BIOLOGICAL EFFECTS OF IONIZING RADIATION

MODULE 4

Terminology

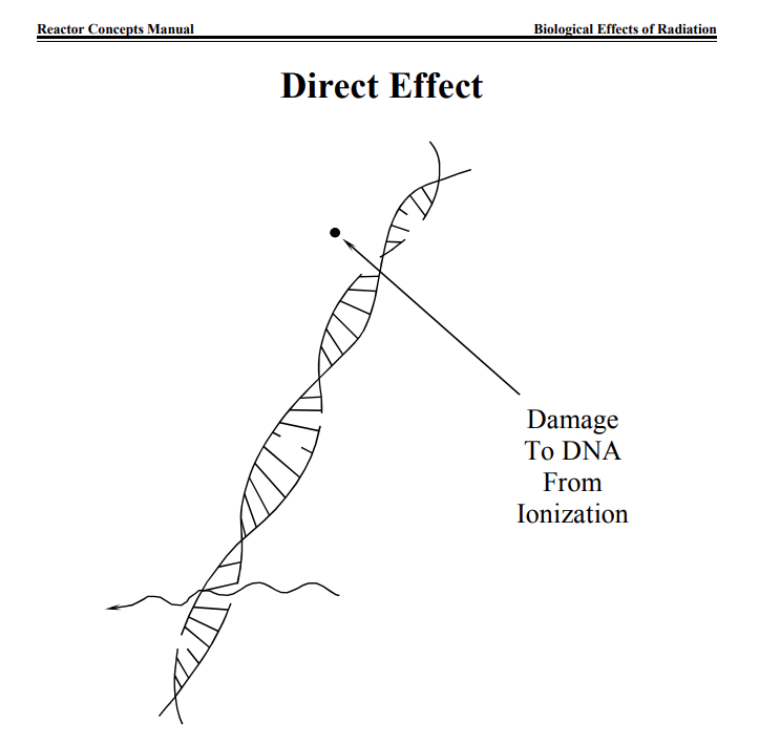
Category	Term	Definition	Key Features	Examples
Exposure Duration	**Acute Exposure**	Large dose received over a short period of time	High dose, short time; effects more likely to appear quickly	Nuclear accident, radiation therapy session
	Chronic Exposure	Low dose received over a long period of time	Prolonged, low-level exposure; often cumulative	Occupational exposure, background radiation
Molecular Mechanism	**Direct Action**	Radiation interacts directly with DNA or critical biomolecules	More likely with high LET radiation (e.g., alpha)	DNA strand breaks caused by direct ionization
	Indirect Action	Radiation interacts with water to produce free radicals that damage DNA	Common with low LET radiation (e.g., gamma, X-rays)	Hydroxyl radical attacking DNA
Timing of Biological Effects	**Prompt (Early) Effects**	Effects that appear within hours, days, or weeks of exposure	Threshold dose; severity increases with dose	Skin burns, nausea, radiation sickness
	Delayed (Late) Effects	Effects that appear months or years after exposure	Can be stochastic or deterministic; no immediate symptoms	Cancer, cataracts, genetic mutations
Biological Outcome Type	**Stochastic Effects**	Probability of effect increases with dose; severity is **not** dose-dependent	No threshold; random; mainly cancer and genetic effects	Radiation-induced cancer
	Non-stochastic (Deterministic) Effects	Severity **does** increase with dose; has a threshold	Clear threshold; above which effect occurs and worsens with dose	Skin erythema, sterility, cataracts

Chain of Events for Direct Action

1. Incident particle or photon
2. Excitation or Ionization
3. Dissociation of a molecule due to the excitation or ionization on one of the molecules atoms
4. Biological Effects possible depending on the molecule dissociated

Direct Action

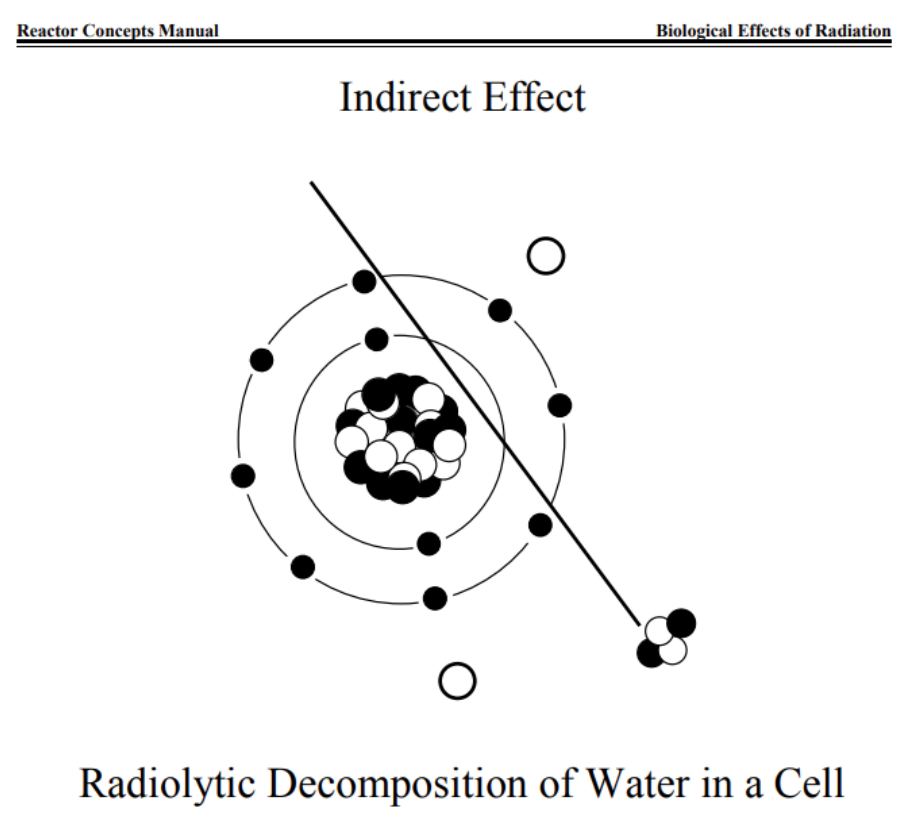
A break in the DNA molecule due to direct action of the radiation or an electron that is freed from an atom.



Chain of Events for Indirect Action

1. Incident Particle or Photon
2. Ionization of Water Molecule
3. Dissociation of Water Molecule
4. Free Radicals Produced
5. Chemical Changes
6. Possible Biological Effects

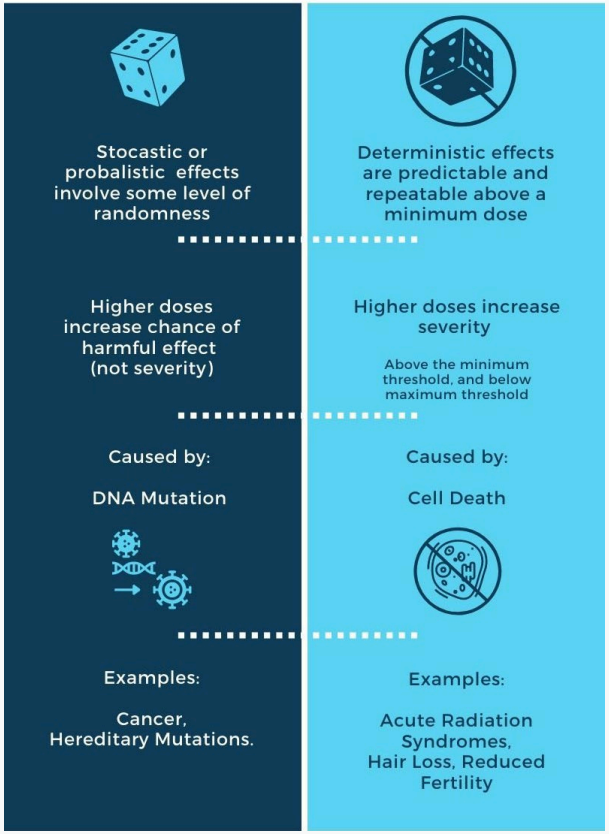
Indirect Action



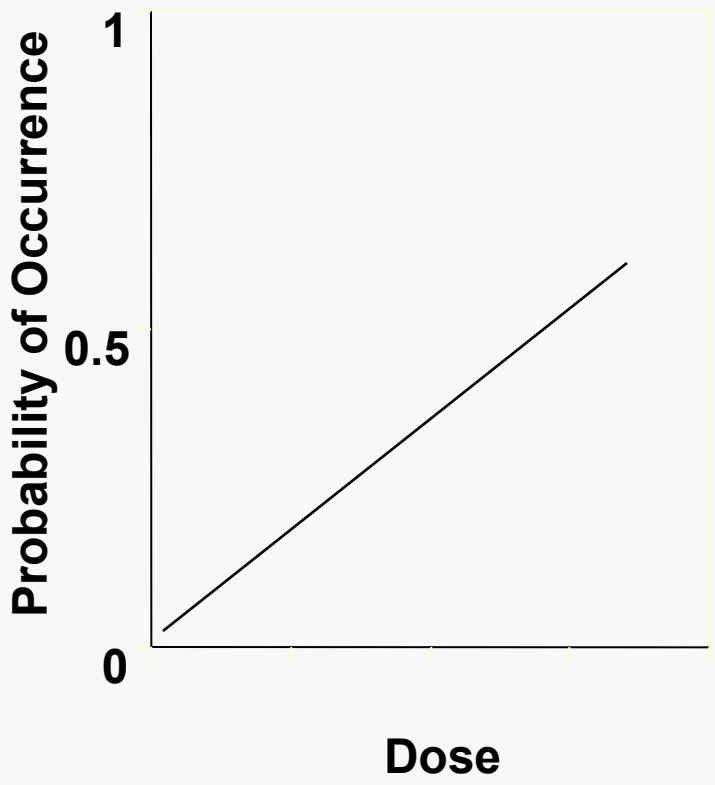
- Radiation ionizes a water molecule
- The positive ion dissociates
- The electron attaches to a neutral water molecule
- The negative ion then dissociates
- The H radicals combine to form hydrogen gas
- Hydrogen peroxide is produced & contributes to cell destruction.

Stochastic (Random) Effects

- Occur by chance
- Occur in both exposed and unexposed individuals
- Are not unequivocally related to the radiation exposure
- Become more likely as dose increases
- Severity is independent of the dose

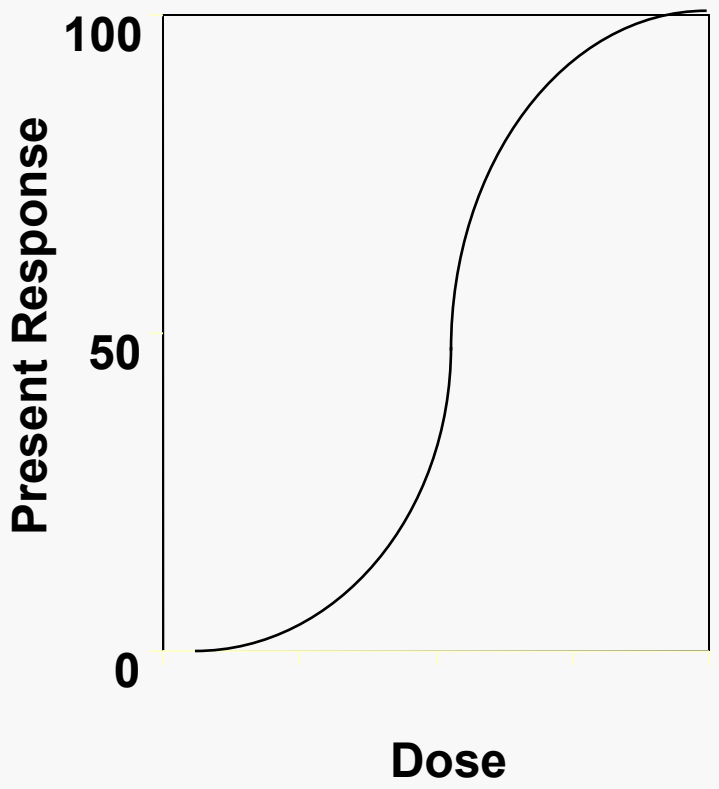


Linear No Threshold Model



- Assumes that any amount of radiation has a detrimental effect.
- Is not a predictive model.
- Is used to establish regulatory dose limits (NRC).

Nonlinear Threshold Response



- No harmful response is seen until a threshold dose is exceeded
- At some dose, all individuals experience the effect
- Used in clinical settings; safe zone exists at low doses

🔍 Comparison Table

Feature	LNT Model	Threshold Model
Minimum dose with effect?	0 (no threshold)	Yes (e.g., 100–200 mGy for some effects)
Risk at very low doses?	Yes	No
Regulatory application?	Stochastic effects (cancer risk)	Deterministic effects (tissue damage)
Common use?	Radiation protection standards	Clinical risk management

Examples of Biological Effects

Cancer

Skin Burns

Hair Loss

Sterility

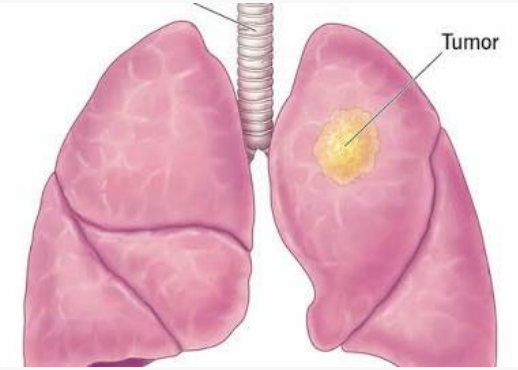
Cataracts

Cancer

- Radiation induced tumors most frequent in the hemopoietic system, thyroid, and skin.
- Cancer induction is well documented at doses of 100 rad or more.
- Induction at lower doses is inconclusive (possible exceptions are leukemia and thyroid cancer).
- Tumor induction has a latent time of 5-20 years.

Cancer (cont.)

- Radiation-induced leukemia in Atomic bomb survivors has been documented at doses above 40 rad
- Bone Cancer induction has been documented in laboratory animals for large injection of “bone seeking” radionuclide
- Radiation induced lung cancer is seen mainly in underground miners exposed to high Radon concentrations



Genetic Effects

- Genetic effects have been observed in animal studies, but no radiation induced genetic effects have been observed in humans.

Sterility

- Temporary sterility had been observed
  - In men at doses as low as 30 rads
  - In women at doses as low as 300 rads
- The higher the dose, the longer the period of sterility

Cataracts

"The lens of the eye is one of the body's most radiosensitive tissues".

In 2011, the International Commission on Radiological Protection (ICRP) reduced the equivalent dose limit from 150 mSv per year to a threshold of **20 mSv per year averaged over five years** (i.e. 100 mSv/5 y, **with no single year exceeding 50 mSv**).

Erythema & Other Skin Effects

- Reddening of the skin (erythema) occurs at photon or beta doses of about 300 rads.
- Higher doses may cause epilation, blistering, necrosis, and ulceration.

Table 1. Acute skin changes with localized radiation dose

Acute skin effect	Dose (Gy)	Onset
Early transient erythema	2	Hours
Faint erythema; epilation	6–10	7–10 Days
Definite erythema; hyperpigmenation	12–20	2–3 Weeks
Dry desquamation	20–25	3–4 Weeks
Moist desquamation	30–40	≥4 Weeks
Ulceration	>40	≥6 Weeks
Late skin effect		
Delayed ulceration	>45	Weeks after radiation
Dermal necrosis/atrophy	>45	Months after radiation
Fibrosis	>45	6 Months to ≥1 year after radiation
Telangiectasia	>45	6 Months to ≥1 year after radiation

Information compiled from Mendelsohn *et al.*, 2002; Hymes *et al.*, 2006; Bey *et al.*, 2010; Wolbarst *et al.*, 2010; and Brown and Rzucidlo, 2011.

Hematopoietic Syndrome

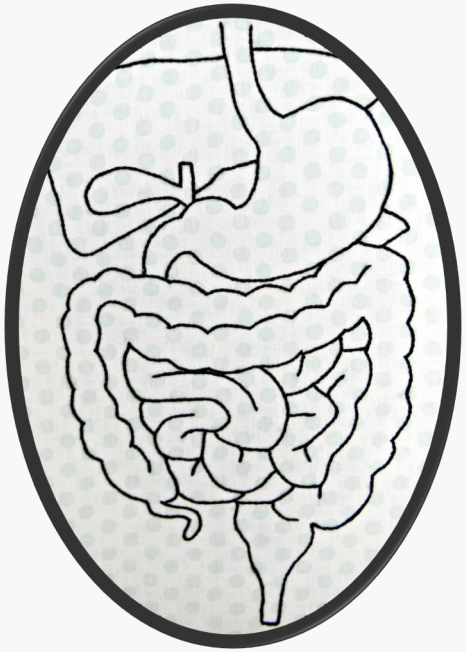
- **Hematopoietic Syndrome**, also known as bone marrow syndrome, is a form of Acute Radiation Syndrome (ARS) characterized by damage to the blood-forming cells in the bone marrow.
- It typically occurs after whole-body radiation exposure and can lead to a range of complications due to the reduction in blood cell production.
- Blood changes may be seen at doses as low as 14 rads.
  - May be accompanied by nausea, vomiting, fatigue, and increased temperature
  - Death occurs within 1-2 months unless medical treatment is successful
- Blood changes almost certain at doses above 50 rads.

Gastrointestinal Syndrome

Gastrointestinal (GI) radiation syndrome, also known as radiation GI syndrome (RGS), is a severe condition resulting from **high** doses of ionizing radiation exposure to the gastrointestinal tract.

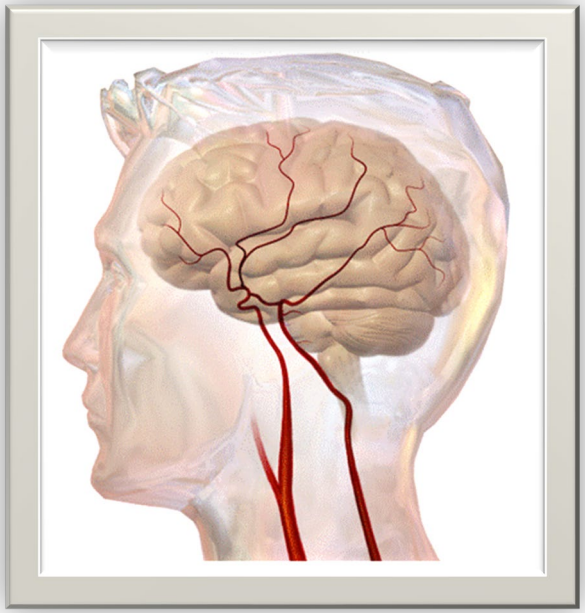
It is characterized by damage to the intestinal lining, leading to symptoms like nausea, vomiting, diarrhea, and potentially death.

Typically occurs with radiation doses exceeding 6-10 Gy (Gray). Doses of 10 Gy or higher are often fatal, usually within 2 weeks.



Cerebral Vascular (a.k.a. CNS) Syndrome

- Occurs at whole body doses of 2000 rads or more
- Damages the central nervous system as well as all other organs and systems
- Unconsciousness occurs within minutes
- Death follows in a matter of a few hours to a few days



Summary of Bio Responses to Exposure

Summary of Biological Response to High Doses of Radiation

< 5 rad	-	No immediate observable effects
~ 5 rad to 50 rad	-	Slight blood changes may be detected by medical evaluations
~ 50 rad to 150 rad	-	Slight blood changes will be noted and symptoms of nausea, fatigue, vomiting, etc. likely
~ 150 rad to 1,100 rad	-	Severe blood changes will be noted and symptoms appear immediately. Approximately 2 weeks later, some of those exposed may die. At about 300 - 500 rad, up to one half of the people exposed will die within 60 days without intensive medical attention. Death is due to the destruction of the blood forming organs. Without white blood cells, infection is likely. At the lower end of the dose range, isolation, antibiotics, and transfusions may provide the bone marrow time to generate new blood cells and full recovery is possible. At the upper end of the dose range, a bone marrow transplant may be required to produce new blood cells.
~ 1,100 rad to 2,000 rad	-	The probability of death increases to 100% within one to two weeks. The initial symptoms appear immediately. A few days later, things get very bad, very quickly since the gastrointestinal system is destroyed. Once the GI system ceases to function, nothing can be done, and medical care is for comfort only.
> 2,000 rad	-	Death is a certainty. At doses above 5,000 rad, the central nervous system (brain and muscles) can no longer control the body functions, including breathing blood circulation. Everything happens very quickly. Nothing can be done, and medical care is for comfort only.

Summary

Biological effects of concern in the occupational setting may not appear until many years after radiation exposure, if they appear at all.

The probability of these effects increases with increased exposure/dose.

In any individual case, it can never be determined with 100% confidence that radiation was the cause.