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

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Traditional Unit</th>
<th>SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Roentgen (R)</td>
<td>Coulombs/kilogram (C/kg)</td>
</tr>
<tr>
<td>Absorbed Dose</td>
<td>Rad</td>
<td>Gray (Gy)</td>
</tr>
<tr>
<td>Dose Equivalent</td>
<td>Rem</td>
<td>Seivert (Sv)</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>Curie (Ci)</td>
<td>Becquerel (Bq)</td>
</tr>
</tbody>
</table>

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?

\[
\begin{align*}
20 \times 1 & = 20 \text{ rad} \\
3 \times 5 & = 15 \text{ rad} \\
2 \times 20 & = 40 \text{ rad} \\
\end{align*}
\]

\[
\text{75 rem}
\]

Effective Dose (EfD)

- Incorporates both the effects of specific types of radiation and the radiosensitivity of the tissue
- \( \text{EfD} = \text{Dose} \times W_t \times W_x \)

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 1 mR

PERSONNEL PROTECTION

Sources of Exposure*

<table>
<thead>
<tr>
<th>Source</th>
<th>Annual Exposure (mrem/yr)</th>
<th>Annual Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Cosmic / Terrestrial</td>
<td>198</td>
<td>1.98</td>
</tr>
<tr>
<td>• Radon</td>
<td>97</td>
<td>0.97</td>
</tr>
<tr>
<td>• Radon</td>
<td>295</td>
<td>2.95</td>
</tr>
<tr>
<td>Manmade / Artificial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Medical / Dental</td>
<td>40</td>
<td>0.40</td>
</tr>
<tr>
<td>• Nuclear Medicine</td>
<td>14</td>
<td>0.14</td>
</tr>
<tr>
<td>• Consumer Products</td>
<td>11</td>
<td>0.11</td>
</tr>
<tr>
<td>• Consumer Products</td>
<td>65</td>
<td>0.65</td>
</tr>
<tr>
<td>Total Annual Exposure</td>
<td>360</td>
<td>3.60</td>
</tr>
</tbody>
</table>

*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 - .35 mm 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

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 (1Ф, 3Ф, 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

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

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

- **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

- **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
- 6-10 Gy (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

Good Luck!