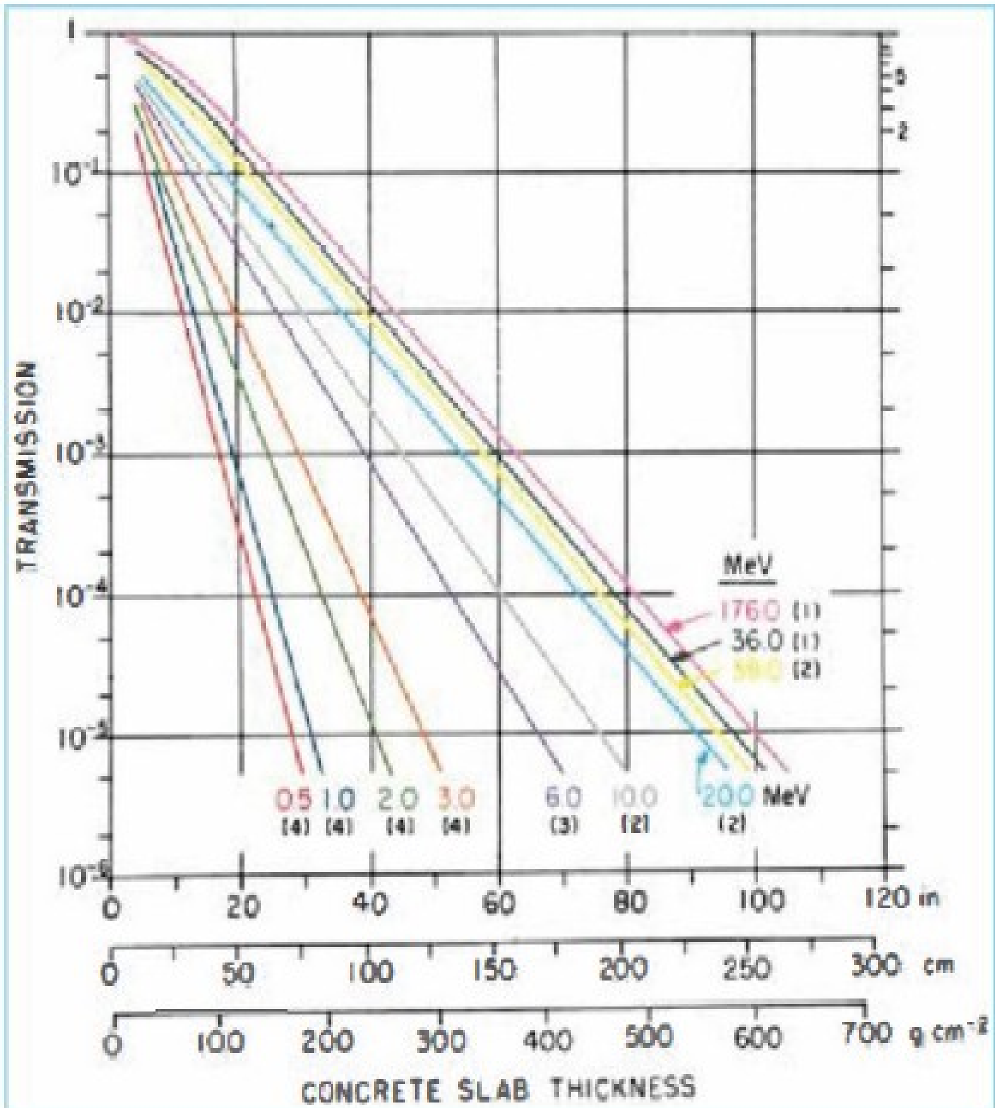
- Suppose the maximum permissible dose equivalent for the area to be protected is P (e.g., 0 .1 mSv/wk for controlled and 0.02 mSv/wk for noncontrolled area) .
- If B is the transmission factor for the barrier to reduce the primary beam dose to P in the area of interest, then

$$P = \frac{WUT}{d^2} \times B$$

Therefore, the required transmission factor B is given by

$$B = \frac{d^2}{WUT} \times P$$

TRANSMISSION FACTOR FOR BARRIER(B):-



Calculation Of Secondary Radiation Barrier Thickness

The amount o f scattered radiation depends on

- the beam intensity incident on the scatterer
- the quality of radiation
- the area of the beam at the scatterer
- the scattering angle

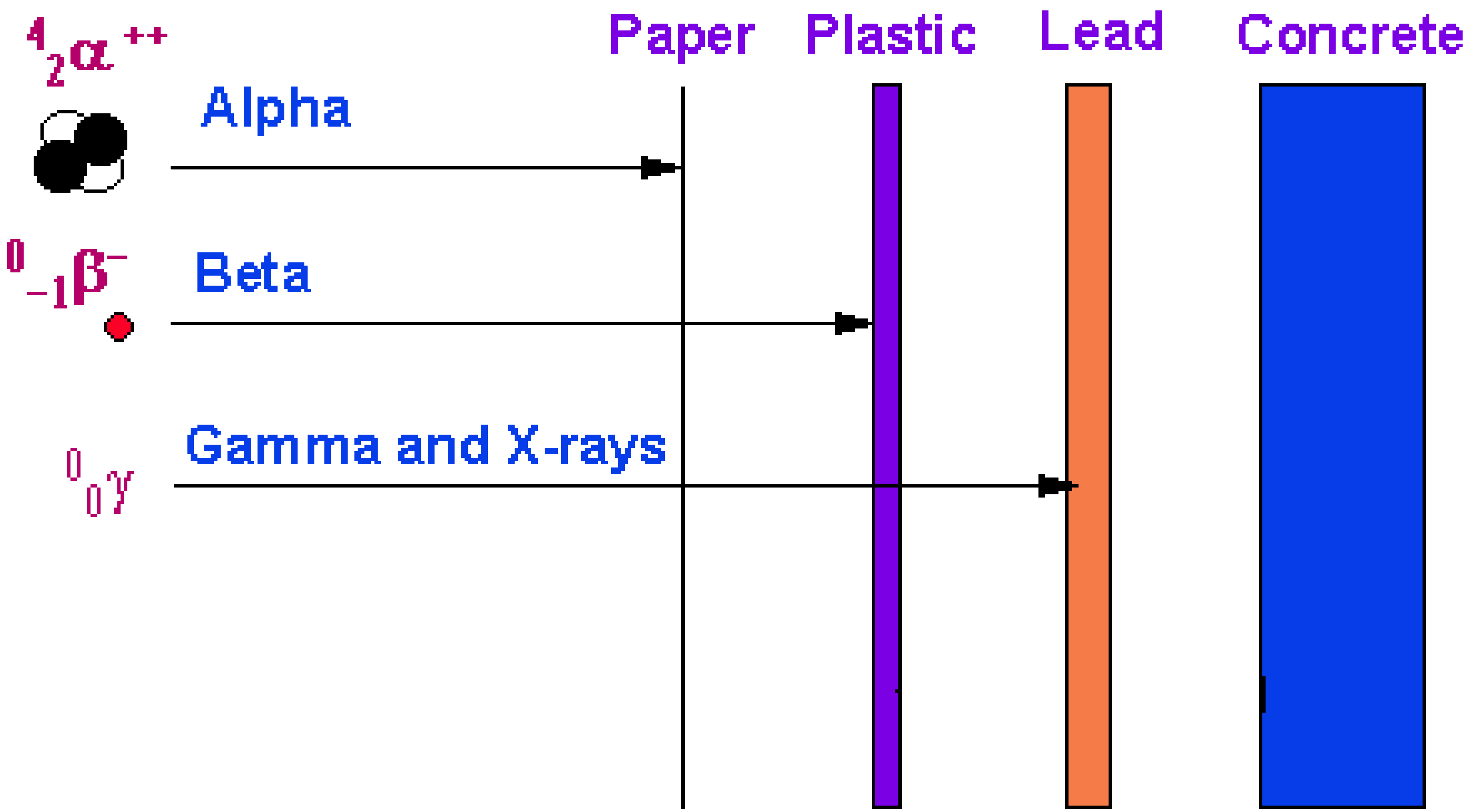
- α= ratio of scattered dose to the incident dose

$$P = \frac{\alpha \cdot WT}{d^2 \cdot d'^2} \cdot \frac{F}{400} \cdot B_s$$

$$B_s = \frac{P}{\alpha WT} \cdot \frac{400}{F} \cdot d^2 \cdot d'^2$$

-d is the distance from source to the scatterer
-d' distance from the scatterer
-beam area of 400 cm2 incident at the scatterer

Penetrating Distances



Types Of Shielding Material

- Concrete:- inexpensive, self supportive, shields neutron, density 2.35g/cm^3
- Lead:- less thickness, high z and density (11.35g/cm^3), expensive, not self supportive
- Steel:- laminated shielding, density 7.8g/cm^3 ,needs external support
- Earth:- very inexpensive, density 1.5 g/cm^3
- Polyethylene:- used for blocking neutrons

Safety Specifications For Radiation Therapy Equipment And Protective Devices

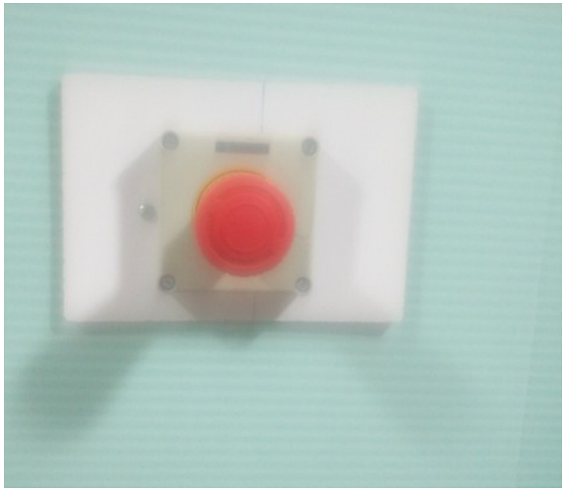
Indication of beam OFF or ON

Colour of light indications for beam OFF or beam ON whether electrically operated or non electrically operated, shall be as follows -

Status	Radiation Head		Treatment Control Panel	Elsewhere
	Electrical	Non-electrical		
Beam OFF	Green	Green	Green	Green
Intermediate Position	Red	Red	Red	Red
Beam ON	Red	Red	Yellow/Orange	Red

Emergency switch

- In case of emergency or someone is left inside treating room accidentally it should be possible to switch beam off by mechanical means from inside the treatment room.
- It should be possible to use mechanical means without the operator being exposed to the radiation beam
- For that purpose multiple emergency buttons are available inside the room



Interlocks and Safety locks

Door Interlocks

Are provided on doors of teletherapy machines, by which beam will be ON only after teletherapy door is properly closed and will remain close till beam is ON

Safety locks

Teletherapy equipment are provided with locking mechanism to prevent unauthorised use. Further, it shall be possible to make the radiation beam ON from the control panel only.

Quality Assurance

- The quality assurance tests shall be repeated at specified intervals and the records of the list of tests performed and their results maintained by the medical physicist in a logbook
- The licensee shall inform the competent authority if the results of tests show any unexpected deviation and corrective action taken
- Main motive is to satisfy needs of the patient treatment and prevent undue radiation to patient

Periodicity of Procedures and Tests

(a) Daily:

Door interlock, radiation room monitor, audiovisual monitor, lasers and optical distance indicator

(b) Weekly:

Check of source positioning

(c) Monthly:

Output constancy, light/radiation field coincidence, field size indicator, gantry and collimator angle indicator, cross-hair centering, latching of wedges and trays, emergency off interlock and wedge interlock

(d) Annual:

Output constancy, field size dependence of output constancy, central axis dosimetry parameter constancy (percentage depth dose, PDD/ tissue air ratio, TAR), transmission factors constancy for all standard accessories, wedge transmission factor constancy, timer linearity and error, output constancy versus gantry angle, beam uniformity versus gantry angle, emergency off interlock, wedge interlock, collimator rotation isocentre, gantry rotation isocentre, couch rotation isocentre, coincidence of collimator, gantry and couch axes with isocentre, coincidence of radiation and mechanical isocentres, tabletop sag, vertical travel of table, field light intensity, and control panel systems.

Warning Symbol of Radiation Hazards

For X ray generating machine

Where MPD>1 mR/h

Radiation hazard

Caution radioactive material

Emergency Preparedness

- Includes planning for the implementation of optimised protection strategies which have the purpose of reducing exposures, should the emergency occur, to below the selected value of the reference level.
- During emergency response, the reference level would act as a benchmark for evaluating the effectiveness of protective actions and as one input into the need for establishing further actions.

Radiation Emergency Action Plan

Licensee shall prepare emergency action plans, consisting of a set of procedures to be implemented for all foreseeable emergencies such as;-

(a) Radioactive source failing to return to the safe shielding position

(b) Damage to, or dislodge/loss/theft of radioactive source at the installation during use, storage, transport, loss of source shielding or natural calamities such as fire, flood,or earthquake

(c) Death of patient, with sources in situ

(d) Teletherapy emergencies such as, selection of wrong treatment mode, selection of wrong beam modifiers and wrong dose delivery

The emergency action plan shall:

(a) Identify personnel for handling radiation emergencies and make them familiar with the responsibilities and functions, line of authority and most direct and alternate lines of communication;

(b) provide for initial training and drills, and periodic retraining and drills, in their respective tasks to ensure effectiveness of the plans;

(c) provide for training needed to recognise abnormal exposures, as well as formal procedures, and for prompt communication to the RSO;

(d) provide for appropriate tools, radiation monitoring instruments and personnel monitoring devices to be kept and maintained in working condition

(e) specify the authorities to be contacted at the initial phase,during progress, and at termination of an emergency.

Role Of Radiation Safety Officer

The RSO shall have responsibilities listed in Rule 22 of the Atomic Energy (Radiation Protection) Rules, 2004 including those to:

3.1 ensure that the provisions of the Atomic Energy (Radiation Protection) Rules, 2004 or modified thereafter, are implemented;

3.2 establish and maintain an effective radiation protection programme to ensure safety of workers, patients and public;

3.3 instruct all workers on relevant safety measures;

3.4 assist the licensee in developing suitable emergency plans to deal with accidents and ensuring appropriate emergency preparedness;

3.5 provide adequate training in radiation protection and safety methodologies to all workers;

3.6 implement all radiation surveillance measures;

3.7 conduct periodic radiation protection surveys to verify compliance with the regulatory requirements;

3.8 ensure safe work practices during procedures, such as source transfer and target replacement;

3.9 carry out personnel monitoring and maintain records thereof;

3.10 ensure periodic calibration of radiation measuring and associated instruments;

3.11 submit periodic reports to the competent authority giving details such as safety status of the installation and inventory of sources; and

3.12 inform the competent authority when he leaves the employment.

Radiation Monitioring

Radiation Monitoring

PERSONNEL MONITORING

- For individual radiation worker
- In form of radiation badges
- Allows estimation of individual doses

WORLPLACE MONITORING

- For the entire workplace and radiation rooms
- Usually require some form of radiation detectors
- Integrated with the workplace
- Allows estimation of exposure levels in the environment

Types of Dosimeters

Immediate Read

Pocket Ionization Chambers, Solid state detectors, handheld GM/Ionization detectors with dose accumulation function

Delayed read / Personnel monitors

Film Badges, TLD (Thermo Luminescent Dosimeters), OSL (Optically Stimulated Light-emitting Dosimeters)

Personnel Monitoring

- The exposure of the individual radiation worker needs to be routinely monitored and records kept of their cumulative radiation doses
- They can also be used to retrospectively determine a dose received by a worker
- Individual monitoring is used to verify the effectiveness of radiation control practices in the workplace
- It is also used to detect changes in the workplace
- Confirm or supplement static workplace monitoring
- Identify working practices that minimize doses
- Provide information in the event of accidental exposure

Who should wear a personal dosimeter?

- Healthcare or laboratory workers in non-emergency environments that may contain radiation

Examples: radiology, nuclear medicine, and radiation oncology department staff

- Workers in emergency environments that may contain radiation
  - Examples: first responders and first receivers

- Workers in industrial environments where radiation is used

Examples: nuclear power plant workers or employees at radiation sterilizing facilities

Where are personal dosimeters usually worn?

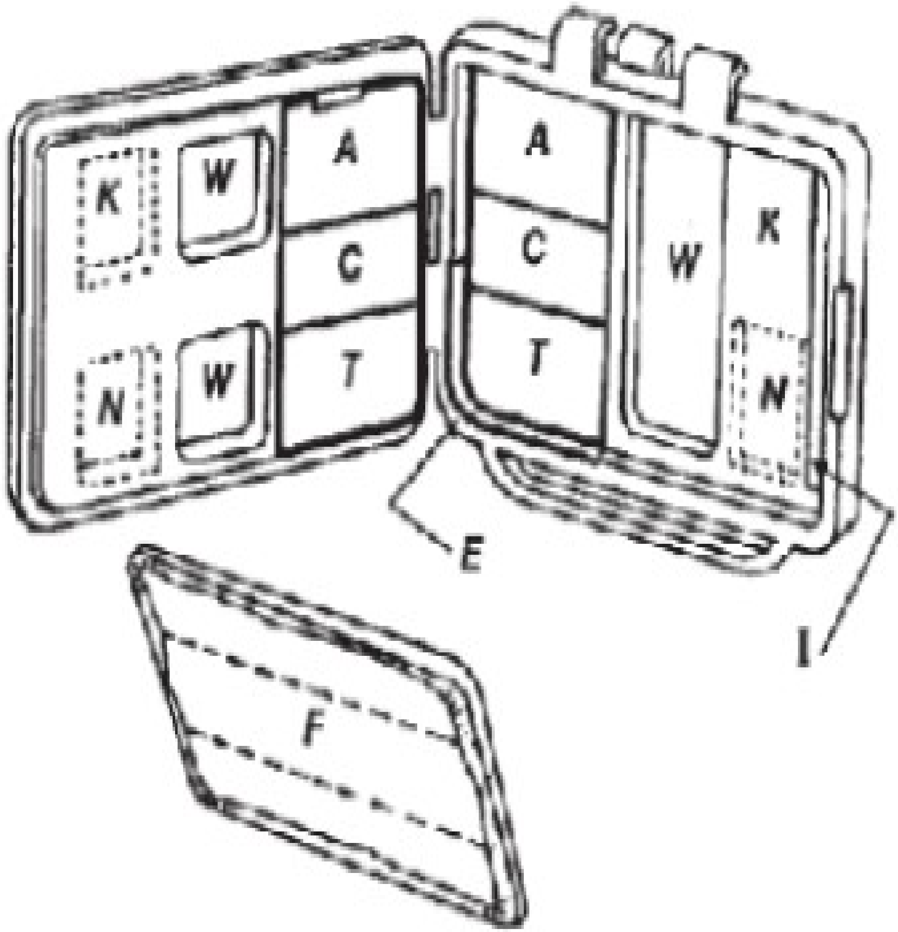
- Flat badges are usually worn on the torso, at the collar or chest level, but can be worn on the belt, or forearm
- Ring shaped badges can be worn on the finger when dose to the finger may exceed dose to the badge worn elsewhere on the body

Devices Used For Personnel Monitoring

- Film Badges
- TLD Badges
- Pocket Dosimeters

Film Badges

- A special emulsion photographic film in a light-tight wrapper enclosed in a case or holder with windows, with appropriate filters, is known as a film badge
- The badge holder creates a distinctive pattern on the film indicating the type and energy of the radiation received.
- Consists of three parts:
  - Plastic film holder
  - Metal filters
  - Film packet



W — window which allows all radiation which can penetrate the wrapper to reach the film;

N — thin plastic filter which attenuates **beta radiation** depending on its energy

K — thick plastic filter which attenuates **low energy photon** radiations and absorbs all but the **highest energy beta radiation**;

A — aluminium filter used with area K to assess doses from photons with energies from **15 to 65 keV**;

C — composite of cadmium and lead filters to assess doses from **thermal neutrons** which interact with the cadmium;

T — composite of tin and lead filters used with area C to assess doses from **thermal neutrons**;

E — edge shielding to prevent low energy photons entering around area T;

I — indium foil sometimes included to detect **fast neutrons**

Advantages And Disadvantages Of The Film Badge

- ✓ Lightweight, durable, portable
- ✓ Cost efficient
- ✓ Permanent legal record
- ✓ Can differentiate between scatter and primary beam
- ✓ Can discriminate between x, gamma, and beta radiation
- ✓ Can indicate direction from where radiation came from
- ✓ Control badge can indicate if exposed in transit

- ✘ Only records exposure where it's worn
- ✘ Not effective if not worn
- ✘ Can be affected by heat and humidity
- ✘ Sensitivity is decreased above and below 50 keV
- ✘ Exposure cannot be determined on day of exposure
- ✘ Accuracy limited to + or - 20%

TLD Badges

- Consists of a set of thermoluminescent dosimeter (TLD) chips enclosed in a plastic holder with filters.

Babha atomic resarch centre

Front cover

Back cover

TLD chip

Personal and inst No.

Name

Radiation monitored

Time period

- Based on the principle of thermoluminescence
- There are certain crystalline materials which acts as TL phosphors such as
  - lithium flouride (LiF)
  - lithium borate($Li_2B_4O_7$)
  - calcium fluoride(CaF_2)
- If impurities such as magnesium(Mg) is introduced, it provides us radiation induced thermoluminescence

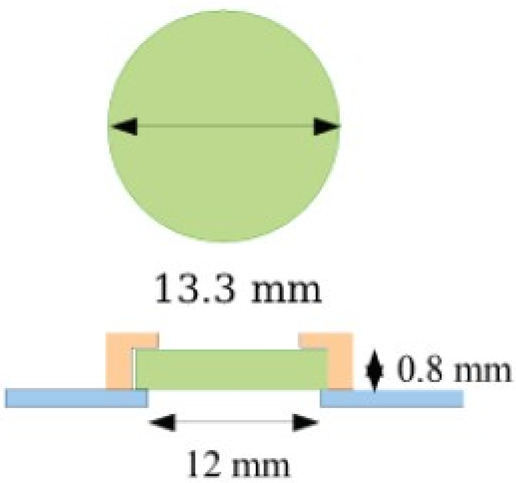
TLD Chips In India

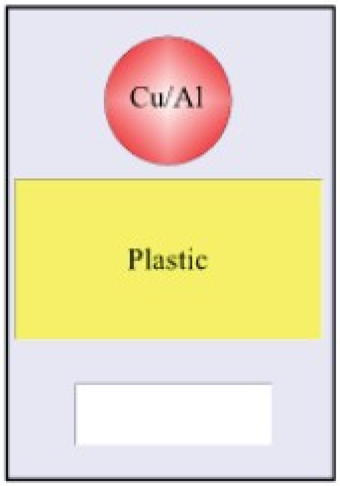
- Are made from $CaSO_4$
- Doping material used in Dysporsium
- Advantages of $CaSO_4$

  - cheap and easily available

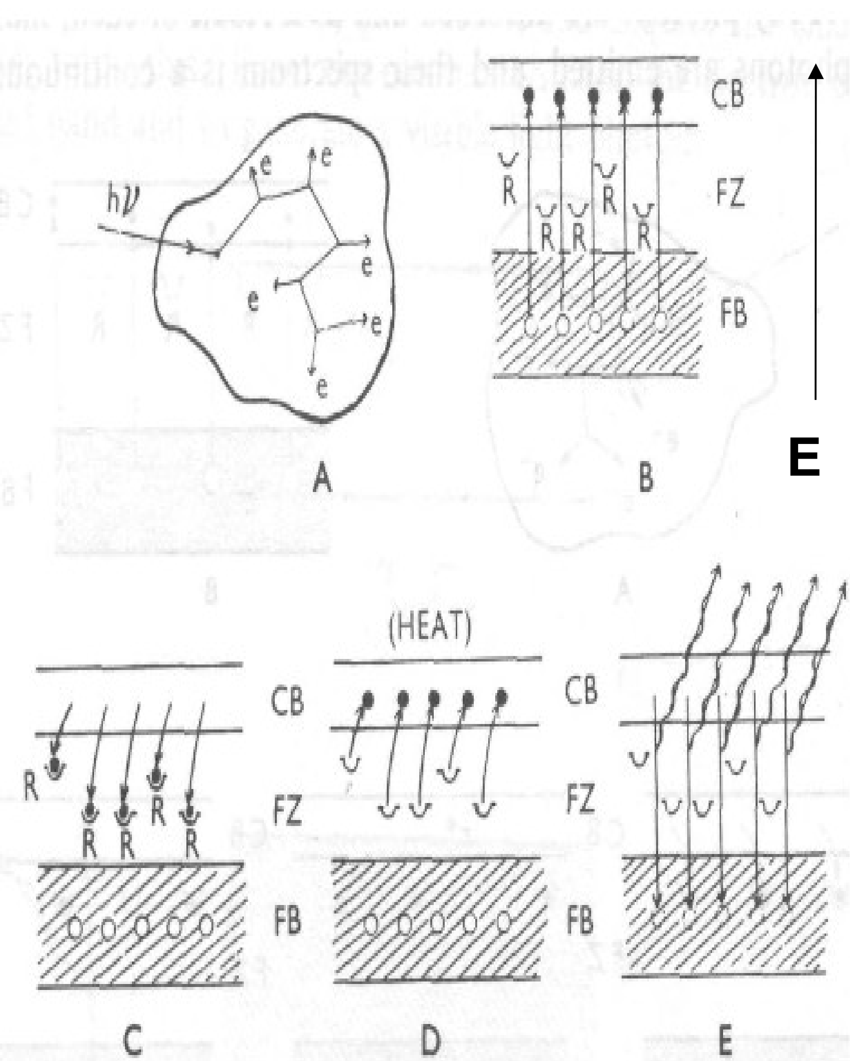
  - highly sensitive

  - useful over large dose range
- Mixed with teflon to form a tablet
- Sealed inside a plastic cover to protect from moisture





Principle Of Thermoluminescence



1. X-ray energy is absorbed and a secondary electron is produced.

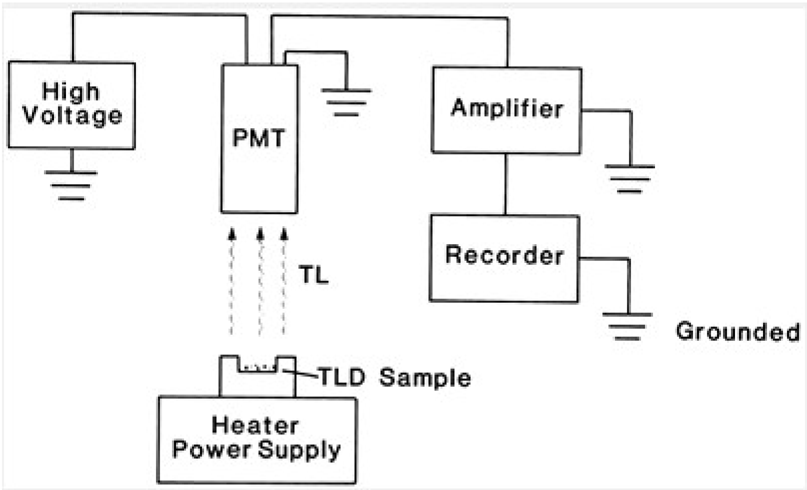
2. The secondary electron causes many holes in the filled bands of atoms through which it passes and so lifts many electrons into the conduction band.

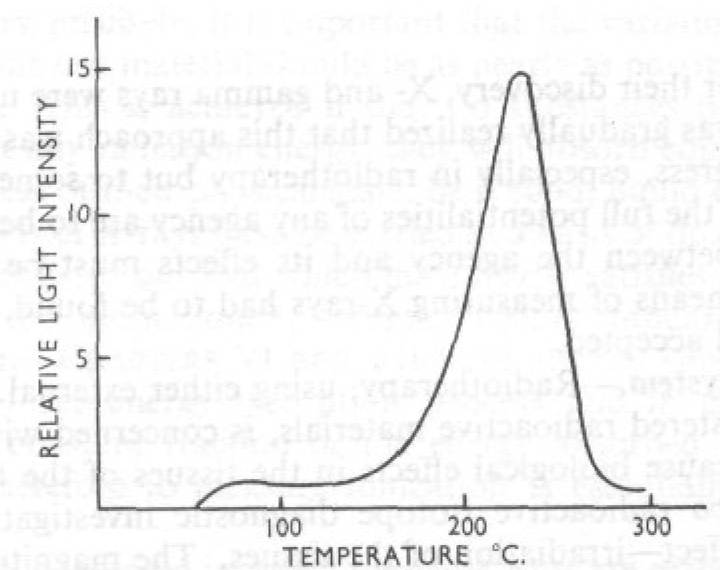
3. These electrons may fall back into traps (R) where they are held.

4. When the material is heated to a temperature of 200-300° C. the trapped electrons can acquire sufficient energy to escape back into the conduction band

5. From the conduction band the electrons can fall back to fill holes in the filled band, visible photons being emitted in the process.

6. It will be noted that the traps occur at different' levels' in the forbidden zone. Escape from some is easier (i.e., is possible at a lower temperature) than from others.





Thermoluminescent "glow"

7. Light is emitted over a range of temperatures,

8. Some light is emitted at quite low temperatures, most at 70-100° C., whilst to empty all the traps heating up to 300° C.

9. The total amount of light emitted (indicated by the area under the curve) is proportional to the amount of radiation energy absorbed, so that the phenomenon is potentially the basis of a method of radiation dosemetry.

Advantages and Disadvantages of TLD Badges

- ✓ Small in size and chemically inert
- ✓ Almost tissue equivalent
- ✓ Usable over wide range of radiation qualities and dose values
- ✓ Are less affected by fading is compared to film badges
- ✓ Can be reused
- ✓ Are comparatively cheaper
- ✓ Have a linear response to dose received and are relatively energy independent
- ✓ Convenient for monitoring doses to parts of the body using special types of dosimeter

- ✘ Does not tell readings immediately
- ✘ Needs to be replaced every three months
- ✘ No permanent record

Pocket Dosimeters

- Provides the wearer the immediate reading of exposure

Workplace Monitoring

- Also known as area survey monitoring

Operational Quantities

- The organ dose D_T, equivalent dose H and effective dose E are not directly measurable and there are no laboratory standards to obtain traceable calibrations for the radiation monitors using these quantities.
- For the purpose of area, the ICRU has defined a set of measurable operational quantities for protection purposes
- They link the external radiation field to the effective dose equivalent in the ICRU sphere phantom, at depth d, on a radius in a specified direction Ω .

1. ambient dose equivalent
2. directional dose equivalent
3. personal dose equivalent

Ambient Dose Equivalent

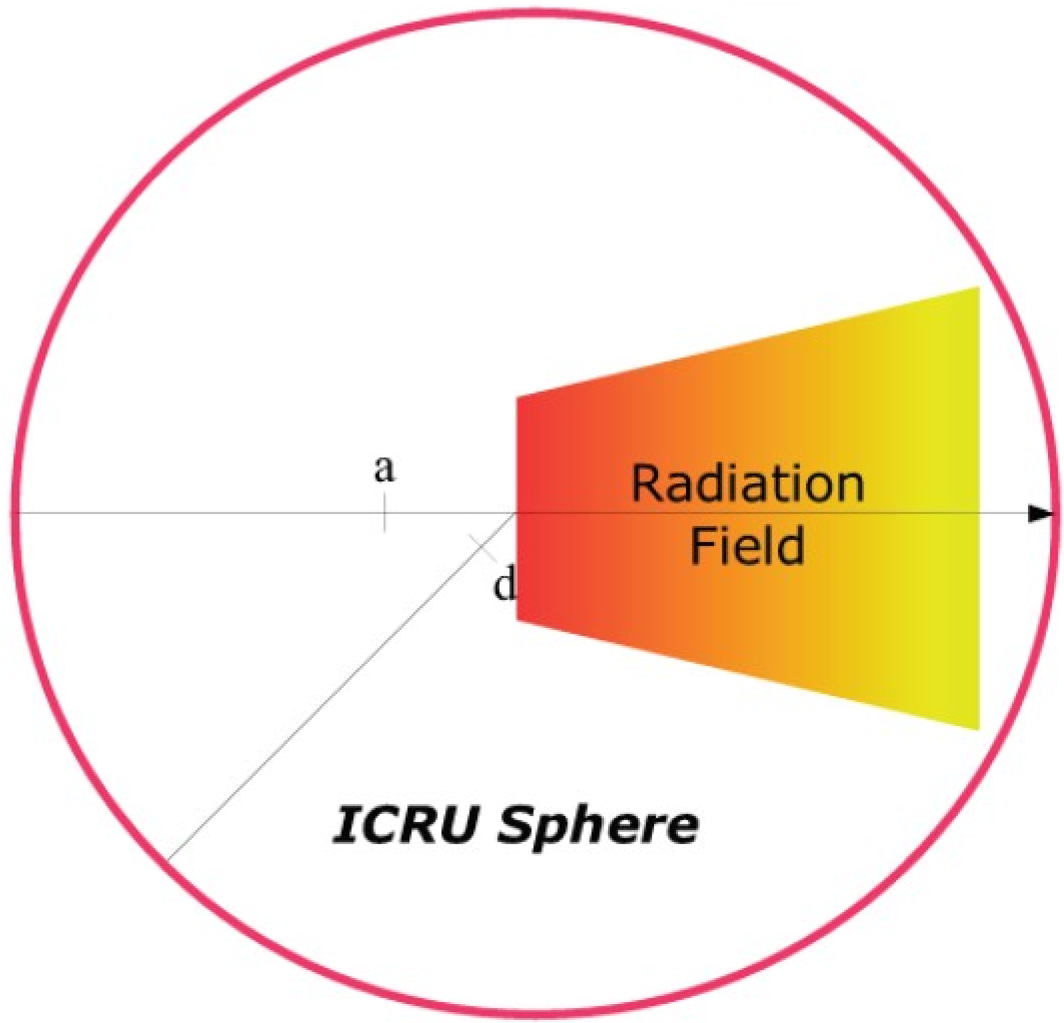
- The ambient dose equivalent at a point in a radiation field $H^*(d)$ is defined as the dose equivalent that would be produced by the corresponding aligned and expanded field in the ICRU sphere at a depth d on the radius opposing the direction of the aligned field.
- The ICRU sphere is a 30 cm diameter tissue equivalent sphere with a composition of
  - 76.2% oxygen
  - 11.1% carbon
  - 10.1% hydrogen
  - 2.6% nitrogen
- A depth d = 10 mm is recommended for strongly penetrating radiation.

Directional Dose Equivalent

- The directional dose equivalent at a point in a radiation field H ¢(d, Ω) is defined as the dose equivalent that would be produced by the corresponding expanded field in the ICRU sphere at depth d on a radius in a specified direction Ω.
- A depth d = 0.07 mm is recommended for weakly penetrating radiation. Angle Ω is the angle between the beam direction and the radius of the ICRU sphere on which the depth d is defined.

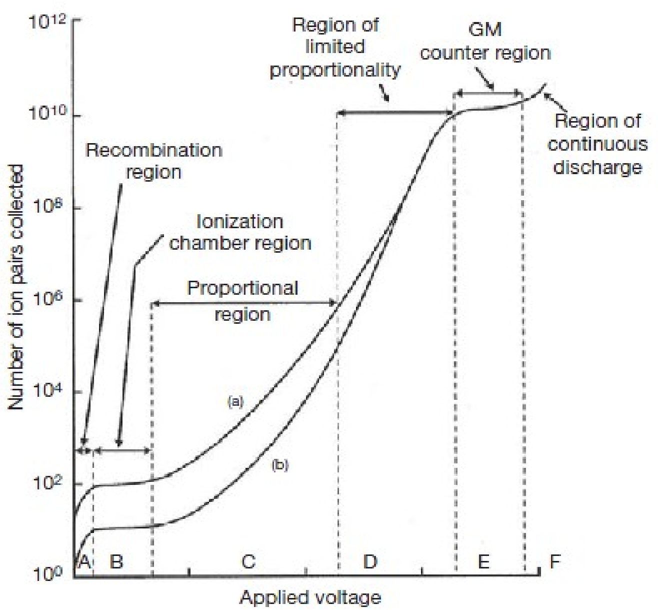
Personal Dose Equivalent

- The personal dose equivalent $H_p(d)$ is defined for both strongly and weakly penetrating radiations as the equivalent dose in soft tissue below a specified point on the body at an appropriate depth d.
- The personal dose equivalent from exposure to penetrating radiation during the year is the radiation quantity to be compared with the annual dose limits (for effective dose) and to demonstrate compliance with the BSS recommendations


a
Radiation
Field
d
ICRU Sphere

Area Survey Meters

- Radiation instruments used as survey monitors are either gas filled detectors or solid state detectors (e.g. scintillator or semiconductor detectors).
- Depending upon the design of the gas filled detector and the voltage applied between the two electrodes, the detector can operate in one of three regions
  - the ionization region B
  - proportional region C
  - Geiger-Müller (GM) region I



Ionization Chambers

- In the ionization region the number of primary ions of either sign collected is proportional to the energy deposited by the charged particle tracks in the detector volume.
- Owing to the linear energy transfer (LET) differences, the particle discrimination function can be used.
- Buildup caps are required to improve detection efficiency when measuring high energy photon radiation, but they should be removed when measuring lower energy photons (10–100 keV) and β particles.

Proportional Counters

- In the proportional region there is an amplification of the primary ion signal due to ionization by collision between ions and gas molecules (charge multiplication).
- This occurs when, between successive collisions, the primary ions gain sufficient energy in the neighbourhood of the thin central electrode to cause further ionization in the detector.
- The amplification is about 103-104-fold.

-They are **more sensitive** than ionization chambers

- Are suitable for measurements in **low intensity radiation fields**.

-The amount of charge collected from each interaction is proportional to the amount of energy deposited in the gas of the counter by the interaction.

Neutron Area Survey Meters

- Neutron area survey meters operate in the proportional region so that the photon background can be easily discriminated against
- Thermal neutron detectors usually have a coating of a boron compound on the inside of the wall, or the counter is filled with BF3 gas.
- A thermal neutron interacts with a ^{10}B nucleus causing an (n,α) reaction, and the a particles can easily be detected by their ionizing interactions.

To detect fast neutrons the same counter is surrounded by a moderator made of hydrogenous material ,the whole assembly is then a fast neutron counter.

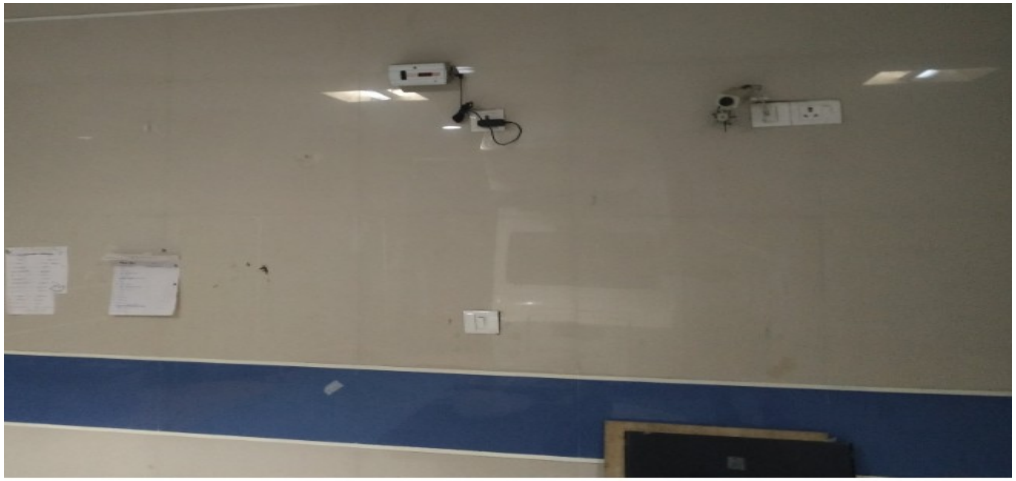
The fast neutrons interacting with the moderator are thermalized and are subsequently detected by a BF3 counter placed inside the moderator.

Filter compensation is applied to reduce thermal range over-response so that the response follows the ICRP radiation weighting factors.

The output is approximately proportional to the dose equivalent in soft tissue over a wide range (10 decades) of neutron energy spectra.

Geiger–Müller counters

- The discharge spreads in the GM region throughout the volume of the detector and the pulse height becomes independent of the primary ionization or the energy of the interacting particles.
- In a GM counter detector the gas multiplication spreads along the entire length of the anode. Gas filled detectors cannot be operated at voltages beyond the GM region because they continuously discharge.



Advantages

- ✓ They are particularly applicable for leak testing and detection of radioactive contamination

Disadvantages

- ✗ Not suitable for use in pulsed radiation fields
- ✗ They are just considered as indicators of radiation as they are not very precise
- ✗ Suffer from very long dead times, ranging from tens to hundreds of milliseconds
- ✗ may become paralysed in a very high radiation field and yield a zero reading

Scintillator detectors

- Detectors based on scintillation (light emission) are known as scintillation detectors and belong to the class of solid state detectors.
- Certain organic and inorganic crystals contain activator atoms, emit scintillations upon absorption of radiation and are referred to as phosphors.
- High atomic number phosphors are mostly used for the measurement of γ rays, while plastic scintillators are mostly used with β particles.

Properties of survey meters

- Sensitivity
- Energy dependence
- Directional dependence
- Dose equivalent range
- Response time
- Overload characteristics
- Log term stability
- Discrimination between different types of radiations
- Uncertainties in area survey measurements

CONCLUSION

- "Radiation is the most serious agent of pollution and the greatest threat to man's survival on earth"- E.F schumacher, in small is beautiful, 1973
- "I am now almost certain that we need more radiation for better health"- john cameron, author, medical physicist
- Radiation protection is a tool for management of measures to protect health against the detriment (for people & environment) generated by the use of ionizing radiation.
- Three basic principles of radiation protection- justification,optimization,dose limitations
- Three main methods of radiation protection are reduce time exposed to the source;increase distance to the source;use appropriate shielding methods
- It's a joint effort of radiation oncologist, RSO, medical physicist,technologist to implement principles of radiation protection
- Constant vigilance and QA are essential in limiting unwanted exposure to radiation

Thanks!