# Radiation Protection Review

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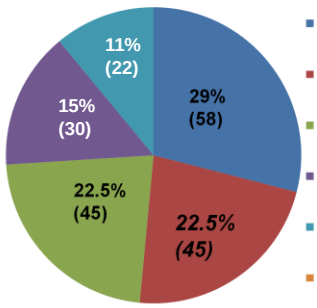


## ARRT Specifications

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

## Radiation Exposure & Monitoring

- Units of Measurement
- Dosimeters

## Units of Measurement

| Quantity | Traditional Unit | SI Unit |
|---|---|---|
| Exposure | Roentgen (R) | Coulombs/kilogram (C/kg) |
| Absorbed Dose | Rad | Gray (Gy) |
| Dose Equivalent | Rem | Seivert (Sv) |
| Radioactivity | Curie (Ci) | Becquerel (Bq) |

## Exposure

- Roentgen (C/kg)
- Measures ionizations in air
- 1R = 2.58 x 10-4 C/kg
- Used in calibration of equipment

## Absorbed Dose

- RAD (Gray)
- Measures amount of energy per unit mass absorbed in any medium
- Used for all types of radiation

## Dose Equivalent

- REM (Sievert)
- Measures biological effects in body tissues
- Uses quality (weighting) factor to determine total radiation dose after exposure from different types of radiation

## 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
- EfD = Dose x $W_r$ x $W_t$

## Radioactivity

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

## 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

## PERSONNEL PROTECTION

### 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

## Annual Occupational Dose

1 rem x age (years)

## 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

Protective Devices

- Primary
  - 1/16" Pb eq; 7 ft. high
- Secondary
  - 1/32" Pb eq; extends to ceiling

## Personnel Protection

Protective Devices

- Lead Shielding
  - Aprons - .5 mm Pb eq
  - Gloves - .25 mm Pb eq
  - Thyroid Shields - .25 mm Pb eq
  - Glasses - .35mm Pb eq
  - Pb Curtain - .25 mm Pb eq
  - Bucky Slot Cover - .25 mm Pb eq

## Personnel Protection

Special Considerations

- 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

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## 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

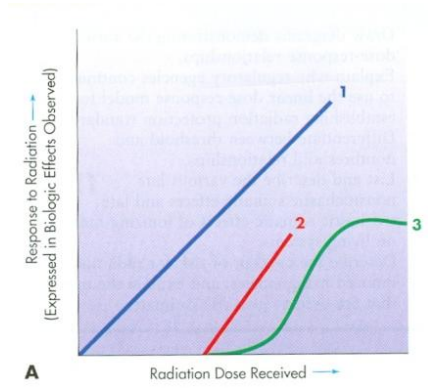
- Linear nonthreshold
  - Model to set standards & dose limits
  - No threshold
  - Response directly proportional to dose received
  - No dose rate effect (no reduced effect at small dose rates)
  - Curve exhibits a stochastic (statistical) response

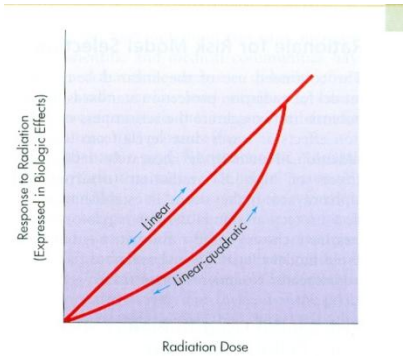
## Dose-Response Relationships

- 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

- 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

- 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
- All or nothing response
- Linear or quadratic dose-response
- Ex: cancer and genetic alterations

## Nonstochastic (Deterministic)

- 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%

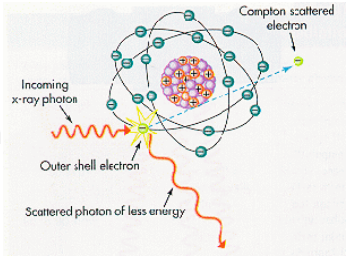
## Genetically Significant Dose

- 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

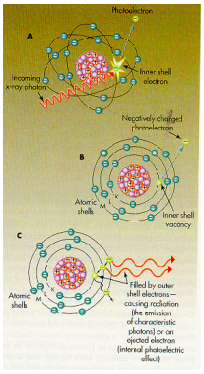
- Coherent (classical)
  - Change in direction of x-ray photon; no energy loss
- Compton
- Photoelectric

## 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 #11

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

| | | |
|---|---|---|
| A. Occupational exposures[a] | | |
| 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[b] (see Section 14, NCRP No. 116) | | |
| C. Public exposures (annual) | | |
| 1. Effective dose limit, continuous or frequent exposure[c] | 1 mSv | (0.1 rem) |
| 2. Effective dose limit, infrequent exposure[c] | 5 mSv | (0.5 rem) |
| 3. Equivalent dose limits for tissues and organs[c] | | |
| 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[d] | >26 J/(m$^3$ $^e$ | (>2 WLM) |
| D. Education and training exposures (annual)[f] | | |
| 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)[f] | 0.01 mSv | (0.001 rem) |

[*]Excluding medical exposures.
[a]See Tables 4.2 and 5.1 in NCRP Report No. 116 for recommendations on radiation weighting factors and tissue weighting factors respectively.
[b]Sum of external and internal exposures, excluding doses from natural sources.
[c]WLM stands for working level month and refers to a cumulative exposure for a working month (170 hours). As applied to radon and its daughter products, 1 WLM represents the cumulative exposure experienced in a 170-hour period resulting from a radon concentration 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.
[d]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).