Biological Effects of Dosimetry

Dosimetry is the measurement of radiation dose absorbed by biological tissues. The biological effects of radiation depend on the **dose, dose rate, radiation type, and tissue sensitivity**. Understanding these effects is crucial for **radiation therapy, radiation protection, and space radiation research**.

1. Types of Biological Effects of Radiation

A. Deterministic Effects (Threshold Effects)

- Occur when radiation **dose exceeds a threshold**.
- The severity **increases with dose**.
- Common in **high-dose exposures**, such as radiation accidents or radiotherapy.

🔻 **Examples**:

- **Skin burns** (erythema) – threshold ~2 Gy.
- **Cataracts** – threshold ~0.5 Gy.
- **Radiation sickness** – occurs at **whole-body doses above 1 Gy**.
- **Sterility** – threshold ~3–5 Gy for testes, ~1.5 Gy for ovaries.

B. Stochastic Effects (Non-Threshold, Probabilistic Effects)

- No minimum dose threshold – **any dose can increase risk**.
- **Probability of occurrence increases with dose**, but **severity is independent of dose**.
- Main concern in **low-dose radiation exposure (e.g., medical imaging, environmental exposure)**.

🔻 **Examples**:

- **Cancer induction** (e.g., leukemia, thyroid cancer).
- **Genetic mutations** → Passed to offspring if germ cells are affected.
- **Long-term cardiovascular diseases** (linked to chronic radiation exposure).

2. Dose-Dependent Biological Responses

A. Low Doses (< 0.1 Gy)

- Minimal **immediate** biological damage.

- **DNA repair mechanisms** usually correct damage.
- Risk of **stochastic effects** (e.g., cancer) **increases over time**.
- Used in **diagnostic imaging (X-rays, CT scans, PET scans)**.

B. Moderate Doses (0.1 – 1 Gy)

- **Cellular damage increases**, but most cells survive.
- **Risk of cancer and genetic mutations rises**.
- Can cause **temporary bone marrow suppression**.

C. High Doses (1 – 10 Gy)

- **Significant tissue damage** and **cell death**.
- Symptoms of **acute radiation syndrome (ARS)** appear (nausea, vomiting, fatigue).
- Used in **radiation therapy**, requiring **fractionation** to minimize normal tissue damage.

D. Very High Doses (> 10 Gy)

- **Severe and often fatal** radiation injuries.
- Whole-body doses **> 6 Gy without treatment are lethal**.
- **Hematopoietic syndrome** (bone marrow failure), **gastrointestinal syndrome**, and **neurological syndrome** occur at extreme doses.

3. Radiation Effects at the Cellular Level

A. DNA Damage & Repair

- Ionizing radiation interacts with **DNA**, causing:
  - **Single-strand breaks (SSBs)** → Usually repairable.
  - **Double-strand breaks (DSBs)** → More severe, leading to **mutations, apoptosis, or carcinogenesis**.
- **Cell fate after radiation exposure**:
  1. **Successful repair** → Cell survives normally.
  2. **Mutation** → Potential cancer initiation.
  3. **Apoptosis (Programmed Cell Death)** → Prevents proliferation of damaged cells.
  4. **Necrosis** → Uncontrolled cell death, leading to tissue damage.

4. Factors Influencing Radiation Effects

A. Radiation Type

- **High-LET radiation (alpha particles, neutrons, heavy ions)** → More damaging due to dense ionization.
- **Low-LET radiation (X-rays, gamma rays, beta particles)** → Less damaging but can still induce long-term effects.

B. Dose Rate

- **High dose rates** → More severe effects due to overwhelming repair mechanisms.
- **Low dose rates** → Allows for better cellular repair, reducing deterministic effects.

C. Tissue Sensitivity (Law of Bergonié and Tribondeau)

- **Rapidly dividing cells (bone marrow, intestines, skin, reproductive cells)** are **more radiosensitive**.
- **Non-dividing cells (neurons, muscle cells)** are **radioresistant**.

5. Applications of Dosimetry in Radiation Protection & Medicine

✓ **Radiation Therapy**:

- Optimizes **tumor control while minimizing normal tissue damage**.
- Uses **fractionated doses to allow healthy tissue recovery**.

✓ **Medical Imaging Safety**:

- Ensures **minimally invasive radiation exposure** in **X-rays, CT scans, and nuclear medicine**.

✓ **Nuclear Industry & Space Radiation Protection**:

- **Dosimeters** worn by workers/astronauts to monitor exposure.

✓ **Epidemiological Studies**:

- Used in research on **cancer risks in radiation-exposed populations** (e.g., atomic bomb survivors, Chernobyl workers).