Objective

• To obtain **optimum diagnostic information** or therapeutic effects with **minimum exposure** of the patient.

Technologist’s Responsibility

• Recognize your duty to protect.
  – The patient
  – The public
  – Health professionals

• Utilize all mechanisms to reduce dose to the patient without compromising image quality.

First Triad of Radiation Protection

• Justification with net benefit

• Dose Limits

• Optimization (ALARA)

Second Triad of Radiation Protection

• aka “Cardinal Principles”

  • **Time:** Exposure is directly proportional to time.

  • **Distance:** Exposure is inversely proportional to the distance squared.

  • **Shielding:** Exposure is reduced by the placement of barriers between the source and the exposed individual.
Classification of Radiation

- Corpuscular
- Electromagnetic

Corpuscular Radiation

- aka Particulate
- Any subatomic particle in motion.
- Types
  - Alpha
  - Beta
  - Neutrons
  - High Speed Electrons

Electromagnetic Radiation

- An electric and magnetic field, perpendicular to each other, but traveling through space in the same direction.
- Types
  - X-rays
  - Gamma radiation

Electromagnetic Radiation

- Energy (photon)/ No mass
- Travel at the speed of light
- Highly penetrating
- Ionizing (x and gamma)

Sources of Radiation Exposure

- Environmental (Background)
  - Cosmic
  - Terrestrial
  - Internal
- Artificial (Man-made)
  - Medical (Diagnostic and Therapeutic)
  - Nuclear Industry
  - Consumer Products
Sources of Radiation Exposure 2009

Annual Dose U.S. Population 2009

- Environmental Radiation: 310 mRem*
- Artificial Radiation: 310 mRem
- Total: 620 mRem

Interactions of Radiation with Matter

- Coherent Scattering
  - Unmodified, Classical, Thomson, Rayleigh
- Photoelectric Effect
  - True absorption
- Compton Effect
  - Modified Scattering

Coherent Scattering

- Occurs at low energy levels (< 30 kVp)
- Photon-intermediate shell electron interaction
- Non-ionizing process

Photoelectric Effect

- Photon-inner shell electron interaction
- Probability depends on:
  - "Z" of absorber
  - Photon energy
  - Mass density of absorber

Compton Effect

- Photon-outer shell interaction
- Scattering with partial absorption
- Probability depends on:
  - Photon energy
  - Mass density
Prevalent Photon Interactions

Tissue Attenuation

Radiation Quantities and Units

- **Exposure (X):** C/kg
- **Absorbed Dose (D):** Gray
- **Equivalent Dose (EqD):** Sievert
- **Effective Dose (EfD):** Sievert

Exposure

- **Unit:** C/kg
- **Measures ionizations produced in air**
- **Applicable to x and gamma radiation at energies < 3 MeV**

Absorbed Dose

- **Unit:** Gray
- **Measures energy deposition in matter**
- **Applicable to all types of radiation**
Equivalent Dose
• Unit: Sievert
• Unit of biological effects
• $\text{EqD} = D \times W_R$ (absorbed dose x radiation weighting factor)

Effective Dose
• Unit: Sievert
• Unit of biological effects
• $\text{EfD} = D \times W_R \times W_T$ 
  \[ D: \text{absorbed dose} \]
  \[ W_R: \text{radiation weighting factor} \]
  \[ W_T: \text{tissue weighting factor} \]

Effective Dose Limits
NCRP Report # 116
• a.k.a. Dose Limits.
• Based on the lifetime risk of somatic or genetic injury.

Effective Dose Limits (stochastic effects):
• 50 mSv

Effective Dose Limits (non-stochastic effects):
• Lens of eye: 150 mSv
• All others: 500 mSv

Radiation Weighting (Quality) Factors
• X-ray, Beta, Gamma 1
• Neutrons $< 10$ keV 5
• Neutrons $> 100$ keV – 2MeV 20
• Alpha particles 20

Tissue Weighting Factors
\begin{center}
\begin{tabular}{|c|c|}
\hline
\textbf{Tissue} & \textbf{Weighting Factor} \\
\hline
Cornea & 0.20 \\
Red Bone Marrow & 0.12 \\
Liver & 0.12 \\
Stomach & 0.05 \\
Breast & 0.05 \\
Bladder & 0.05 \\
Eye & 0.05 \\
Esophagus & 0.05 \\
Thyroid & 0.05 \\
Skin & 0.01 \\
Bone Surface & 0.01 \\
Remainder & 0.01 \\
Total & 1.00 \\
\hline
\end{tabular}
\end{center}

For purposes of calculation, the remainder is comprised of the following additional tissues and organs:
- Adrenals
- Kidneys
- Uterus
- Large intestine, small intestine
- Palatine, tonsil
- Salivary, breast
- Thymus and thymus
- Bladder
- These organs are chosen as they are likely to be selectively irradiated.
Annual Educational and Training Exposure

- Effective dose: 1 mSv
- DE Limit (skin, hands, & feet): 50 mSv
- DE Limit (lens of eye): 15 mSv

Embryo-fetus Exposure

- Equivalent Dose Limit:
  - Month
    - 0.5 mSv
  - Gestation Period
    - 5.0 mSv

Dosimeters

- Film Badge
- Pocket Dosimeters
- TLD
- OSL Dosimeters

Advantages/Disadvantages

- Advantages
  - Constitutes a permanent, legal record of personnel exposure
  - Economical
  - Distinguish all types of low level radiation and their energies.

- Disadvantages
  - Temperature and humidity extremes cause fogging
  - Radiation exposure cannot be determined on the day of occurrence.
  - Has a limited range of sensitivity (>10 mR).

Film Badge

Three parts:
- lightweight plastic film holder
- metal filters
- film packet

Pocket Dosimeter

- Resembles a fountain pen
- Contains a thimble ionization chamber
- Two types
  - The self-reading type
  - The non-reading type
Function

- Contains two electrodes, one positive (the central electrode) and one negative (the outer electrode).
- The quantity of charge determines the position of the shadow along the scale.

Advantages/Disadvantages

- Advantages
  - Immediate readout for radiation workers.
  - Compact, easy to carry, and easy to use.
  - Accurate and sensitive, great for procedures that are relatively short in duration.
- Disadvantages
  - Expensive.
  - If not read every day, could give an inaccurate reading.
  - Discharge if subjected to mechanical shock.
  - No permanent legal record of exposure.

Thermoluminescent dosimeter (TLD)

- Lithium Fluoride Crystals

Function

- When irradiated, electrons in LiF absorb energy and are "Excited".
- When heated, the electrons return to their original position and emit light.
- The intensity of light is proportional to the amount of radiation.

Advantages/Disadvantages

- Advantages
  - The LiF crystals interact as human tissue does.
  - Read as low as 5 mR.
  - Not affected by temperature and humidity.
  - May be worn up to 3 months/reusable.
- Disadvantages
  - Can be read only once.
  - Calibrated dosimeters must be prepared and read with each group of TLD's as they are processed.

Optically Stimulated Luminescent Dosimeter (OSL)

- A lightweight plastic holder.
- Aluminum oxide detector.
Function

- Radiation exposure is detected by the Aluminum oxide detector.
- The dosimeter is “read” using a laser.
- When laser light strikes the dosimeter, the sensing material becomes luminescent in proportion to the amount of radiation exposure received.

Advantages/Disadvantages

- Advantages
  - Read as low as 1 mR
  - Temperature and humidity changes do not affect the OSL
  - Can undergo reanalysis
- Disadvantages
  - No known disadvantages

Minimizing Patient Exposure

- Exposure Reduction
  - Communication
  - Patient Positioning
- Exposure Factors
- Shielding
- Beam Restriction
- Filtration
- Image Receptor Type

Patient Positioning

- PA vs AP
  - Scoliosis examinations
  - Skull examinations
  - Lumbar Spine examinations

Exposure Factors

- High kVp / low mAs techniques are best for patient protection.
  - Choose a kVp level which is “optimum”.
  - Optimum kVp gives adequate penetration, an acceptable level of contrast, and an acceptable level of scatter production.

Shielding

Shielding should be used if:
1. the reproductive organs are within or near the primary beam.
2. the objectives of the exam are not compromised.
3. the patient has reasonable reproductive potential.
Types of Shields

- Flat Contact Shields
- Shaped Contact Shields
- Shadow Shields

Beam Restriction

- Apertures
- Cones and cylinders
- Collimators

Beam Restriction

- Increased beam restriction results in:
  - Decreased patient dose
  - Improved image quality
    - Contrast

Filtration

- Reduces exposure to the patient’s skin and superficial body tissues.
- Absorbs low energy, long wavelength photons.
- Increases average beam energy

Filtration

- Two types:
  - inherent
  - added
- Total Filtration:
  - 2.5 mm Al (>70 kVp)
  - 1.5 mm Al (50-70 kVp)
  - 0.5 mm Al (< 50 kVp)

Image Receptor Type

- High DQE receptors require less exposure.
**Grids**

- Grids are an image quality device
  - Absorb scatter radiation
  - Increase image contrast
- Increase patient dose
  - Higher grid ratio; higher patient dose

**Fluoroscopy**

- Pulsed progressive fluoro
  - Decreases dose
- Exposure factors
  - Low mA; high kVp
  - Decrease dose
- Fluoro Time
  - Increased time; increased dose

**Fluoroscopy**

- Receptor positioning
- Magnification mode
- Last image hold
- Dose documentation

**Personnel Protection**

- Cardinal Principles
  - Time
  - Distance
  - Shielding
- Sources of Exposure

**Sources of Radiation Exposure**

- Medical Diagnostic Exposure
  - Primary Beam
  - Secondary Beam
  - Leakage
  - Stray Radiation (leakage + scatter)

**Protective Barriers**

- Primary
  - 1/16 in. Pb. eq.
  - 7 feet high
- Secondary
  - 1/32nd in. Pb. eq.
  - Extend to ceiling
Equipment Recommendations NCRP Report #102

- **Aprons/Thyroid Shields**
  - 0.5 mm Pb equivalency

- **Gloves**
  - 0.25 mm Pb equivalency

- **Glasses**
  - 0.35 mm Pb equivalency

Equipment Recommendations NCRP Report #102

- **Mobile Equipment**
  - **Exposure Cord:**
    - 6 feet (180 cm).
    - Operators should wear leaded apron.
    - Operators should stand at a right angle to the scattering object.

Equipment Recommendations NCRP Report #102

- **Radiographic Units**
  - **Tube Housing:**
    - < 100 mR/hr at 1 meter from source.
  - **SID:**
    - +/- 2% of indicated SID.
  - **Collimator:**
    - +/- 2% of SID.
  - **Filtration:**
    - 2.5 mm Al (> 70 kVp).

Equipment Recommendations NCRP Report #102

- **Fluoroscopic Units**
  - **Source-to-Table-top Distance:**
    - Should not be less than 15 inches (38 cm);
    - Shall not be less than 12 inches (30 cm).
  - **Primary Protective Barrier:**
    - Must be interlocked with x-ray tube.
  - **Exposure Switch:**
    - Dead-Man type.

Equipment Recommendations NCRP Report #102

- **Fluoroscopic Units**
  - **Protective Drape:**
    - Minimum 0.25 mm lead equivalent.
  - **Bucky Slot Cover:**
    - Minimum 0.25 mm lead equivalent.
  - **Cumulative Timer:**
    - Produces an audible signal or interrupts beam at 5 minutes fluoro time.
  - **Exposure Rate:**
    - Must not exceed 10 R/min.

Biological Effects

- Result from energy deposited into the biological system.

- **Mechanisms of interaction:**
  - Ionization (Photoelectric + Compton)
  - Excitation
Biological Effects

• Somatic Effects
• Genetic Effects

Somatic Effects

• Effects occurring in the exposed individual.

• Somatic Effects
• Stochastic
  – Mutational
  – Non-threshold
  – Example:
    • Cancer
• Non-stochastic
  – aka Deterministic
  – Cell killing
  – Threshold
  – Examples:
    • Burns
    • Epilation
    • Cataracts

Genetic Effects

• Effects occurring in unborn generations.
• Linear, non-threshold dose response relationship

• Mutations
  – Typically recessive
  – Usually harmful
• Chromosome damage
  – Breaks
  – Gene rearrangement
Genetic Effects

• Genetically Significant Dose
  – The average annual gonadal equivalent dose to members of the population who are of childbearing age
  – Estimated at 20 mR

• Doubling Dose
  – The radiation dose that causes the number of spontaneously occurring mutations in a given population to double.

Long Term Effects

• Carcinogenesis
  – Radium watch dial painters
  – Uranium miners
  – Atomic bomb survivors
  – Thorotrast patients

• Cataractogenesis

• Life Span Shortening

• Embryological Effects

Embryological Effects

• Pre-implantation
• Major organogenesis
• Fetal development

Factors Influencing Biological Effects

• Biological Factors
  – Related to the Organism

• Physical Factors
  – Related to the type and delivery of the radiation

Biological Factors

• Tissue Sensitivity

• Oxygen Effect

• Age

Tissue Radiosensitivity

• Law of Bergonie’ and Tribondeau
  – Cells which are poorly differentiated and rapidly dividing are most radiosensitive.
  – Cells which are highly differentiated and slowly dividing are most radioresistant.
Radiosensitive Tissues
- Blood Cells (Lymphocytes)
- Epithelial Tissues
- Intestinal Crypt Cells
- Reproductive Cells
- Lens of the eye

Radioresistant Tissues
- Nervous Tissue
- Muscle Tissue
- Liver

Biological Factors
- Tissue Sensitivity
- Oxygen Effect (OER)
- Age

Physical Factors
- LET: Linear Energy Transfer
  - Rate of energy deposition as radiation travels through matter
- RBE: Relative Biological Effectiveness
  - The relative effectiveness of a radiation in producing a given biological effect when compared to 250 keV x-rays

Physical Factors
- Time of dose delivery
  - Acute
  - Fractionation/protraction
- Quantity of Radiation
- Quality of Radiation

Radiation Protection and Biology Review
- The End!