RADIATION PROTECTION

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Varanasi

First publicly taken radiograph of a living object, taken in January 1896, just a few months after the discovery of x-rays.

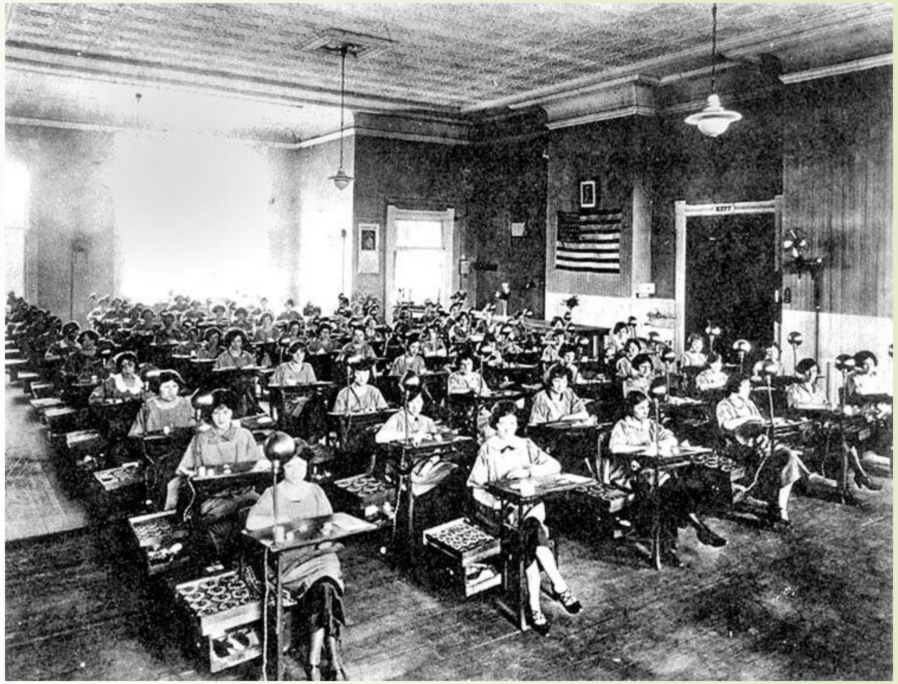
Based on Becquerel’s earlier observation, Pierre Curie is said to have used a radium tube to produce a radiation ulcer on his arm. He charted its appearance and subsequent healing.

Earlier Radiation Worker

Radiation Accident, Goiania, Brazil, Sept 13, 1987. External irradiation of hand

RADIUM GIRLS

These were women working in factories tasked with painting the numerals and other markings on watch dials with a luminous paint comprising glue, water, and radium powder. Little did they know the consequences of the job.



Women painting radium on watch dials for the proudly (and aptly) named Radium Dial company

Six Women Who Await Beckoning Hand of Death

HELEN MUNCH. MARIE ROSSITER. MARGUERITE GLACINSKI. MRS. OLIVE WITT. FRANCES O'CONNELL. MAXINE SMITH

Her fate their fate, radium victims listen to Catherine Donohue plead for compensation in Ottawa court.

Radium Watch Dials And Radium Girls: Who Would Have Thought 'Eating' Radioactive Material Was Deadly?

History of Radiation & Radioactivity

- 1895 - Röntgen discovers x-rays.
- 1896 - Becquerel presents to Paris Academy of Sciences - results of his discovery of radiations emitted by uranium compounds.

  - First biologic effects of x-rays - skin "burns,"epilation, & eye irritation.

  - Treatment of a hairy nevus by Freund.
- 1897 - Rutherford examines radiations from uranium after Becquerel's discovery of radioactivity- finds two types, α- and β-rays.

  - Rival claims 1st x-rays use to treat cancer: Grubbe, Despeignes, Williams, Voigt.

History of Radiation & Radioactivity

- 1898 - Marie & Pierre Curie - discovery of “polonium” in July & “radium” in Dec.
- 1902 - Cancer in x-ray ulcer reported: Frieben.
  - Chromosome theory of heredity.
- 1903 -“Law of Bergonie and Tribondeau”; radiosensitivity related to mitotic activity.
  - First suggestion to treat cancer by implanting radium: Bell.
- 1911 - Leukemia in five radiation workers reported: Jagic.
- 1934 - Joliot and Irene Joliot-Curie produce artificial radioactivity

History of Radiation Protection

- 1915 - British Röntgen Society introduces proposals for radiation protection.
- 1928 - 2nd Int. Cong. of Radiology (ICR) -
  - Unit of x-ray intensity proposed by Second ICR
  - Int. Committee on X-ray and Radium Protection established.
  - 1st Int. Recommend. on Radiation Protection adopted by 2nd ICR.
- 1929 - Advisory Committee on X-ray and Radium Protection established (United States). Dr. Lauriston Taylor- US representative to 1928 Congress brought back agreed radiation protection criteria.
- 1931 - Roentgen adopted as the unit of exposure for x-rays.

History of Radiation Protection

- 1937 - 5th ICR accepts Roentgen as international dosage unit for x-ray & γ- radiation.
- 1946 - Advisory Committee on X-ray and Radium Protection reorganized to National Committee on Radiation Protection (NCRP) - indepen. body to provide advice & recommendations on matters pertaining to radiation protection in US.
- 1950 - International Committee on X-ray and Radium Protection reorganized into:

  (1) Int. Commission on Radiological Protection (ICRP)

  (2) Int. Commission on Radiation Units & Measurements (ICRU)
- 1952 - ICRU introduces concept of absorbed dose

History of Radiation Protection

- 1975 - The Radiation Effects Research Foundation (RERF) created to replace the Atomic Bomb Casualty Commission (ABCC).
- 1981 - Estimation of hereditary effects of radiation in humans: Schull, Otaka, Neel.
- 1990 - The Committee on the Biological Effects of Ionizing Radiation report (BEIR V) on Health Effects of Exposure to Low Levels of Ionizing Radiation.
- 2005 - BEIR VII report on Health Risks from Exposure to Low Levels of Ionizing Radiation.

Backgroud Radiation

Background radiation contributed principally by three sources:

- Terrestrial radiation
- Cosmic radiation
- Radiation from radioactive elements in our bodies

Estimated Total Effective Dose-Equivalent Rate for a Member of the Population in the United States and Canada from Various Sources of Natural Background Radiation

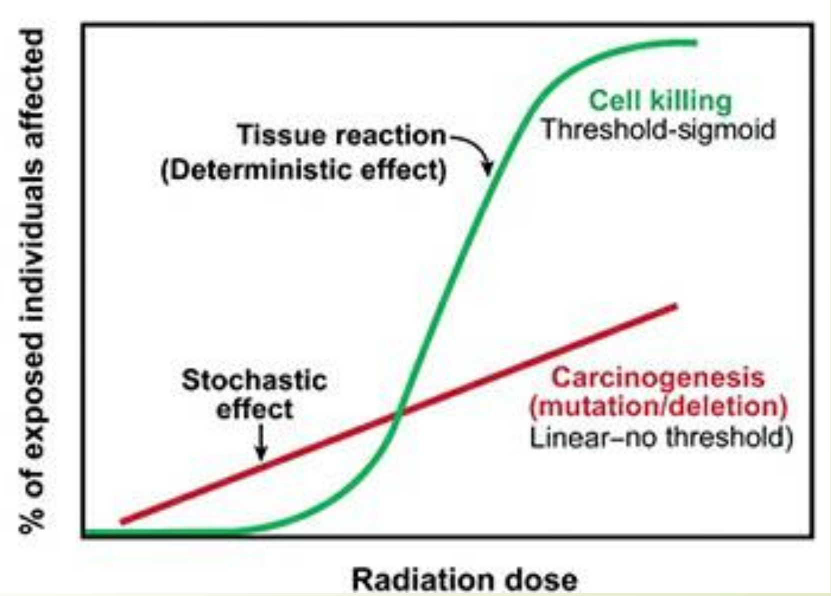
Total Effective Dose-Equivalent Rate (mSv/y)[b]						
Source	**Lung**	**Gonads**	**Bone Surfaces**	**Bone Marrow**	**Other Tissues**	**Total**
W_T	0.12	0.25	0.03	0.12	0.48	1.0
Cosmic	0.03	0.07	0.008	0.03	0.13	0.27
Cosmogenic	0.001	0.002	—	0.004	0.003	0.01
Terrestrial	0.03	0.07	0.008	0.03	0.14	0.28
Inhaled	2.0	—	—	—	—	2.0
In the body	0.04	0.09	0.03	0.06	0.17	0.40
Rounded totals	2.1	0.23	0.05	0.12	0.44	3.0

Background Radiation (Contd)

- Terrestrial radiation varies over earth :
  - Diff. in amount of natural radioactive elements in earth's surface
  - Building materials- may have natural radioactive materials.
  - Many buildings - levels of radon from natural occurring U-238 in soil
- Avg. annual dose equiv. to bronchial epithelium from radon decay- 24 mSv
- Cosmic radiation levels change with elevation - at 30,000 feet, dose equivalent is approximately 5 μSv/h
- Internal irradiation - from ^{40}K in body - emits β & γ-rays- HL 1.3×10^9 year
- Radiation from radiologic procedures- in 1970 in US - 0.2 mSv/y
- Ordinarily, exposures from natural background radiation & medical procedures not included in occupational exposure controls for individuals.

Tissue Reactions and Stochastic Effects

Attributes	Tissue Reactions Deterministic	Stochastic
Severity	↑ with Dose	Independent of Dose
Threshold	Practical Threshold	No Threshold
Probability of Occurrence	↑ with Dose	↑ with Dose



Two very different types of damage:

(1) Due to cells being killed and removed from an organ or tissue.

(2) Due to cells that are not killed by the radiation but are changed or mutated in some way.

Quantities and Units

- Dose (Absorbed Dose)-energy absorbed per unit mass, and its unit is Joules per Kilogram

1 J/kg = 1 Gray = 100 Rad = 100 Ergs/gm

- Radiation Weighting Factor - W_R

Probability of a Stochastic effect, such as the induction of cancer or of heritable events, depends on: (1) Dose

(2)Type and Energy of Radiation

Some radiations are biologically more effective for a given dose than others.

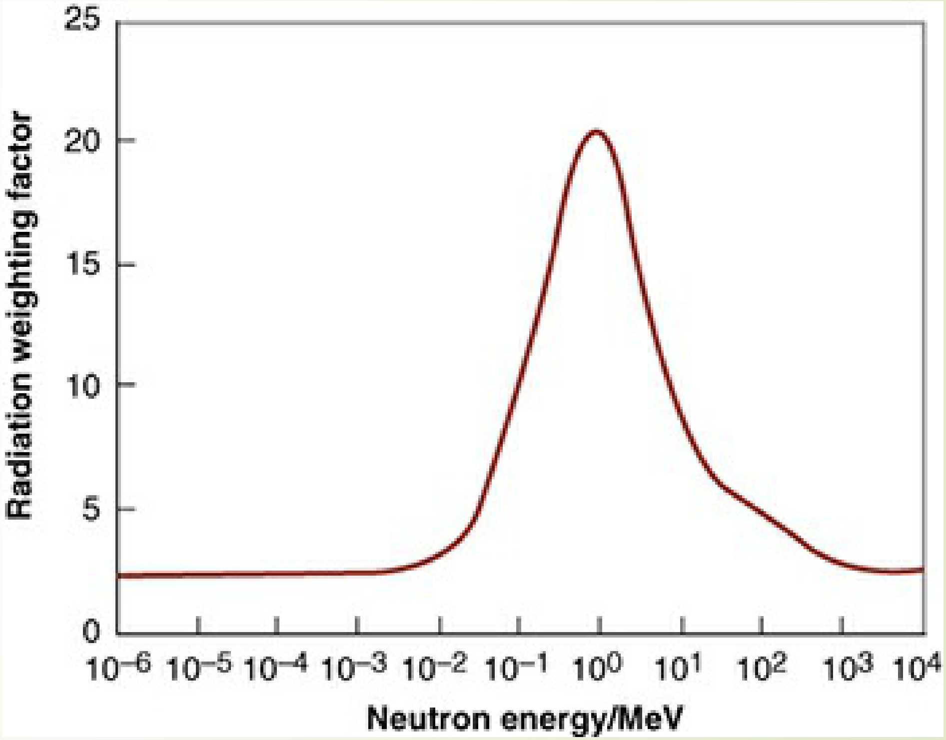
A dimensionless multiplier used to place biologic effects (risks) from exposure to different types of radiation on a common scale

WRs chosen by ICRP as representative of RBE applicable to low doses and LDR and for biologic end points relevant to Stochastic late effects.

Quantities and Units (Contd)

Radiation Weighting Factors

RADIATION TYPE	*RADIATION WEIGHTING FACTORS*
Photons	1
Electrons and muons	1
Protons & charged pions	2
α - Particles, fission fragments, heavy ions	20
Neutrons	Continuous curve as a function of neutron energy



Radiation weighting factor for neutrons as a function of neutron energy

Quantities and Units (Contd)

- **Equivalent dose** = absorbed dose averaged over the tissue or organ × W_R

  Absorbed dose measured in gray (Gy)

  Equivalent dose measured in sievert (Sv) = 1J/kg

  Older unit of dose equivalent is Rem = 10^{-2} Sv

  If radiation field is made up of mixture of radiations, **equivalent dose** is sum of individual doses of various types of radiations, each multiplied by appropriate W_R

  If body uniformly irradiated, probability of occurrence of stochastic effects is assumed to be proportional to equivalent dose, and the risk can be represented by a single value.

  Equivalent doses to various tissues differ substantially.

- **Tissue Weighting Factor W_T** - relative contribution of each tissue or organ to the total detriment resulting from uniform irradiation of the whole body

Quantities and Units (Contd)

ORGAN/TISSUE	NUMBER OF TISSUES	W_T	TOTAL CONTRIBUTION
Lung, stomach, colon, bone marrow, breast, and remainder	6	0.12	0.72
Gonads	1	0.08	0.08
Thyroid, esophagus, bladder, and liver	4	0.04	0.16
Bone surface, skin, brain, and salivary glands	4	0.01	0.04

Remainder tissues (14 in total, 13 in each sex) are adrenals, extrathoracic tissue (ET), gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (m), small intestine (SI), spleen, thymus, uterus/cervix (f)

Quantities and Units (Contd)

- **Effective Dose** = Σ absorbed dose × W_R × W_T

  Sum of all of the weighted equivalent doses in all the tissues or organs irradiated

  In principle, as well as in practice, a nonmeasurable quantity

  Unit is Sievert (Sv)

- **Committed Equivalent Dose** - integral over 50 years of the equivalent dose in a given tissue after intake of a radionuclide.

  Time was chosen to correspond to the working life of a person.

  For radionuclides with effective HL ≤3 months, is essentially equal to annual equivalent dose in year of intake.

  For radionuclides with longer effective half-lives, greater because it reflects the dose that will accrue over future years.

- **Committed Effective Dose**

  Committed Effective Dose= Σ Committed equivalent doses to individual organs or tissues X W_T

Quantities and Units (Contd)

- **Collective Equivalent Dose** - Average equivalent dose to a population X number of persons exposed

  Unit is Person Sievert

- **Collective Effective Dose -** Average effective dose to a population X number of persons exposed

  Unit is Person Sievert

- **Collective Committed Effective Dose** - Integral of Effective Dose over the entire population out to a period of 50 years
  - Quantities used to give rough guide to probability of cancer and heritable effects in a population exposed to radiation.
  - Used to compare approximate impact of different types of radiation accidents in terms of several health effects that might arise in that population.

Summary-Quantities & Units in Radiation Protection

QUANTITY	DEFINITION	UNIT
Absorbed Dose	Energy per unit mass	Gray
	For Individuals	
Equivalent Dose (Radiation Weighted Dose)	Average dose × W_R	Sievert
Effective Dose	**Σ** Equivalent doses to organs and tissues X $\mathbf{W_T}$	Sievert
Committed Equivalent Dose	Equivalent dose integrated over 50 y (relevant to incorporated radionuclides)	Sievert
	For Populations	
Collective Effective Dose	Average effective dose X Number of individuals exposed	Person-sievert
Collective Committed Effective Dose	Collective dose integrated over 50 y (relevant to incorporated radionuclides)	Person-sievert

Principles of Radiation Protection

- NCRP in its 1993 recommendations
- Framework for radiation protection composed of three main elements:

1. **Justification** - need to justify an activity which involves radiation exposure on basis that the expected benefits to society exceed the overall societal costs.
2. **As low as Reasonably achieveable (ALARA)** - need to ensure that the total societal detriment from such justifiable activities or practices is maintained ALARA
3. **Limitation** - need to apply individual dose limits- ensure that procedures of justification and ALARA do not result in individuals or groups of individuals exceeding levels of acceptable risk

- **Objectives of Radiation Protection**:
  1. Prevent clinically significant radiation-induced tissue reactions by adhering to dose limits below apparent or practical dose threshold
  2. Limit risk of Stochastic effects to reasonable level in relation to societal needs, values, and benefits gained
- **Achieving Objectives of Radiation Protection**:
  1. Reducing all exposure to ALARA
  2. Applying dose limits for occupational and general public exposures.
- Assumed that risk of Stochastic Effects strictly proportional to dose without threshold throughout range of dose and dose rates of importance in radiation protection
- Probability of response (risk) assumed to accumulate linearly with dose
- Higher doses - radiation accidents- more complex (nonlinear) dose–risk relationships

Basis for Exposure Limits

- Exposure limits have changed over the years
- 1930s - **Tolerance Dose -** dose to which workers could be exposed continuously without any evident deleterious acute effects such as erythema of the skin
- 1950s - Emphasis shifted to late effects - **Maximum Permissible Dose** - probability of occurrence of injuries was so low that risk would be readily acceptable to average person
- 1980s - NCRP comparing probability of radiation-induced cancer death in radiation workers with annual accidental mortality rates in "safe" industries.

Deleterious Effects of Radiation that Highlight the Need for Protection

END POINT	RISK ESTIMATE
Severe mental retardation	
Exposure of embryo/fetus (8–15 wk)	40%/Sv
Carcinogenesis	
General population (low dose, low dose rate)	5%/Sv
Heritable effects	
General population	0.2%/Sv

Based on International Commission on Radiological Protection (ICRP), Biologic Effects of Ionizing Radiation (BEIR), and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

Limits for Occupational Exposure

- **Stochastic Effects**

1. No occupational exposure be permitted till age of 18 years.
2. Effective dose in any year not to exceed 50 mSv (5 rem).
3. Individual worker's lifetime effective dose ≯ age in years × 10 mSv

These limits apply to sum of effective dose from external radiation and committed effective dose from internal exposures.

- **Tissue Reactions (Former Deterministic Effects)**

1. 50 mSv per year for the lens of the eye
2. 500 mSv per year for localized areas of skin and the hands and feet

Additional limits for tissue reactions required because of low sensitivity of particular tissues involved to radiation-induced cancer.

In case of lens of eye, if radiation other than x-rays involved- appropriate RBE should be used.

Summary of Recommended Dose Limits

	NCRP	ICRP
Occupational exposure		
Stochastic effects: effective dose limits		
Cumulative	10 mSv × age	20 mSv/y avg. over 5 y
Annual	50 mSv/y	50 mSv/y
Tissue reactions (deterministic effects): dose equivalent limits for tissues and organs (annual):		
Lens of eye	50 mSv/y	20 mSv/y avg. over 5 y ≤50 mSv in any year
Skin, hands, and feet	500 mSv/y	500 mSv/y
Embryo/fetus exposure		
Eff. dose limit after pregnancy declared	0.5 mSv/mo	Tot.1 mSv to emb/fetus

Summary of Recommended Dose Limits *(Contd)*

	NCRP	ICRP
Public exposure (annual)		
Effective dose limit, continuous or frequent exposure	1 mSv/y	No distinction bet. Freq. & infrequent - 1 mSv/y
Effective dose limit, infrequent exposure	5 mSv/y	1 mSv/y
Dose equivalent limits; lens of the eye	15 mSv/y	15 mSv/y
Skin and extremities	50 mSv/y	50 mSv/y
Education and training exposure (annual)		
Effective dose limit	1 mSv/y	No statement
Dose equivalent limit for lens of eye	15 mSv/y	No statement
Skin and extremities	50 mSv/y	No statement
Negligible individual dose (annual):	0.01 mSv/y	No statement

AERB Recommendation

The normal exposure of individuals resulting from all relevant practices should be subject to dose limits to ensure that no individuals is exposed to a risk that is judged to be unacceptable

Dose Limitations		
Part of the Body	**Occupational Exposure**	**Public Exposure**
Whole Body (Effective Dose)	20mSv/year averaged over 5 consecutive yrs. 30mSv in given year	1mSv/year
Lens of Eye (Equivalent Dose)	150mSv/yr	15 mSv/yr
Skin (Equivalent Dose)	500 mSv/yr	50 mSv/yr
Extremities (Hands and Feet) Equivalent Dose	500 mSv/year	
For pregnant radiation workers, after declaration of pregnancy	1mSv on the Embryo / Foetus should not exceed	

Radiation Detriment

- ICRP introduced concept - to quantify harmful effects of radiation exposure to different parts of body, taking into account severity of the disease in terms of lethality, loss of quality of life, and years of life lost
- Detriment includes:
  - A small component for heritable effects,
  - A large component for lethal cancers,
  - An allowance for nonlethal cancers - have an impact on quality of life
- ICRP suggested detriment-adjusted risk coefficients for stochastic effects after exposure of the whole population to radiation at LDR:
  - 5.5% per Sv for cancer (lethal and nonlethal combined)
  - 0.2% per Sv for heritable effects

Structural Shielding Design

- Radiation protection guidelines - design of structural shielding for radiation installations - discussed in the NCRP Reports 49, 51, 102, and 151
- Technical information and recommendations for planning new facilities and remodelling existing facilities
- Protective barriers - ensure that dose equivalent received does not exceed applicable maximum permissible value.
- Designated as **Controlled** or **Noncontrolled** - depending on whether or not exposure of persons in the area is under supervision of a radiation protection supervisor
- Maximum Permissible Dose equivalent (P) is assumed to be:

  0.1 mSv/wk (5 mSv/y) for **Controlled Areas**

  0.02 mSv/wk (1 mSv/y) for **Noncontrolled Areas**

Structural Shielding Design

- Protection required against three types of radiation:
  - Primary radiation
  - Scattered radiation
  - Leakage radiation through source housing
- Primary barrier - sufficient to attenuate useful beam to required degree
- Secondary barrier - against stray radiation (leakage and scatter)

Factors for Calculation of Barrier Thicknesses

1. **Workload (W)**
   - X-ray equip. <500kVp: mA minutes/week= max. mA **X** appx. min / week of ‘beam on’ time
   - mV machines: wkly dose at 1 m from source = Nos. of patients per week X dose/patient at 1 m
   - ***W*** is expressed in dose per week at 1 m
2. **Use factor (U)**
   - Fraction of operating time when radiation directed toward barrier
   - Vary depending on the techniques used in a given facility
3. **Occupancy factor (T)**
   - Fraction of operating time when area of interest is occupied by the individual
4. **Distance (d)**
   - Distance in meters from radiation source to area to be protected

Typical Use Factor for Primary Protective Barriers

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

From National Council on Radiation Protection and Measurements. Report No-151; 2005

Typical Occupancy Factors

Location	Occupancy Factor (T)
Full occupancy areas (areas occupied full-time by an individual), for example, work offices, treatment planning areas, nurse 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

From National Council on Radiation Protection and Measurements. Report No-151; 2005

Primary Radiation Barrier

Supposing, MPD equivalent for area to be protected

P= 0.1 mSv/wk for Controlled

0.02 mSv/wk for Noncontrolled area.

As Dose, P= 0.01 cGy/wk for Controlled

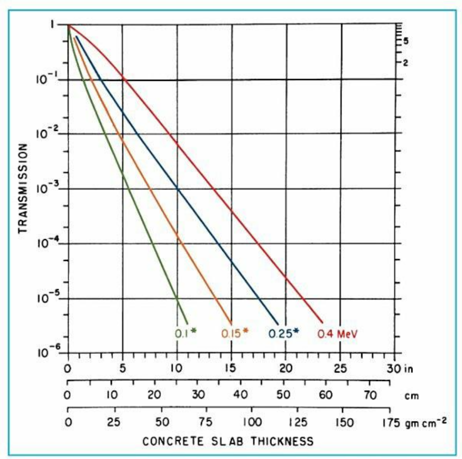
0.002 cGy/wk for Noncontrolled area

If **B** is Transmission Factor for barrier to reduce the Primary Beam dose to **P**, then

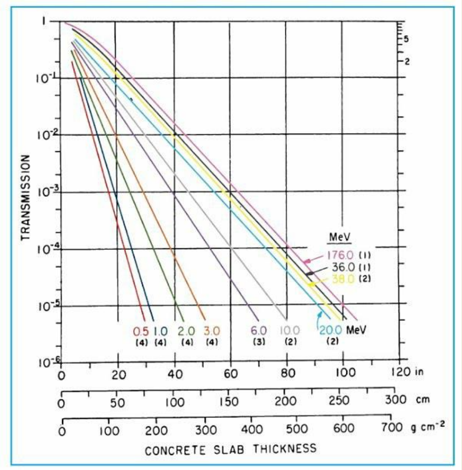
$$P = \frac{WUT}{d^2} \cdot B$$

Hence, required Transmission Factor **B** is

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



Transmission through concrete (density 2.35 g/cm3) of x-rays produced by 0.1- to 0.4-MeV electrons, under broad-beam conditions



Transmission of thick-target x-rays through ordinary concrete (density 2.35 g/cm3), under broad-beam conditions.

Primary Radiation Barrier

- Alternative method to determining barrier thickness - calculate the number (n) of tenth-value layers (TVL) required from the transmission factor B:

$$n = -\log(B)$$

Barrier thickness then determined by looking up TVL of given energy beam in the shielding material

- In NCRP 151, beam hardening taken into consideration by computing the barrier thickness as:

TVL1 & TVLe - First and Equilibrium TVLs of given energy beam in shielding material:

$$t_{\text{barrier}} = \text{TVL}_1 + (n-1)\,\text{TVL}_e$$

- Choice of barrier material - concrete, lead, or steel, depends on structural & spatial considerations
- Lead or steel can be used where space at a premium

Secondary Barrier for Scattered Radiation

- Amount of scattered radiation depends on:
  - Beam intensity incident on the scatterer
  - Quality of radiation
  - Area of the beam at the scatterer
  - Scattering angle
- Ratio of scattered dose to the incident dose may be denoted by α
- MV beams - α usually assumed to be 0.1% for 90º scatter
- Scattered radiation- in general, lower energy compared with incident energy
- Softening of beam - result of Compton Scatter depends on the incident energy and direction of scatter

Secondary Barrier for Scattered Radiation

- Orthovoltage radiation - quality of scattered radiation usually assumed to be same as that of incident beam
- MV beams – max. energy of 90^o scattered photons is 500 keV
  - Transmission of this scattered radiation through a barrier is estimated to be approx. same as that for a 500-kVp useful beam.
  - At smaller scattering angles - scattered beam has greater penetrating power
  - Greater fraction of the incident beam is scattered at smaller angles

Secondary Barrier for Scattered Radiation

- Suppose a transmission factor of B_s , required to reduce scattered dose to an acceptable level P in the area of interest

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

Where α = Fractional scatter at 1 m from scatterer; Beam area = 400 cm^2 incident at the scatterer; d= distance from source to scatterer; d'= distance from scatterer to area of interest; F= area of beam incident at scatterer

Use factor for secondary barrier is considered unity

- Hence, barrier transmission B_s is given by

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

- Required thickness of concrete or lead can be determined for appropriate transmission curves given by NCRP

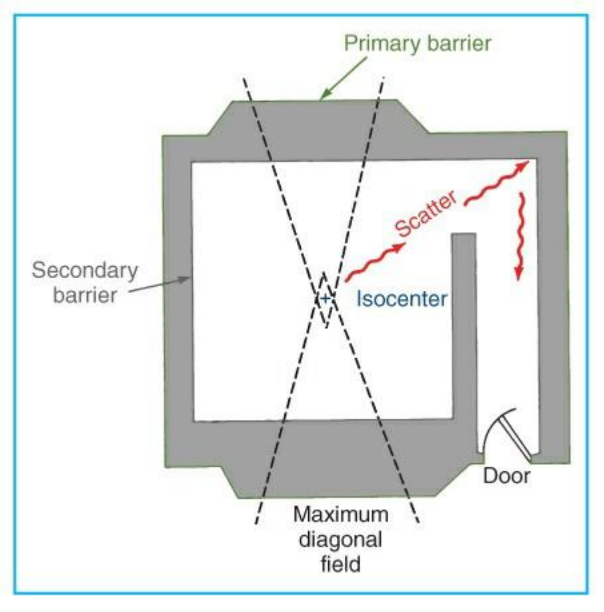
Secondary Barrier for Leakage Radiation

- 5 to 50 kVp : The leakage exposure rate ≯ 0.1 R in any 1 hour at any point 5 cm from the source assembly
- >50 kVp and <500 kVp : leakage exposure rate at a distance of 1 m from the source ≯ 1 R in any 1 hour - shall limit exposure rate to 30 R/h at 5 cm from surface of assembly
- >500 kVp : Absorbed dose rate due to leakage (excluding neutrons) at point outside max. field size, but within circular plane of radius 2 m perpendicular to and centered on central axis at normal treatment distance, ≯0.2% of the useful beam dose rate at treatment distance.
- Cobalt teletherapy. Leakage dose rate with beam in “off” position ≯ 2 mrad/h (20 μGy/h) on average and 10 mrad/h (100 μGy/h) max. in any direction, at 1 m from source.

For sources with useful beam dose rate <1,000 cGy/h at 1 m, leakage from source housing ≯ 1 cGy/h at 1 m from the source.

Door Shielding

- If maze entrance way not provided – door to provide shielding equivalent to wall surrounding door - extremely heavy, motorized and manual operation in emergency
- Maze arrangement - drastically reduces shielding requirements for door
- Proper maze design - door exposed to multiply scattered radiation of significantly reduced intensity and energy



- Compton scatter at ≥90º will reduce energy ≤500 keV - intensity will also be greatly reduced at each large-angle scatter
- Door shielding can calculated by tracing path of scattered radiation from patient to door and repeatedly applying Equation
- Required shielding turns out to be <6 mm of lead

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

Protection Against Neutrons

- High-energy x-ray beams (e.g., >10 MV) are contaminated with neutrons
- Produced by high-energy photons & electrons incident on various materials of target, flattening filter, collimators, & shielding components
- Neutron production during electron beam therapy - small compared with x-ray mode.
- Neutron contamination > rapidly as energy of beam > from 10 to 20 MV and then remains approximately constant above this.
- 16 - 25-MV x-ray - neutron dose equivalent along central axis approx. 0.5% of x-ray dose and falls off to about 0.1% outside field.
- Neutron energy considerably degraded after multiple scattering from walls, roof, and floor - proportion of fast neutron (>0.1 MeV) reaching inside of maze is small
- Concrete barriers for x-ray shielding sufficient for protection against neutrons.
- Door must be protected against neutrons that diffuse into maze and reach door.
- Longer maze (>5 m) is desirable in reducing the neutron fluence at door
- Few inches of hydrogenous material like polyethylene can be added to door to thermalize neutrons

Special Procedures

- Modifications to workload and use factors required if significant component of linear accelerator use is for special treatment
- If treatment room planned for significant number of total body irradiation (TBI)- use factor for treatment wall should be increased
- Most significant impact on shielding design from nonconventional deliveries likely to be from IMRT procedures
- Other special procedures (e.g., stereotactic radiosurgery) or even QA measurements be considered if they will comprise a significant portion of planned workload

Radiation from Brachytherapy Sources

A. **STORAGE**

- Lead-lined safes with lead-filled drawers commercially available
- Consideration be given to:
  - Adequacy of shielding
  - Distribution of sources
  - Time required to remove sources from, and return sources to safe
- Storage area for radium, for encapsulated powdered sources or sources containing microspheres - ventilated by direct filtered exhaust to outdoors - possibility of radon leaks
- This precaution so that if source ruptures, radionuclide not drawn into general ventilation system of building
- Storage rooms are usually with a sink for cleaning source applicators.
- Sink provided with filter or trap to prevent loss of source

Radiation from Brachytherapy Sources

B. SOURCE PREPARATION

- Source preparation bench provided close to safe
- Preparation and dismantling of source applicators carried out behind suitable barrier to shield operator adequately.
- Many facilities with a protective "L-block," usually of lead
- Lead glass viewing window provides some protection by shielding as well as a suitable distance between face of operator and sources
- Suitably long forceps to provide as much distance as practical between sources and operator
- Besides protective shielding operator must be aware of effectiveness of time and distance in radiation protection
- After-loading techniques
- Use of low energy sources in place of radium or radon

Radiation from Brachytherapy Sources

C. SOURCE TRANSPORTATION

- Sources transported in lead containers or leaded carts
- Thickness of lead required depend on type of source and amount of radioactive material to be transported

D. LEAK TESTING

- Various methods for sealed source are available
- Radium source can be checked for radon leaks by placing it in a small test tube with some activated carbon or a ball of cotton.
- After 24 hours, carbon or the cotton ball can be counted in a scintillation well counter
- Periodic leak testing of radium is usually specified by state regulations.
- Source is considered to be leaking if presence of 0.005 μCi or more of removable contamination is measured

Radiation Protection Surveys

After installation of radiation equipment includes

- Checking equipment specifications and interlocks
- Evaluating potential radiation exposure to individuals in surrounding

A. **RADIATION MONITORING INSTRUMENTS**

- Choice of particular radiation detector or dosimeter depends on type of measurement required
- Radiation protection surveys- low levels of radiation are measured
- Instrument to be sensitive enough to measure low levels
- X-ray measurements- Ionization chambers, Geiger counters, TLDs and Photographic film
- An ionization chamber for low-level x-ray measurements (of order of mR/hr has large volume (~600 mL) to obtain high sensitivity

Radiation Protection Surveys

B. EQUIPMENT SURVEYS

- Some of design specifications related to patient and personnel safety-determined by visual inspection
- Operational and beam limiting interlocks checked as part of field testing
- If unit equipped with beam interceptor to reduce structural shielding requirements, radiation transmitted through interceptor ≯ 0.1% of useful beam. - Should also reduce by same factor radiation scattered by patient through an angle of up to 30 degrees from central ray

Radiation Protection Surveys

C. AREA SURVEY

- Areas outside treatment room accessible to individual be designed as controlled or noncontrolled-depending on whether exposure of persons in area is monitored or not
- Exposure levels in these areas be measured with beam oriented in various possible directions.
- Through primary barrier - measured with beam of maximum size directly incident at barrier.
- Measurements outside secondary barriers made with phantom at treatment position.
- Conditions such as TBI may present special treatment conditions- considered in area survey

Radiation Protection Surveys

C. AREA SURVEY *(Cont)*

- Results of survey be evaluated accounting for actual operating conditions - workload, use factor, occupancy factor, attenuation and scattering of useful beam by patient
- Survey data based on instantaneous dose rate - supplemented with cumulative radiation measurements and personnel monitoring over appropriate time period
- If supplementary shielding added to protective barriers – survey be made to evaluate adequacy of shielding after the modification.

Personnel Monitoring

- Used in Controlled Areas for occupationally exposed individuals
- Cumulative radiation monitoring- mostly performed with film badges, TLD badges
- Mostly used to monitor whole-body exposure - on the chest or abdomen.
- Special badges - exposure to specific parts of the body (e.g. hands) if higher exposures are expected during particular procedures
- Pocket dosimeters - Radiation monitoring during a particular procedure may be done with these – useful where exposure needs to be monitored more frequently than possible with the regular film badge service


Thank You