CHAPTER 3: INTERACTION OF RADIATION WITH MATTER

PARTICLE INTERACTIONS

Excitation – charged particle transfers energy to orbital electron not exceeding its binding energy, which moves to a higher energy level then returns to the lower energy level (de-excitation), emitting EM radiation

Ionization – charged particle transfers energy to orbital electron exceeding its binding energy; electron is ejected from the atom, forming an ion pair (ejected electron and positively charged atom)
- Secondary ionizations can be produced by sufficiently high energy ejected electrons (delta rays)
- Specific ionization is the number of ion pairs produced per unit mass of charged particle's path; increases with electrical charge and decreases with incident particle velocity
- Linear Energy Transfer = energy deposited per cm path length; proportional to square of charge and inversely proportional to incident particle kinetic energy

Scattering – interaction resulting in deflection of particle or photon from its original trajectory

Bremsstrahlung (Braking Radiation) – electron decelerated by interaction with positively charged nucleus; loses kinetic energy as a photon

X- AND GAMMA-RAY INTERACTIONS

Coherent (Rayleigh) scatter – low energy photon excites an atom but passes through without any net transfer of energy to the atom; scattered photon has same energy but a slightly different direction than incident photon
- Scattered photon usually emitted in forward direction
- Minimal concern in diagnostic radiology

Compton scatter – incident photon interacts with loosely bound outer shell electron; electron is ejected from atom and photon is scattered with some reduction in energy and a new direction
- Scattered photon may participate in additional tissue interactions or reach the image receptor and degrade image quality
- Scattered photons are more likely to be in forward direction with higher incident photon energy
- Energy of scattered photon increases as angle of deflection decreases
- Energy of incident photon = energy of scattered photon + ejected electron
- Accounts for most scattered radiation in diagnostic radiology

- Probability increases with number of outer shell electrons (density of material) and decreases with increasing incident photon energy

PHOTOELECTRIC EFFECT

In the photoelectric effect, a photon transfers all its energy to an electron located in one of the atomic shells. The electron is ejected from the atom by this energy. Photoelectric interactions usually occur with electrons that have a relatively high binding energy, but only slightly less than the energy of the photon. If the binding energy is more than the energy of the photon, a photoelectric interaction cannot occur. The photon's energy is divided into two parts by the interaction. A portion of the energy is used to overcome the electron's binding energy and to remove it from the atom. The remaining energy is transferred to the electron as kinetic energy and is deposited near the interaction site. This interaction opens one of the electron shells, and an electron moves down to fill in. The drop in energy of the filling electron often produces a characteristic x-ray photon. The energy of the characteristic radiation depends on the binding energy of the electrons involved.

Pair Production:

Pair production is a photon-matter interaction that is not encountered in diagnostic imaging because it can occur only with photons with energies in excess of 1.02 MeV. In a pair-production interaction, the photon interacts with the nucleus in such a manner that its energy is converted into matter. The interaction produces a pair of particles, an electron and a positively charged positron. These two particles have the same mass, each equivalent to a rest mass energy of 0.51 MeV.

ATTENUATION

Attenuation is the removal of photons from a beam of x- or gamma rays as it passes through matter. This is caused by both absorption and scattering of the primary photons.

Linear Attenuation Coefficient:

The linear attenuation coefficient ($\mu$) is the actual fraction of photons interacting per 1-unit thickness of material. In the example below, the fraction that interacts in the 1-cm thickness is 0.1, or 10%, and the value of the linear attenuation coefficient is $\mu = 0.1 \text{ cm}^{-1}$.

Linear attenuation coefficient values indicate the rate at which photons interact as they move through material and are inversely related to the average distance photons travel before interacting. The rate at which photons interact (attenuation coefficient value) is determined by the energy of the individual photons and the atomic number and density of the material.

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* Equivalent dose is a measure of radiation specific biologic
damage in humans and has SI units of Sievert (Sv) or
traditional units of rem.

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system specific damage in humans and has SI units of
Sievert (Sv) or traditional units of rem.

* Activity is the amount of radioactive material expressed
as the nuclear transformation rate and has SI units of
Becquerel (Bq) or traditional units of Curie (Ci).