Radiation Protection Review

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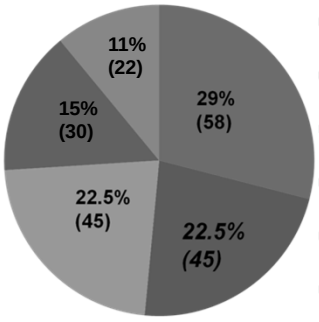


ARRT Specifications

- Radiation Protection (45)
  - Biological Aspects of Radiation (10)
  - Minimizing Patient Exposure (15)
  - Personnel Protection (11)
  - Radiation Exposure and Monitoring (9)

Definitions

- Radiation – transfer of energy that results from either a naturally occurring change within an atom or by the interaction of a particle with an atom
- Ionizing Radiation – radiation that produces positively and negatively charged particles (ions) when passing through matter
- Attenuation – any process that decreases the intensity of the primary beam
- Absorption – transference of energy from an x-ray beam to the atoms or molecules of matter through which it passes

Radiation Exposure & Monitoring

- Units of Measurement
- Dosimeters

Units of Measurement

Measurement (Quantity)	Traditional Unit	SI Unit	Medium	Effect
Exposure	Roentgen	Coulomb/kg (C/kg)	Air	Ionization of Air
Absorbed Dose	Rad	Gray (Gy)	Any Object	Amount of Energy Per Unit Mass
Absorbed Dose Equivalent	Rem	Sievert (Sv)	Body Tissue	Biologic Effects

Radioactivity

- Curie (Ci) or Bequerel (Bq)
- Indicates quantity of radioactive material representing the number of decay events per second

Radiation Quality (Weighting) Factors

- X-ray, Beta, Gamma 1
- Slow Neutrons 5
- Fast Neutrons 20
- Alpha Particles 20

DE = AD x QF

- DE = Dose Equivalent
- AD = Absorbed Dose
- QF = Quality Factor
- Ex: What is the DE for a patient receiving 20 rad x-ray, 3 rad slow neutrons, 2 rad alpha particles?

20 x 1 = 20 rad
3 x 5 = 15 rad
2 x 20 = 40 rad
} 75 rem

Effective Dose (EfD)

- Incorporates both the effects of specific types of radiation and the radiosensitivity of the tissue (tissue weighting factors)
  - Tissue weighting factor – relative risk associated with irradiation of different body tissues and organs
- EfD = Dose x W_r x W_t

Equivalent Dose vs. Effective Dose

- Equivalent Dose – uses radiation weighting factors (W_r)to adjust the quantity of absorbed dose to equate various energies of ionizing radiation
- Effective Dose – uses tissue weighting factors (W_t) of equivalent dose to reflect the harm to a person as a whole depending on tissues and organs irradiated

Sources of Exposure*

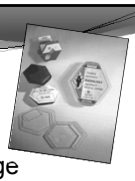
•Environmental		
•Cosmic / Terrestrial	198 mrem/yr	1.98 mSv
•Radon	97 mrem/yr	.97 mSv
	295 mrem/yr	2.95 mSv
•Manmade / Artificial		
•Medical / Dental	40 mrem/yr	0.40 mSv
•Nuclear Medicine	14 mrem/yr	0.14 mSv
•Consumer Products	11 mrem/yr	0.11 mSv
	65 mrem/yr	0.65 mSv
Total Annual Exposure	360 mrem	3.60 mSv

*Exposures in US from NCRP

Dosimeters

- Measure radiation exposure
- Should be worn at the collar
  - Outside the apron for fluoroscopy
  - 2nd device for pregnant or childbearing age women; worn under apron at waist

Dosimeters



- Pocket Dosimeters
  - Immediate readout
- TLD
  - Worn up to 3 months
  - Sensitive to 5 mR
- Film Badge
  - Inexpensive
  - Sensitive to 10 mR
- OSL
  - Extended wear
  - Sensitive to 1mR

Cumulative Absorbed Dose Equivalent

Age in years x 1 rem (10mSv)

Personnel Protection

Sources of Exposure

- Primary
- Leakage
- Scatter

Personnel Protection

Sources of Exposure

- Patient
  - Greatest source of scatter radiation
  - At a 90° angle to the x-ray beam at a distance of 1 meter the scattered x-ray intensity is approximately 1/1000 the intensity of the primary beam

Personnel Protection

Methods of Protection

- Cardinal Principles
  - Time
  - Distance
  - Shielding

Personnel Protection
Barriers

- Primary
  - 1/16" Pb eq; 7 ft. high
- Secondary
  - 1/32" Pb eq; extends to ceiling; overlap 1 by ½"
  - Radiation scattering should occur twice before reaching these barriers
- Barrier Determination
  - Controlled Area – occupied by radiation workers who are trained in radiation safety and wear monitors
    - Exposure must not exceed 100 mR/wk
  - Uncontrolled Area – occupied by general public
    - Exposure must not exceed 10 mR/wk

Personnel Protection
Radiographic Suite Design

- Use Factor
  - Percentage of time primary beam is directed toward a particular wall
  - One factor in determining barrier thickness
- Workload
  - Determined by the number of x-ray exposures made per week
- Occupancy Factor
  - Reflection of who occupies particular areas
  - Factor in determining barrier thickness

Personnel Protection
Protective Devices

- Lead Shielding
  - Aprons - 0.5 mm Pb eq
  - Gloves - 0.25 mm Pb eq
  - Thyroid Shields - 0.5 mm Pb eq
  - Glasses - 0.35mm Pb eq
  - Pb Curtain - 0.25 mm Pb eq
  - Bucky Slot Cover - 0.25 mm Pb eq
  - Pb window – 1.5 mm Pb eq

Personnel Protection

- Tube housing
  - Must keep off focus/leakage radiation to no more than 100 mR/hr at 1m (3.3 ft) when tube operated at maximum potential
- Mobile Units
  - 6 foot (180 cm) exposure cord
  - Pb apron
  - RT stands at 90° angle to scattering object

Personnel Protection
Special Considerations

- Fluoroscopy
  - Source-to-Tabletop Distance
    - Fixed – 15" (38cm)
    - Mobile – 12" (30 cm)
  - Exposure Switch – Dead-man type
  - Audible Timer – 5 minutes
  - Exposure Rate – must not exceed 10R/min

Minimizing Patient Exposure
ALARA

- Keep radiation exposure
  As Low As Reasonably Achievable
- Responsibility of employers and technologists

Minimizing Patient Exposure
Exposure Factors

- Highest practical kVp, lowest mAs
- Use AEC when available
- Highest film/screen combinations
- Appropriate SID
- X-ray generator (1Φ, 3Φ, HF)

Minimizing Patient Exposure
Shielding

- When to use:
  - Reproductive organs within 5 cm of beam
  - Doesn't interfere with exam
  - Patient within reasonable reproductive age

Minimizing Patient Exposure
Shielding

- Types:
  - Contact
    - Flat
    - Shaped
  - Shadow

Minimizing Patient Exposure
Beam Restriction

- Decreases patient exposure
- Improves image quality
- Types
  - Collimators
  - Aperture Diaphragms
  - Extension Cylinders/Cones

Minimizing Patient Exposure
Filtration

- Removal of low energy photons from the primary beam; hardening of the beam
- Increases average energy of the beam
- Reduces exposure to patient's skin and superficial organs

Minimizing Patient Exposure
Positioning

- Choose AP or PA to reduce exposure
  - Scoliosis
  - Oblique c-spine
  - Skull

Minimizing Patient Exposure
Communication

- Give clear, concise instructions
- Be truthful about pain/discomfort

Minimizing Patient Exposure
Pediatrics

- Children more vulnerable effects of radiation
- Smaller doses of ionizing radiation are sufficient
- Children have limited ability to understand procedure
  - Explain with age appropriate terminology, use entertaining devices (cartoons, posters, puppets, etc.)
  - Use restraining devices, collimation, shielding

Dose-Response Relationships

- Linear
  - Proportional relationship between dose & response
- Nonlinear
  - no fixed proportional response between dose & response
- Threshold
  - A level is reached below which no effect is observed
- Nonthreshold
  - Even the smallest dose could cause an effect

Dose-Response Relationships

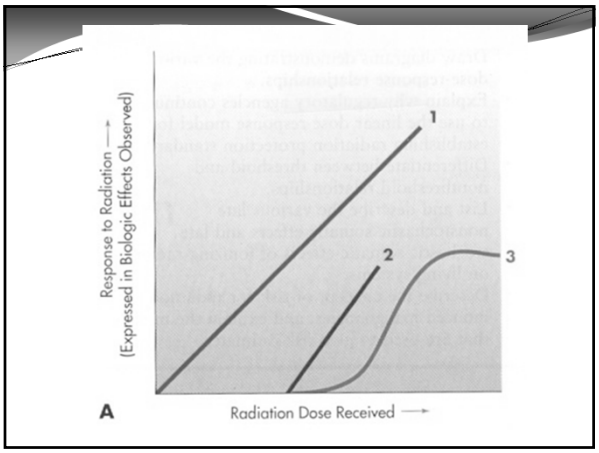
- Linear nonthreshold
  - Model to set standards & dose limits
  - No threshold
  - Response directly proportional to dose received
  - No dose rate effect (no reduced effect at small dose rates)
  - Curve exhibits a stochastic (statistical) response

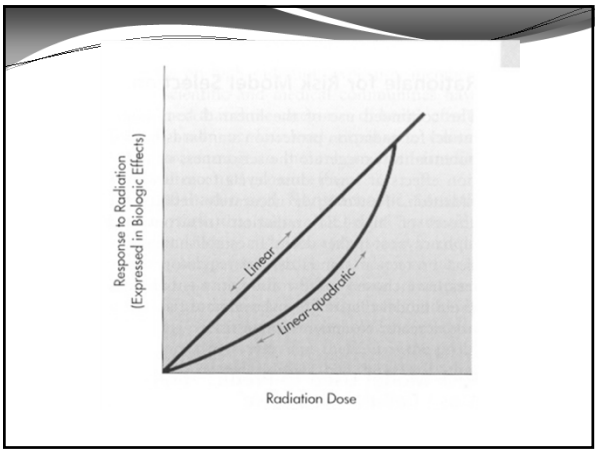
Dose-Response Relationships

- Linear quadratic
  - Curve is linear or proportional at low dose levels and becomes curvilinear at high doses
  - May underestimate low dose effects
  - No threshold
  - Quadratic response at high dose levels
  - Curve exhibits the stochastic (statistical) effect

Dose-Response Relationships

- Sigmoid Threshold
  - Applies primarily to the high dose effects seen in radiation therapy
  - Usually does have threshold





Radiosensitivity

- Law of Bergonie and Tribondeau
  - Radiosensitivity is directly proportional to cellular reproductive activity and inversely proportional to the degree of differentiation
  - Greater damage occurs to cells which are the least mature, least specialized, most rapidly dividing, and have longest mitotic phases

Radiosensitivity

- Cells listed from *MOST* to *LEAST* sensitive
  - Lymphocytes
  - Spermatogonia
  - Erythroblasts
  - Platelets
  - Intestinal crypt cells
  - Epithelial cells
  - Muscle cells
  - Nerve cells

Radiosensitivity

- Linear Energy Transfer (LET)
  - Average energy deposited per unit length
    - Low LET
      - Gamma rays
      - X-rays
    - High LET
      - Alpha particles
      - Ions of heavy nuclei
      - Low energy neutrons

Radiosensitivity

- RBE – Relative Biological Effectiveness
  - Compares the biologic effects from equal doses of different types of radiation
  - LET and RBE have a directly proportional relationship
  - High LET radiations have high RBE

Radiosensitivity

- OER – Oxygen Enhancement Ratio
  - Tissue is more sensitive to radiation when irradiated in the oxygenated state than when irradiated under anoxic or hypoxic conditions

Target Theory

- DNA is the master molecule and is necessary for survival of the cell
- If master molecule is inactivated by exposure to radiation the cell will die

- Molecular Effects of Irradiation
  - Indirect
    - Radiolysis of water
  - Direct
    - Target Theory

Types of DNA Damage

- Single-strand break (point mutation)
  - Occurs with low LET
  - Enzymes may be able to repair damage
- Double-strand break
  - More common with high LET
- Main-chain scission
  - Divides a long single molecule into many molecules

Biological Aspects of Radiation

Somatic Effects

- Stochastic (Late)
- Nonstochastic

Stochastic (Late)

- Nonthreshold, random, probablistic
- All or nothing response
- Severity of effect proportional to dose
- Linear or quadratic dose-response
- Ex: cancer and genetic alterations

Nonstochastic
(Deterministic/Certainty)

- Directly related to dose received
- Threshold dose
- Usually occur only after large doses of radiation
- Effects can be manifested as an early or late effect

Early (Acute) Nonstochastic Effects

- Appear within minutes, hours, days or weeks of exposure; short term
  - Nausea
  - Fatigue
  - Epilation
  - Fever
  - Blood disorders
  - Desquamation

Late Nonstochastic Effects

- May takes months or years to manifest or possibly future generations
  - Cataract formation
  - Fibrosis
  - Organ atrophy
  - Loss of parenchymal cells
  - Reduced fertility
  - Sterility

Late Stochastic Somatic Effects

- Cancer
- Embryologic effects (birth defects)

Genetic Effects

- Biologic effects of ionizing radiation on future generations

Acute Radiation Syndrome

- Prodromal
  - Occurs within hours of whole body absorbed dose of 1 Gy (100 rad)
  - Nausea, vomiting, diarrhea, fatigue, and leukopenia
- Latent - No visible symptoms
- Manifest Illness
  - Visible symptoms classified as specific syndrome
- Recovery or Death

Hematopoietic / Hematologic

- Bone marrow syndrome
- Whole body dose from 1-10 Gy (100-1000 rad)
- Decrease in WBC and platelets

Gastrointestinal

- Severe nausea, vomiting, diarrhea, fever, fatigue, loss of appetite, lethargy, anemia, leukopenia, hemorrhage, electrolyte imbalance, emaciation
- 6-10Gy (600-1000 rad)

CNS

- Same symptoms as other syndromes but may not have time to manifest
- 50 Gy (5000 rad)

LD 50/30

- Whole body dose that is lethal to 50% of those exposed within 30 days
- 3-4 Gy (300-400 rad)

Doubling Dose

- Dose required per generation to double the spontaneous mutation rate
- Spontaneous mutation rate is approximately 6%

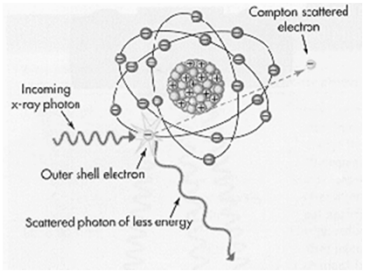
Genetically Significant Dose

- Used to evaluate genetic influences of low doses to the whole population
- Average annual gonadal equivalent dose to members of the population who are of childbearing age
- Estimated at 0.2 mSv (20 mrem)

Photon Interactions in Matter

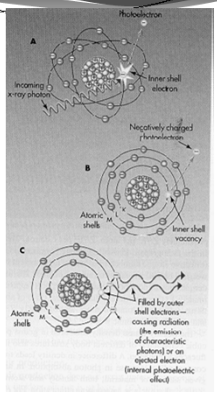
- Coherent (classical)
  - Change in direction of x-ray photon; no energy loss
- Compton
- Photoelectric

Compton - Scatter production



Photoelectric

X-ray photon and inner shell e-; absorption in patient



NCRP #102

- Aprons – 0.5 mm Pb eq
- Gloves – 0.25 mm Pb eq
- Glasses – 0.35 mm Pb eq
- Mobile equipment
  - Exposure cord – 6ft
  - Operators should wear Pb aprons
  - Operators should stand at right angle to scattering object (patient)

NCRP #102

- Tube Housing – 100 mR/hr at 1m from source
- SID - +/- 2% SID
- Collimator - +/- 2% SID
- Filtration – 2.5 mm Al (>70 kVp)
- Fluoroscopy Source-to-Tabletop Distance
  - Stationary – 15”
  - Mobile – 12”

NCRP #102

- Fluoroscopy
  - Primary Protective Barrier – interlocked with tube
  - Exposure Switch – dead-man type
  - Protective Drape – 0.25 mm Pb eq
  - Cumulative Timer – audible, 5 min
  - Exposure Rate – must not exceed 10R/mn

NCRP #116

TABLE 9-3 Summary of the National Council on Radiation Protection and Measurements (NCRP) Recommendations[a] (NCRP Report No. 116)

A. Occupational exposures[b]		
1. Effective dose limits		
a. Annual	50 mSv	(5 rem)
b. Cumulative	10 mSv × age	1 rem × age
2. Equivalent dose annual limits for tissues and organs		
a. Lens of eye	150 mSv	(15 rem)
b. Localized areas of the skin, hands, and feet	500 mSv	(50 rem)
B. Guidance for emergency occupational exposure[c] (see Section 14, NCRP No. 116)		
C. Public exposures (annual)		
1. Effective dose limit, continuous or frequent exposure[d]	1 mSv	(0.1 rem)
2. Effective dose limit, infrequent exposure[d]	5 mSv	(0.5 rem)
3. Equivalent dose limits for tissues and organs[d]		
a. Lens of eye	15 mSv	(1.5 rem)
b. Localized areas of the 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 and its decay products[e]	>26 J/(sm^{-3})[f]	(>2 WLM)
D. Education and training exposures (annual)[b]		
1. Effective dose limit	1 mSv	(0.1 rem)
2. Equivalent dose limit for tissues and organs		
a. Lens of eye	15 mSv	(1.5 rem)
b. Localized areas of the skin, hands, and feet	50 mSv	(5 rem)
E. Embryo and fetus exposures[g]		
1. Equivalent dose limit		
a. Monthly	0.5 mSv	(0.05 rem)
b. Entire gestation	5.0 mSv	(0.50 rem)
F. Negligible individual dose (annual)[h]	0.01 mSv	(0.001 rem)

[a]Excluding medical exposures.
[b]See Tables 4.2 and 5.1 in NCRP Report No. 116 for recommendations on radiation weighting factors and tissue weighting factor respectively.
[c]Sum of external and internal exposures, excluding doses from natural sources.
[e]WLM stands for working level month and refers to a cumulative exposure for a working month (170 hours). As applied to radon an its daughter products, 1 WLM represents the cumulative exposure experienced in a 170-hour period resulting from a radon concentratio of 100 pCi/L. The occupational limit for miners is 4 WLM per year, which results in an equivalent dose of approximately 0.15 Sv (15 rem per year.
[f]A measure of the rate of release of energy (joules per second) by radon and its decay products per unit volume of air (cubic meters)