Lecture 14 – Radiation biology and protection

This lecture will cover:

- Radiation dose and measurement
- Ionizing radiation biological effects
- Fundamental principles of radiation protection
- Methods of exposure control
- Medical radiation protection

(*Supplementary reading: The Essential Physics of Medical Imaging CH21)*

The types of radiation

- **Ionizing radiation (电离辐射)**
  - Direct ionizing radiation
    - ✓ Charged particles collide with atoms of matter and cause ionization and excitation of the atoms
    - ✓ Proton, ion, α-particle and β-particle
  - Indirect ionizing radiation
    - ✓ Firstly interact with matters and produce charged particles (electrons)
    - ✓ X-ray, γ-ray, neutron
- **Non-ionizing radiation (非电离辐射)**

  Infrared-ray, ultraviolet ray, visible light, ultrasound

Radiation dose and measurement

- Exposure (照射量): $X = \frac{\mathrm{d}Q}{\mathrm{d}m}$, where Q is electric charge, m is the mass
- Kerma (比释动能): $K = \frac{\mathrm{d}\varepsilon_{\mathrm{tr}}}{\mathrm{d}m}$, $\varepsilon_{\mathrm{tr}}$ is the kinetic energy of electrons; unit: Gy
- Absorbed dose (吸收剂量): $D = \frac{\mathrm{d}\overline{\varepsilon}}{\mathrm{d}m}$
- The relation among exposure, kerma and absorbed dose:

$$X = \frac{e}{\overline{W_a}} \cdot \frac{\mathrm{d}\varepsilon_{\mathrm{tr}}}{\mathrm{d}m} = \frac{e}{\overline{W_a}} \cdot K \qquad K = \frac{\mathrm{d}\varepsilon_{\mathrm{tr}}}{\mathrm{d}m} = D = \frac{\mathrm{d}\overline{\varepsilon}}{\mathrm{d}m}$$

Where $\overline{W_a}$ is the energy to ionize a pair of ion and electron, e is the charge of an electron.

Dose for radiation protection

- Equivalent dose (当量剂量): $H = W_{\mathrm{R}} \cdot D$, unit: Sv

where W_{R} is the radiation weighting factor, and when multiple radiations on a tissue

$$H_{\mathrm{T}} = \sum_{\mathrm{R}} W_{\mathrm{R}} D_{\mathrm{TR}}$$

- Effective dose (有效剂量) :

$$E = \sum_{\mathrm{T}} E_{\mathrm{T}} = \sum_{\mathrm{T}} W_{\mathrm{T}} H_{\mathrm{T}}$$

where W_{T} is the tissue weighting factor, and $\sum_{\mathrm{T}} W_{\mathrm{T}} = 1$

Tissue weighting factors

Tissue / organ	Tissue weighting factor, w_T
Gonads	0.2
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Chest	0.05
Bladder	0.05
Liver	0.05
Thyroid	0.05
Oesophagus	0.05
Average (brain, small intestines, adrenals, kidney, pancreas, muscle, spleen, thymus, uterus)	0.05
Skin	0.01
Bone surface	0.01

Radiation Dosimetry

Biological effect

- **Deterministic effect (确定性效应)**
  - Cellular damage which leads to a loss in tissue function if a sufficient number of cells are damaged;
  - Above a certain threshold level, the severity of effect is proportional to the radiation dose.
- **Stochastic effect (随机性效应)**
  - Biological situation in which the genetic mutations caused by chromosomal damage lead to development of cancer;
  - May occur at a much lower dose
  - No absolute threshold level
  - The higher the dose, the greater probability of cancer occurring.

Radiation hazard

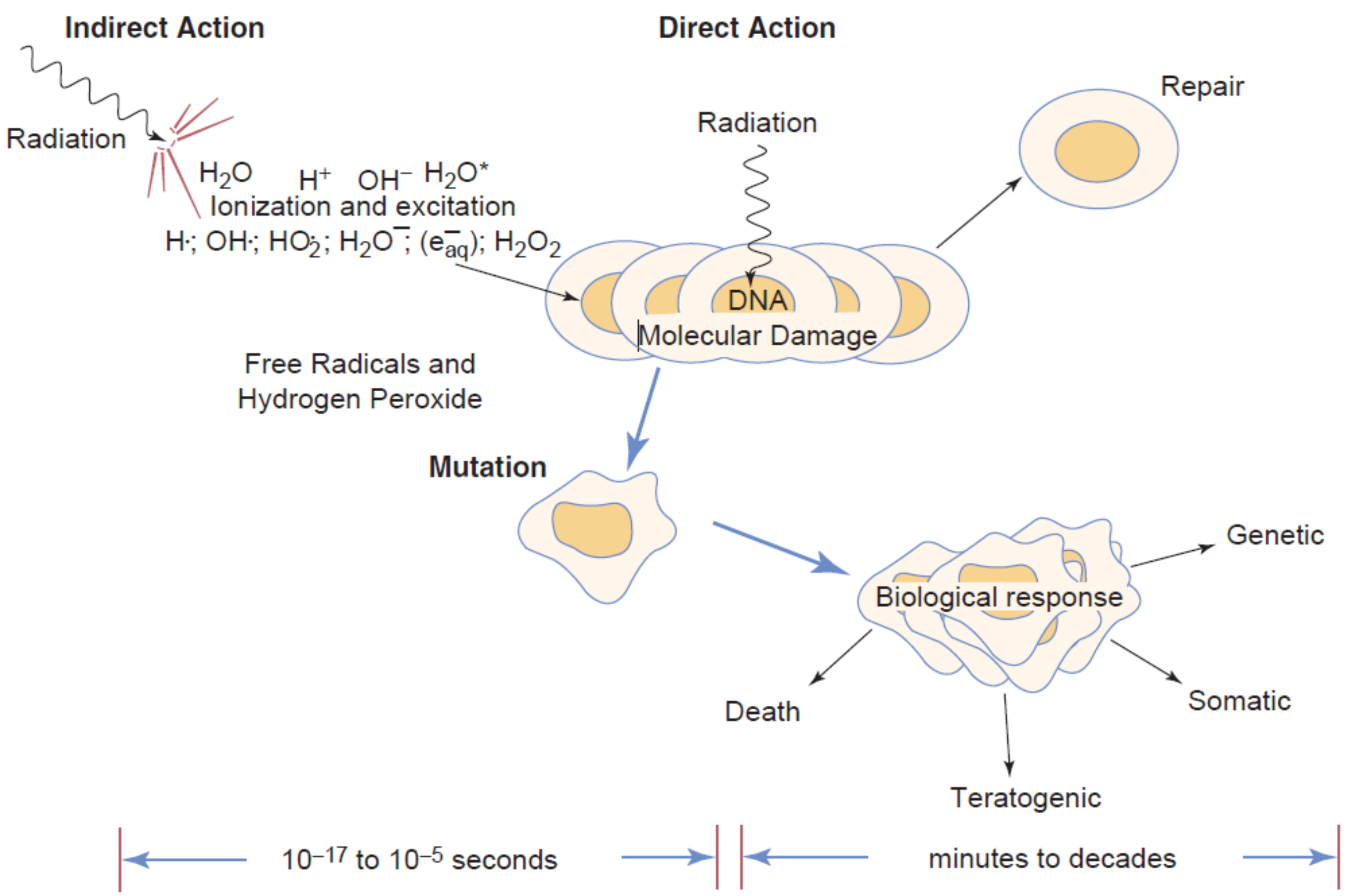

Fig. Physical and biologic responses to ionizing radiation. Ionizing radiation causes damage either directly by damaging the molecular target or indirectly by ionizing water, which in turn generates free radicals that attack molecular targets. The physical steps that lead to energy deposition and free radical formation occur within 10^{-5} to 10^{-6} seconds, whereas the biologic expression of the physical damage may occur from seconds to decades later.

Fundamental principles of radiation protection

- **Goals for Radiation protection**
  - To prevent hazardous deterministic effect
  - To limit the occurrence of stochastic effect to acceptable level
- **Fundamental principles of radiation protection**
  - The principle of justification (正当化原则): Any decision that alters the radiation exposure situation, should do more good than harm, i.e. yield an individual or societal benefit that is higher than the detriment it causes.
  - The principle of optimization of protection (防护最优化原则): Optimization of protection should ensure the selection of the best protection option under the prevailing circumstances, i.e. maximizing the margin of good over harm.
  - The principle of limitation of maximum doses (剂量限值的应用原则): In planned situations, the total dose to any individual from all the regulated sources should not exceed the appropriate regulatory limits.

Radiation doses

from common planar radiography and CT scans

Procedure	Effective dose (mSv)
Abdominal planar X-ray	1.5
Chest planar X-ray	0.04
Lumbar spine planar X-ray	2.4
Intravenous pyelogram	4.6
Chest CT scan	8.3
Brain CT scan	1.8
Abdominal CT scan	7.2

Methods of Exposure Control

- Reducing time of exposure;
- Increasing distance
- Using shielding:
  - **Selection of shielding materials**
    - ✓ The properties of the material: protection, structure, stability
    - ✓ Commonly used materials
      1. For X-ray and γ-ray: High Z and density metal (lead), construction material (concrete)
      2. For neutron: with more hydrogen atom and graphite;
      3. For electron: aluminum, glass
    - ✓ Lead equivalent
- Controlling contamination by radioactive material.

Medical radiation protection

- **For medical diagnosis**
  - X-ray Imaging: X-ray tube window, leakage, scattering
  - Nuclear medicine imaging: storage, distribution, disposal
- **For medical treatment**
  - Cyclotron: shielding for neutron
  - Monitoring and shielding for γ-ray source
- **For interventional radiology**: higher dose

Quiz