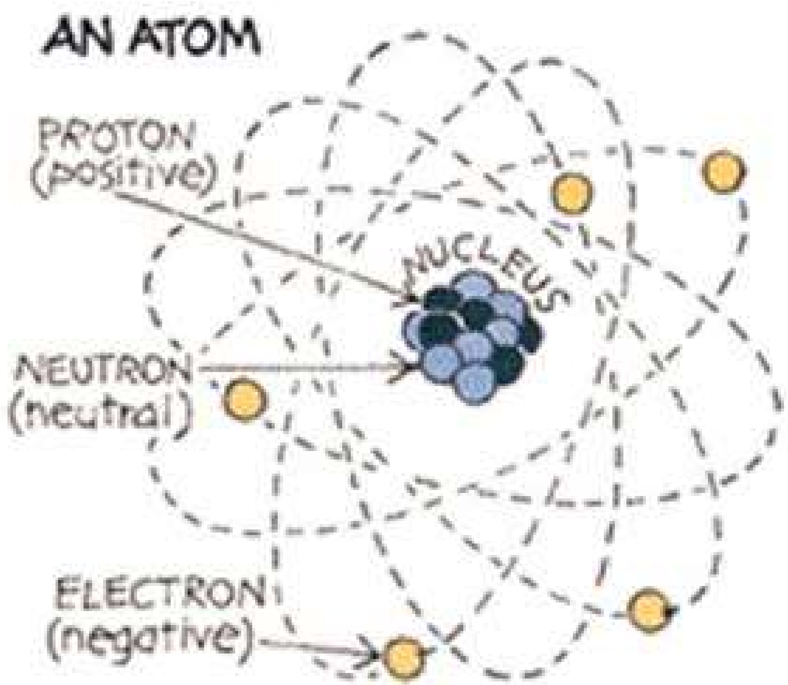
Radiation Basics and Radiation Protection

Fundamentals



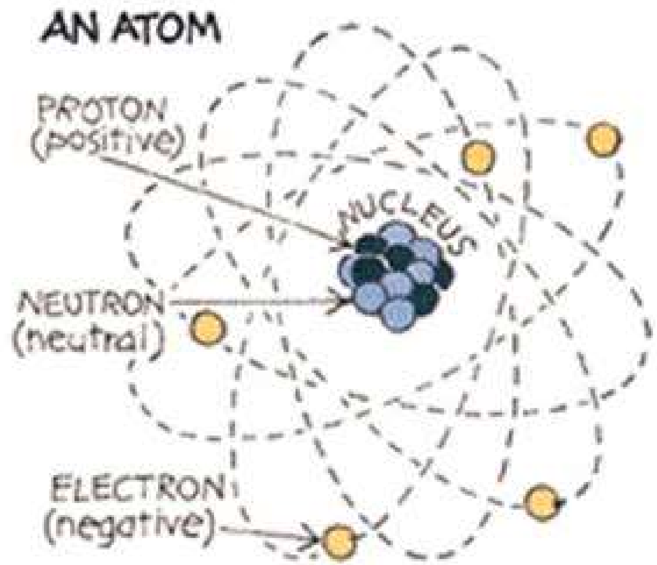
The Atom

ATOMS made up of 3 types of particles: **electrons**, **protons,** n**eutrons**

Electrons: Tiny, very light particles that have negative electrical charge (-)

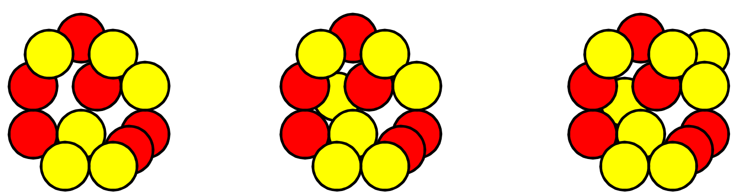
Protons: Much larger and heavier than electrons, with a positive charge (+)

Neutrons: Large and heavy but have no electrical charge



Isotopes

- Atoms that have the same number of **protons** but different numbers of **neutrons** are called isotopes
- The element carbon, for example, has three **isotopes**.



carbon-12
98.9%
6 protons
6 neutrons

carbon-13
1.1%
6 protons
7 neutrons

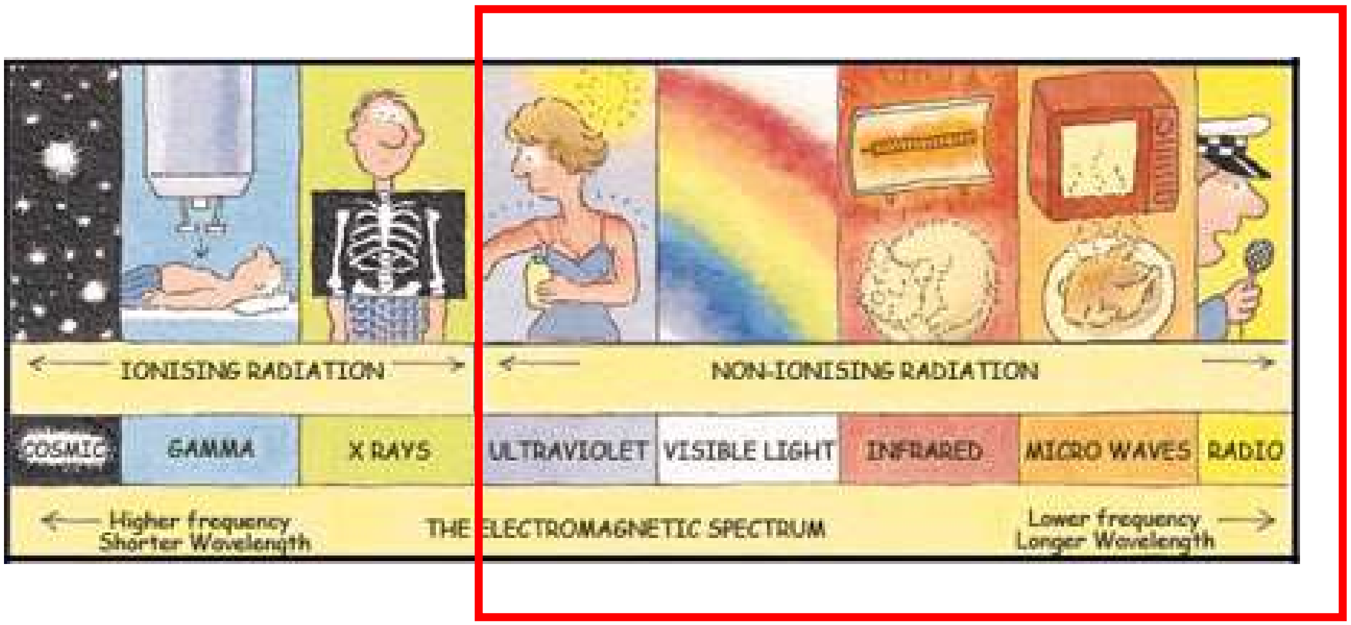
carbon-14
<0.1%
6 protons
8 neutrons

What is Radiation?

- Radioactive isotopes emit radiation when they return to a stable state (i.e., decay)
- Radiation is energy in the form of electromagnetic waves or moving subatomic particles emitted by an atom or other body as it changes from a higher energy state to a lower energy state
- Radiation can be classified as *ionizing* or *non-ionizing radiation*, depending on how it interacts with matter

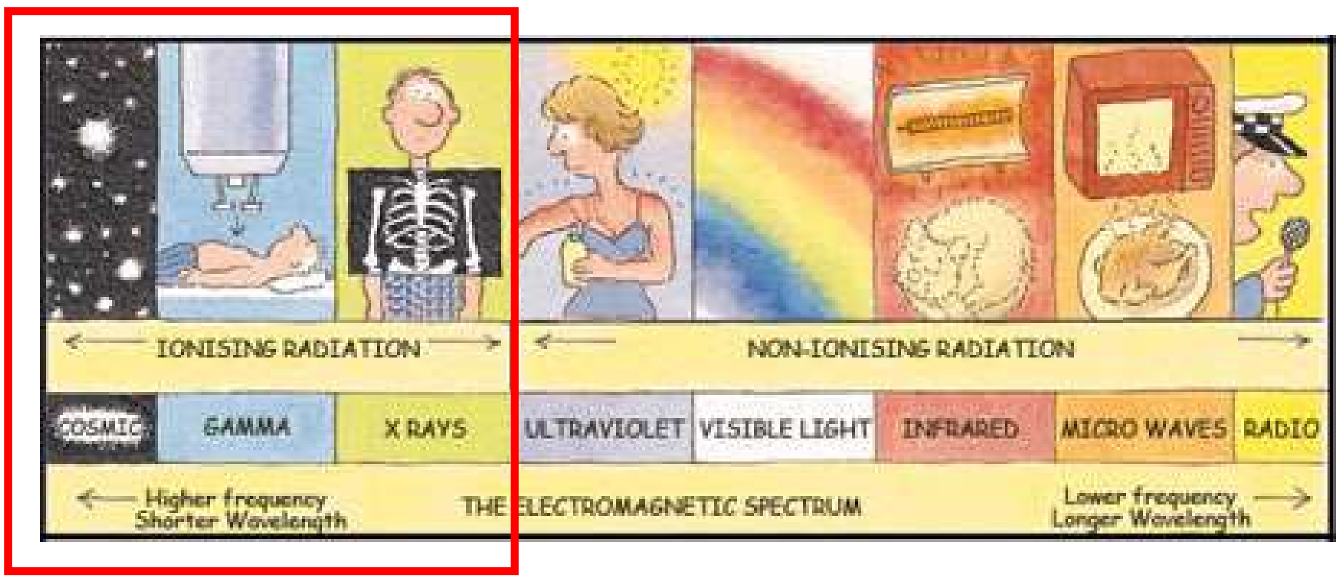
Non-Ionizing Radiation

Any type of electromagnetic radiation that does not carry enough energy to ionize atoms or molecules — that is, to completely remove an electron from an atom or molecule



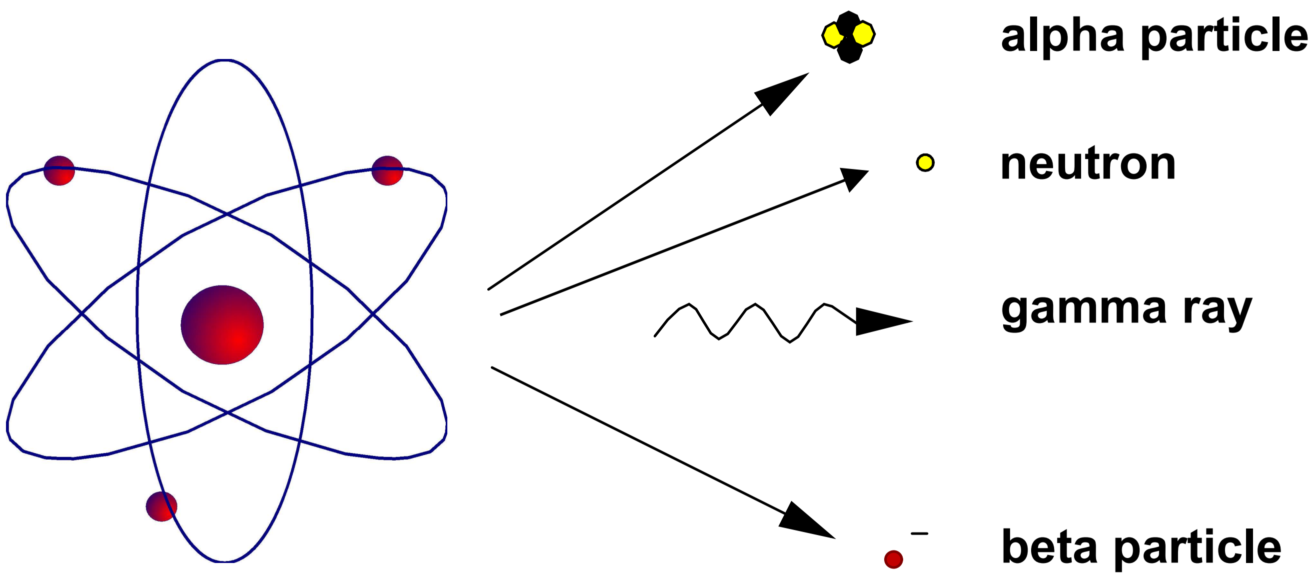
Ionizing Radiation

- **Ionizing radiation** consists of highly-energetic particles or waves that can remove (ionize) at least one electron from an atom or molecule
- Ionizing ability depends on the energy of individual particles or waves, and not on their number (Intensity)



Ionizing Radiation

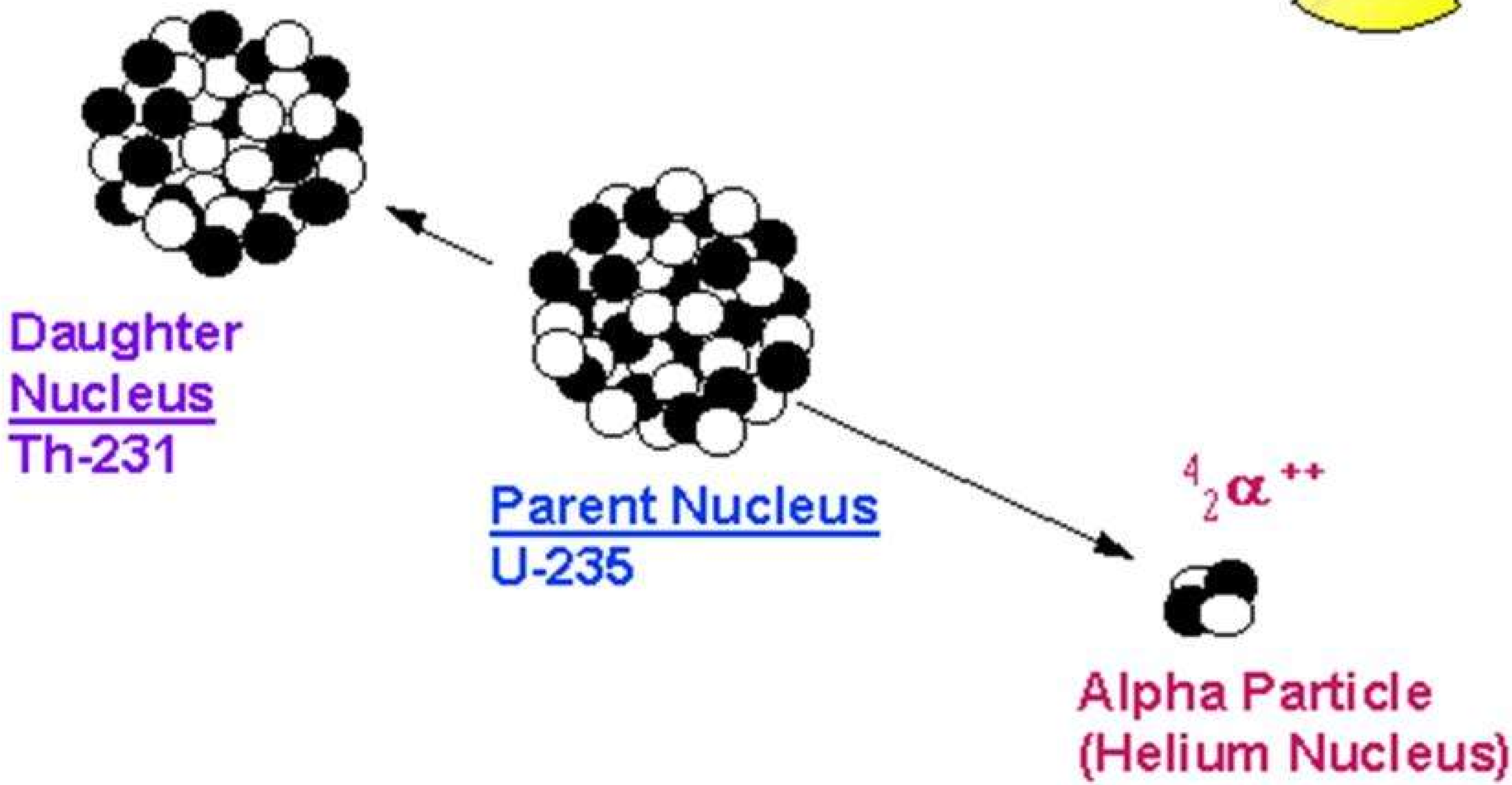
- Ionizing radiation can cause damage to the human body by interactions with cells
- There are four basic types of ionizing radiation:



Alpha Radiation (α)

- A large, charged particle consisting of two protons and two neutrons bound together into a particle identical to a helium nucleus
- Travels only a few centimeters in air
- It cannot penetrate the human skin
- Alpha radiation is solely an internal hazard

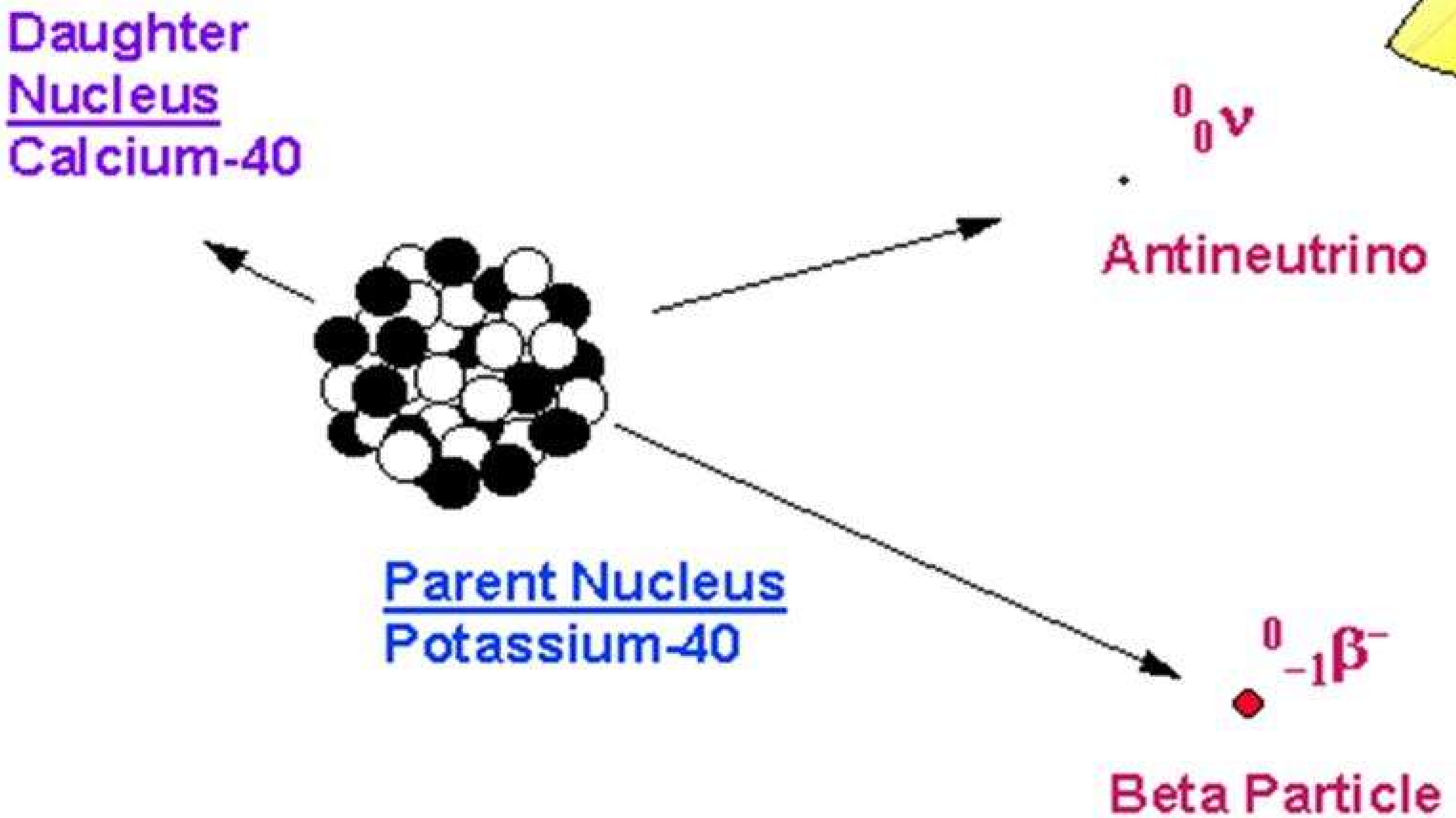
Alpha Particle Radiation



Beta Radiation (β)

- A small, charged particle (an electron)
- It is fast moving and has more penetrating power than alpha particles
- Travels a few meters in air
- Can cause skin burns (at high doses)
- Can cause damage to the lens of the eye (at high doses)
- Beta radiation is both an internal and external hazard

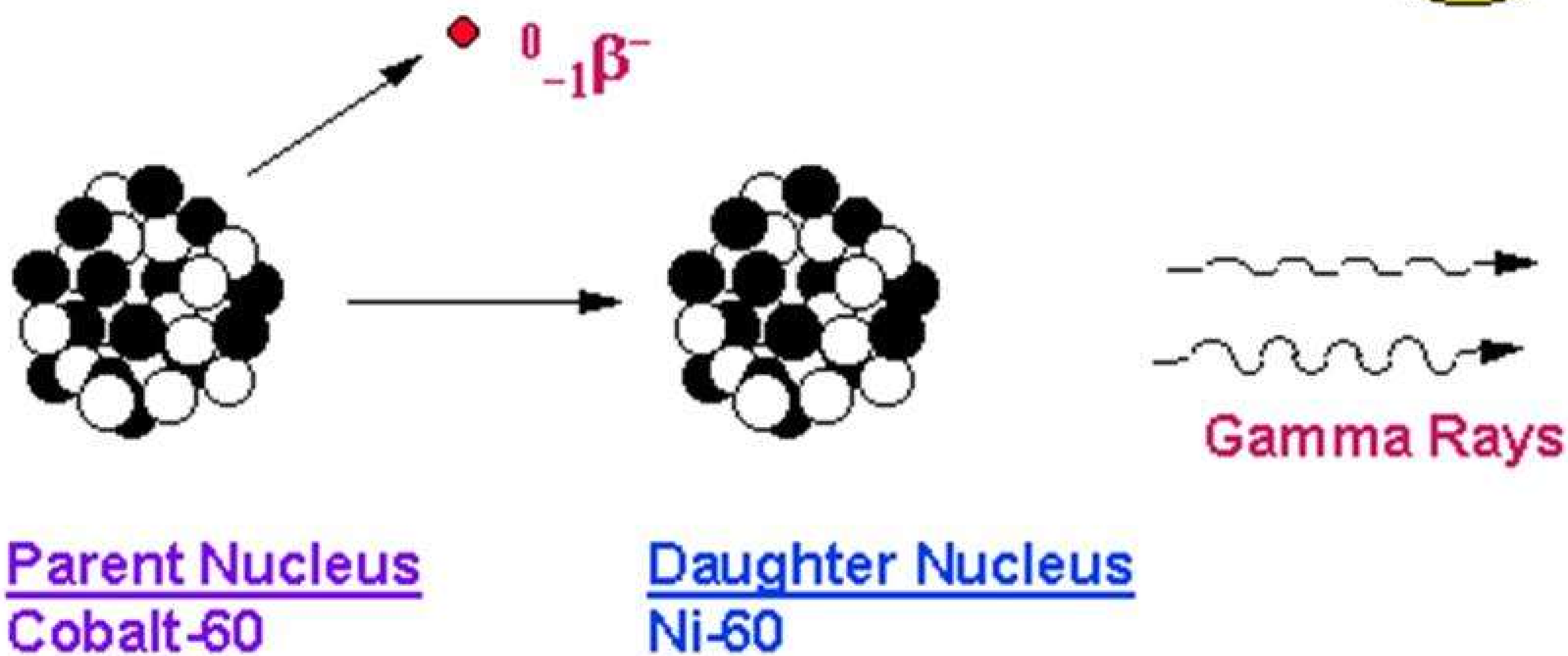
Beta Particle Radiation



Gamma Radiation (γ)

- Electromagnetic waves
- No charge, very short wavelengths
- The shorter the wavelength, the higher the energy
- Capable of penetrating and passing through the body, with few interactions
- Travel long distances in air
- Gamma rays are an external as well as an internal hazard

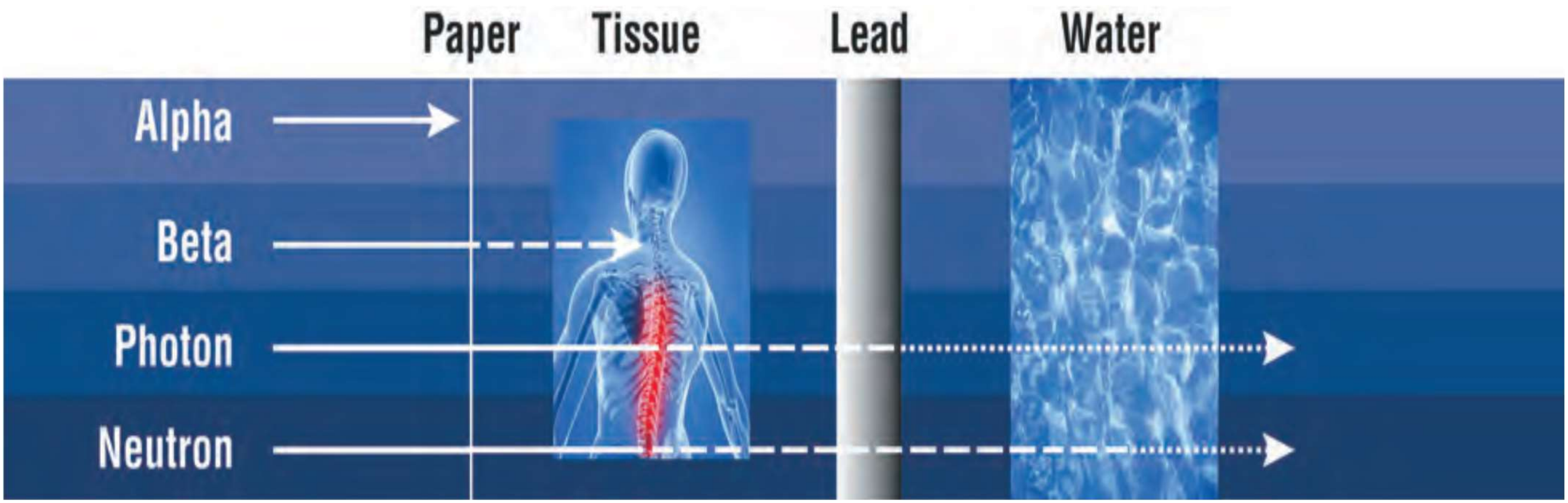
Gamma-Ray Radiation



Neutron Radiation

- Neutrons are ejected from the nucleus of an atom
- They carry a neutral charge and can be very penetrating
- Travels a great distance in air
- Neutrons are an external hazard

Penetration of Ionizing Radiation



Explanation of Activity and Dose

- **Activity** is the number of radioactive atoms decaying per second (a measure of how ‘hot’ the source is)

- **Dose** is a measure of radiation energy absorbed by the body

Dose Concepts
Radioactivity vs. Radiation Dose

Radioactivity in Bq	Measure activity
Radiation energy (α/β/γ/n) in eV	Measure energy

Absorbed dose in Gy	Measure/calculate absorbed dose
Equivalent dose in Sv	Calculate equivalent dose (w_R)
Effective dose in Sv	Calculate effective dose (w_T)

Activity of Radioactive Material

The activity of a source, or source strength is measured in **Becquerels** (Bq)

- 1 **Bq** = 1 disintegration per second (dps)
- Bq is the SI unit that replaces the old unit of Curie (Ci)
- 1 **Curie** = 37 Billion Becquerels = 3.7×10^{10} Bq (37 GBq)

Radioactive Decay Energy

- Energy of the radiation emitted during decay
- Measured in electron volts (eV)
- Usually expressed as **keV** (thousand eV) or **MeV** (million eV)
- 34 eV required to ionize an electron in the body

Examples of Radioactive Decay Energies

- **Cesium-137:** 0.662 MeV (gamma)
- **Carbon-14:** 0.156 MeV (beta)
- **Polonium-210:** 5.3 MeV (alpha)
- **Hydrogen-3 (tritium):** 0.018 MeV (beta)

Dose Quantities

Dose Quantities

Absorbed dose

⇩

Energy "deposited" in a kilogram of a substance by radiation

Equivalent dose

⇩

Absorbed dose weighted for the degree of the effect of different radiations
(radiation weighting factor w_R)

Effective dose

⇩

Equivalent dose weighted for susceptibility to effect of different tissues
(tissue weighting factor w_T)

Dose Concepts: Absorbed Dose

- When ionizing radiation interacts with matter, it deposits energy
- The energy deposited into matter is measured in gray (Gy)
- A gray is the number of Joules (J) absorbed in 1 kg of matter
- 1 Gy = 1 J/kg

1 Gy alpha ≠ 1 Gy beta radiation with respect to biological effect

Dose Concepts: Equivalent Dose

- Equivalent dose is a measure of the biological effectiveness of radiation energy deposited in tissue
- Equivalent dose = absorbed dose (Gy) x W_R (radiation weighting factor)
- Equivalent dose is measured in Sieverts (Sv)

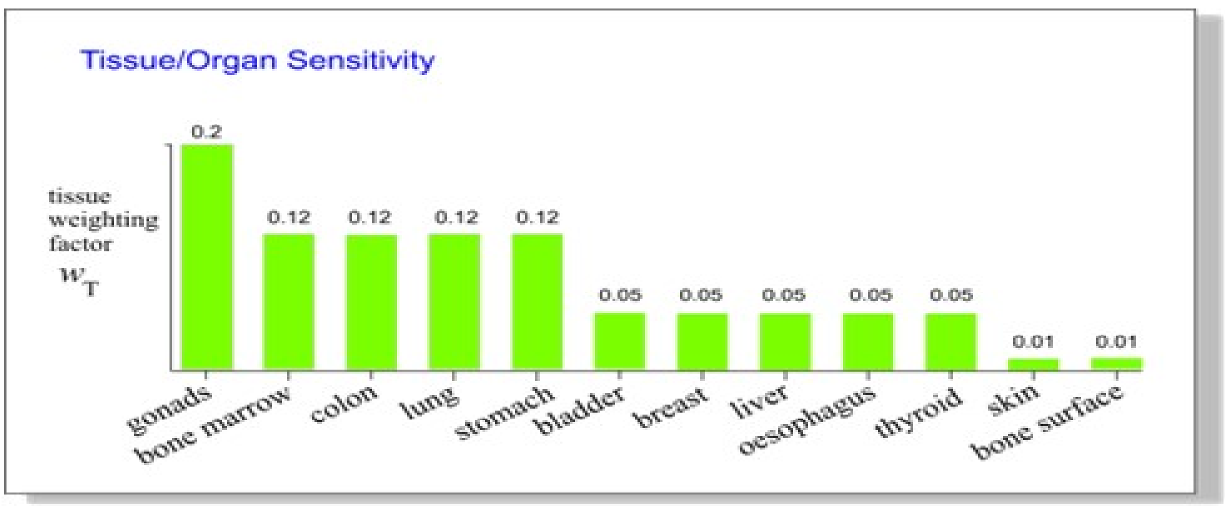
Type of radiation	**Weighting factor**
Photons, electrons	1
Protons	5
Neutrons	5-20
Alpha	20

1 Sv alpha= 1 Sv beta with respect to biological effects

1 Sv dose to lung ≠ 1 Sv dose to thyroid with respect to health detriment

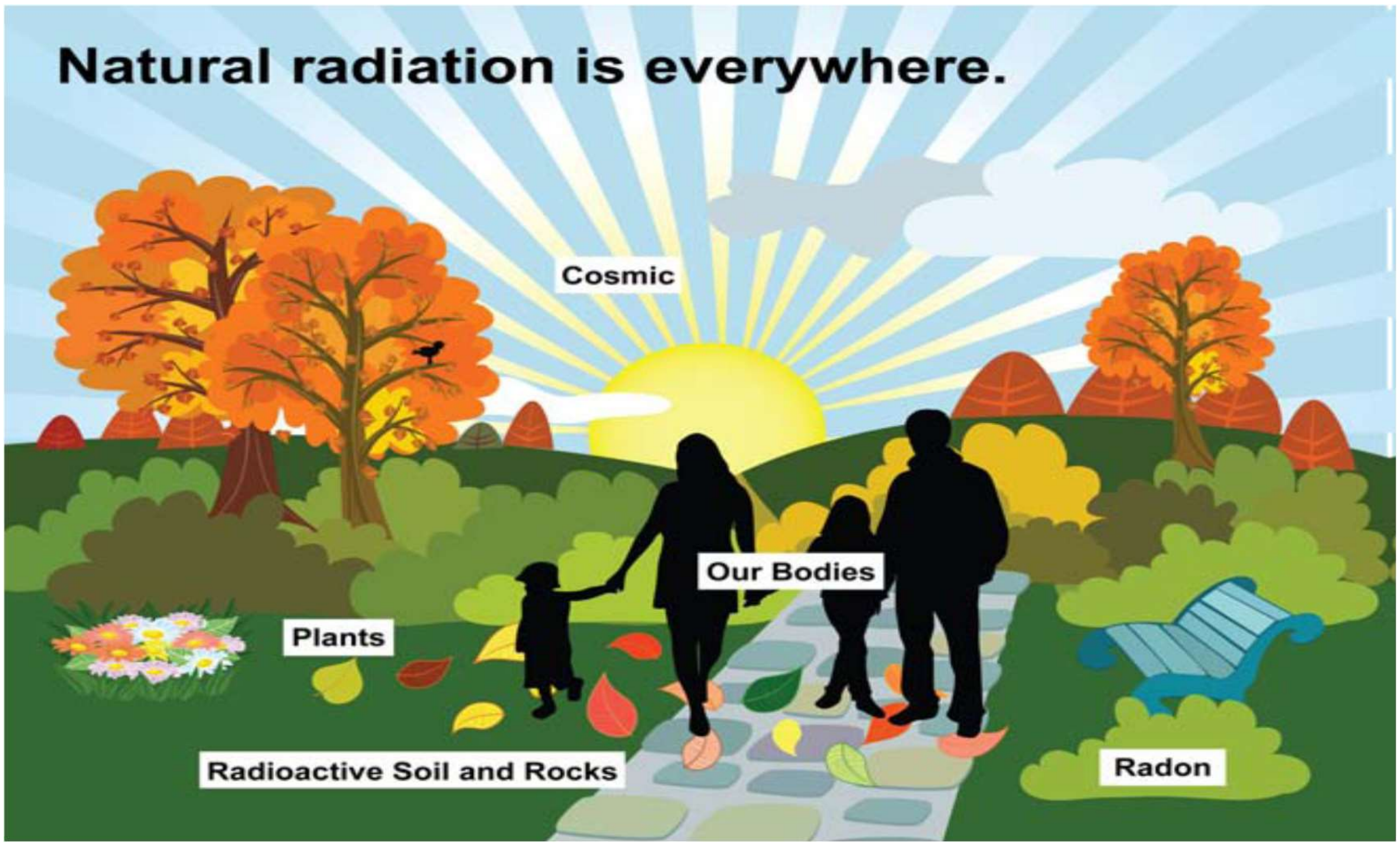
Dose Concepts: Effective Dose

- Effective dose is a measure of the health detriment from radiation
- Effective dose = Equivalent dose x W_T (tissue weighting factor)
- Usually measured as a whole body dose (sum of health detriment)



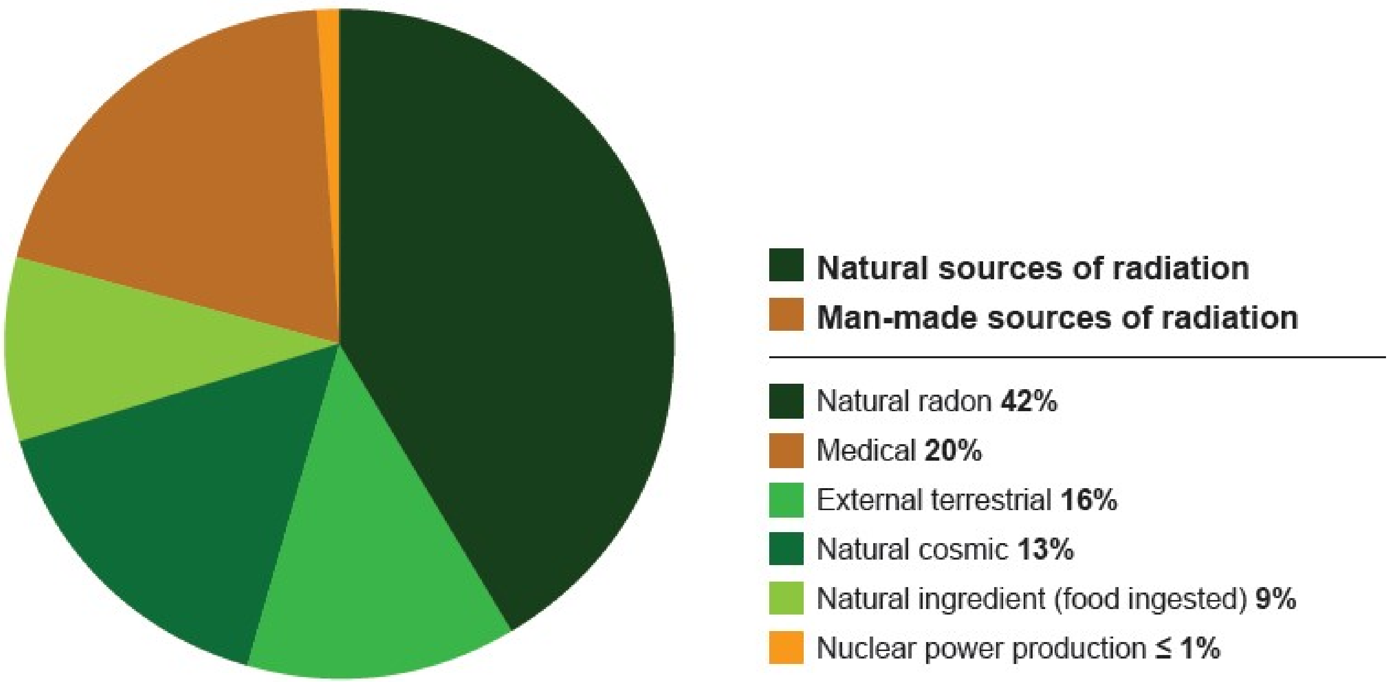
Sources of Radiation: man-made

Sources of Radiation: Natural

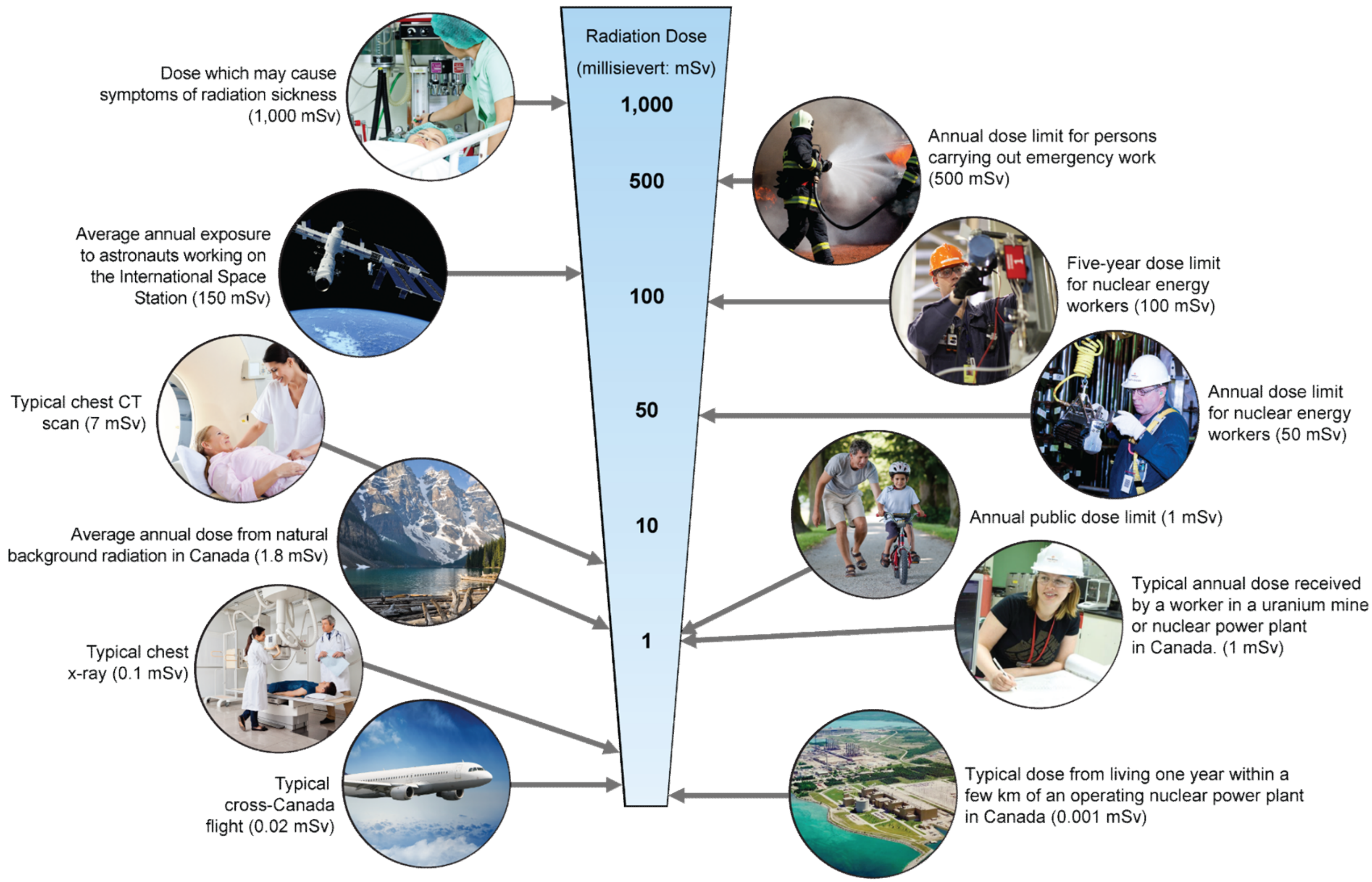


Average Annual Exposure in Canada

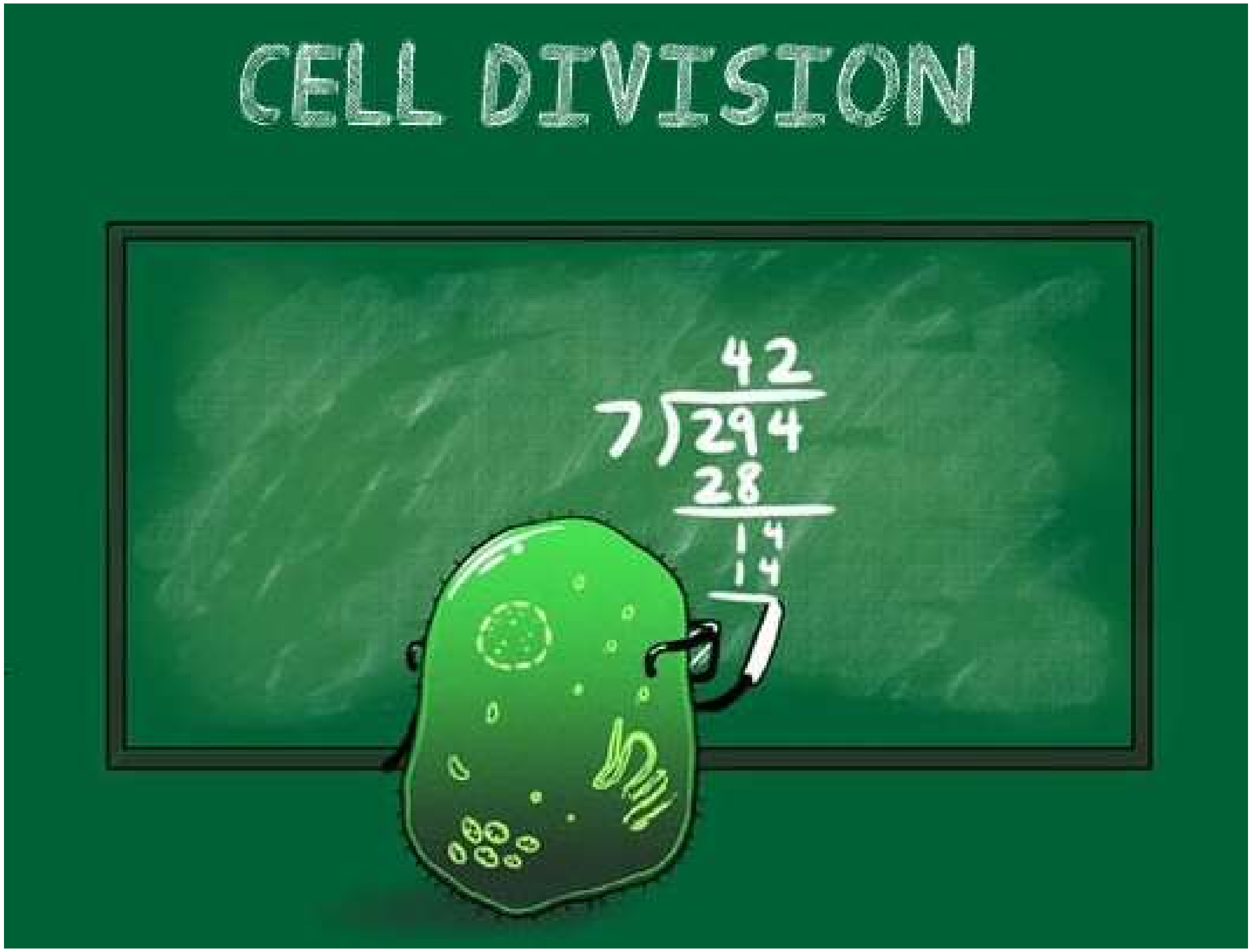
Figure 2: Source of Radiation to Which an Individual is Exposed in Everyday Life – Total Dose: 3.0 mSv/year [1]



Radiation Dose Examples



Radiation Biology

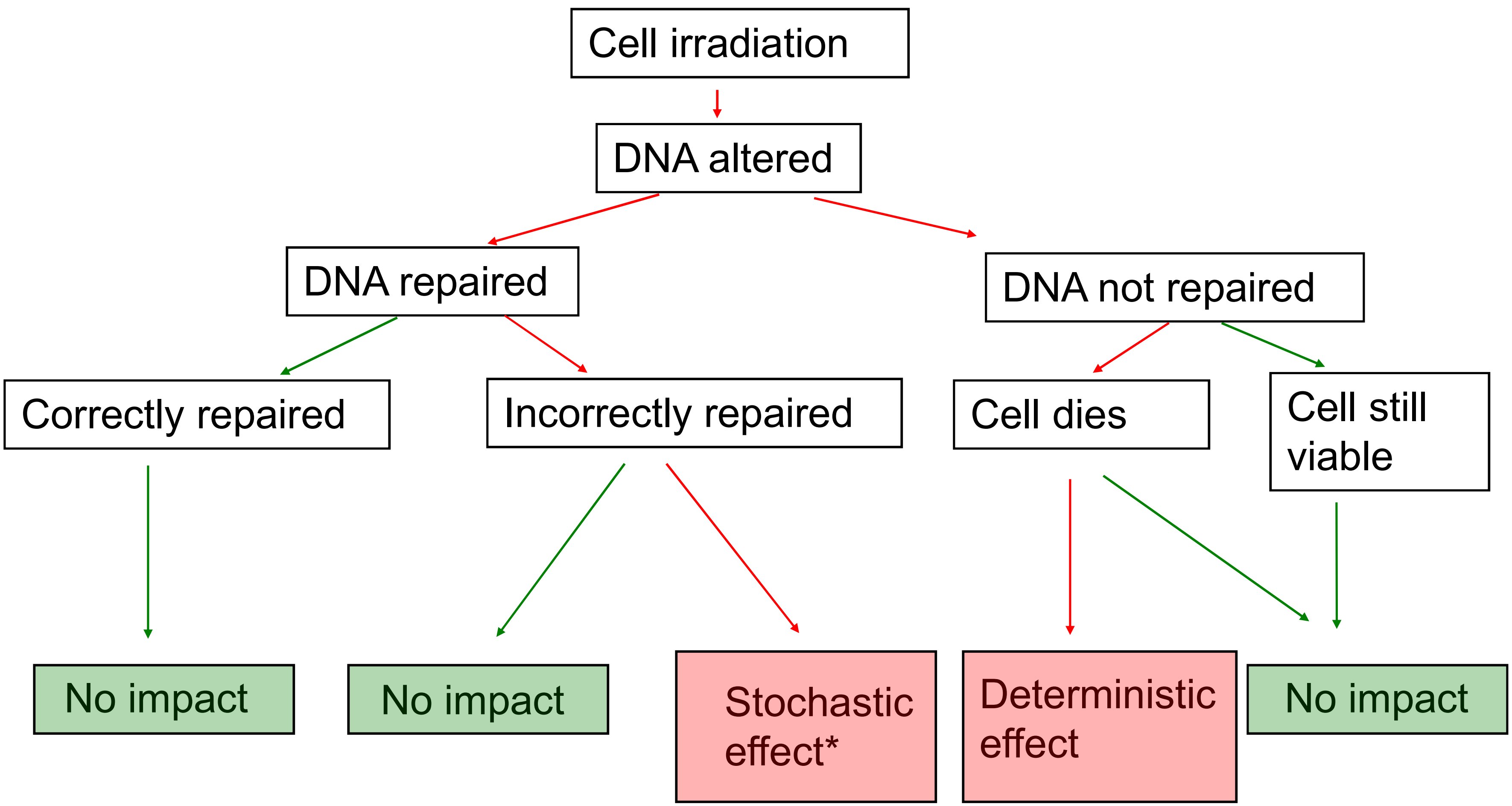


Radiation Effects

Depending upon severity of damage, the cell may:

1. Die (apoptosis or by DNA damage)
2. Incorrectly repair DNA, may eventually become cancerous
3. Repair DNA, continue to function

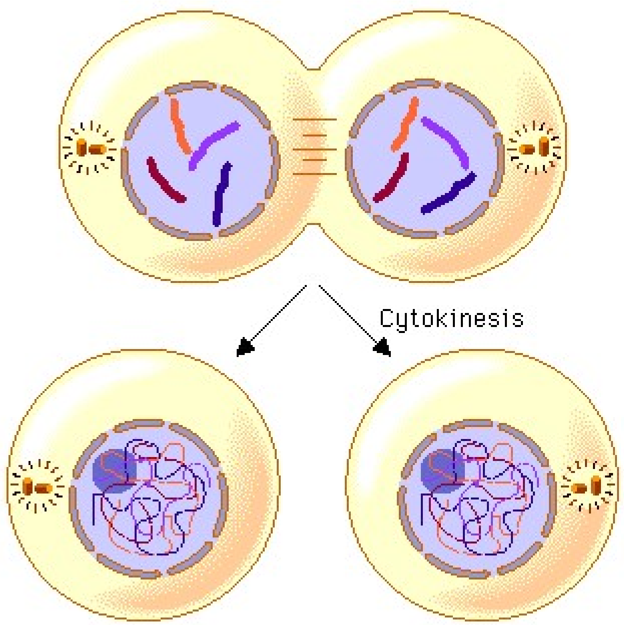
Radiation Effects



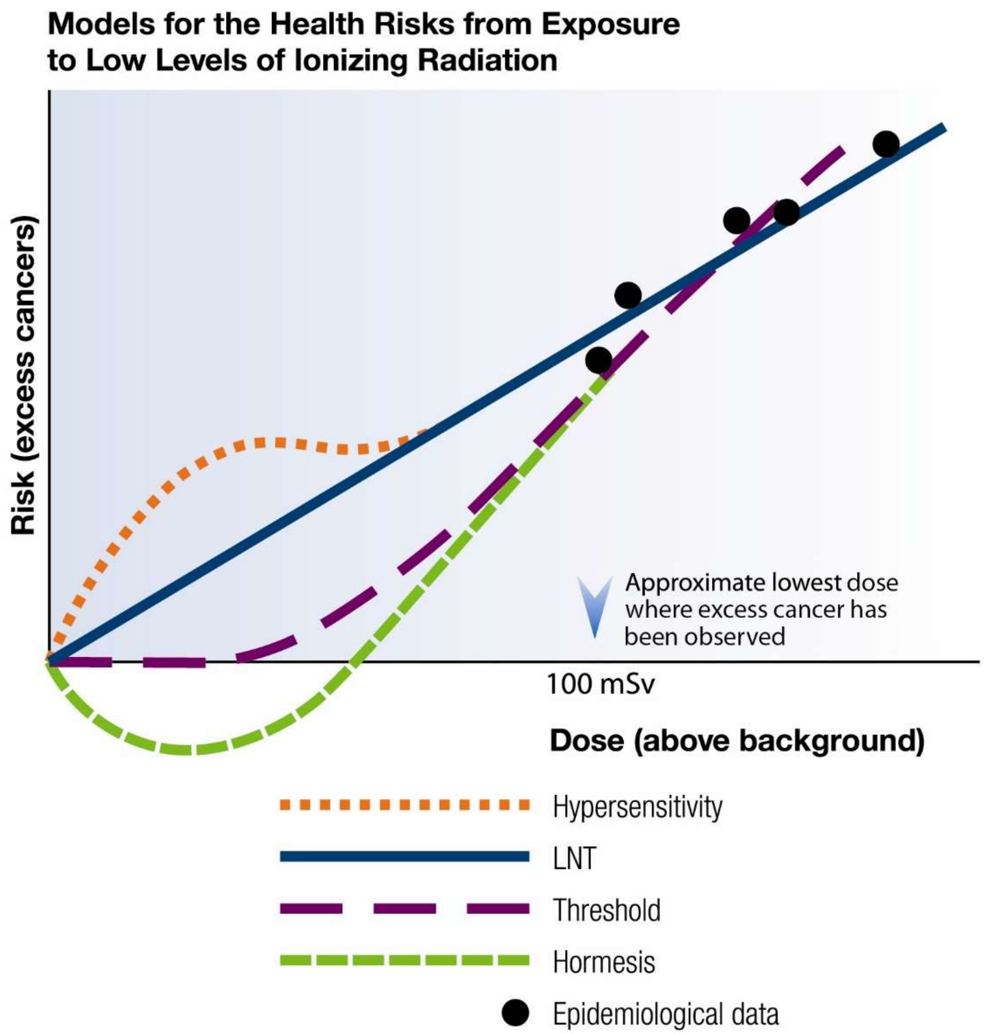
* Hereditary effect could occur if stochastic effect is apparent in the germ cells

Radiation Damage to the Cell

- Cells are the most sensitive to radiation just before they divide
  - i.e., chromosomes have just condensed
- Generally, cells that divide the most are the most sensitive to radiation damage
  - i.e., stem cells for blood, intestines

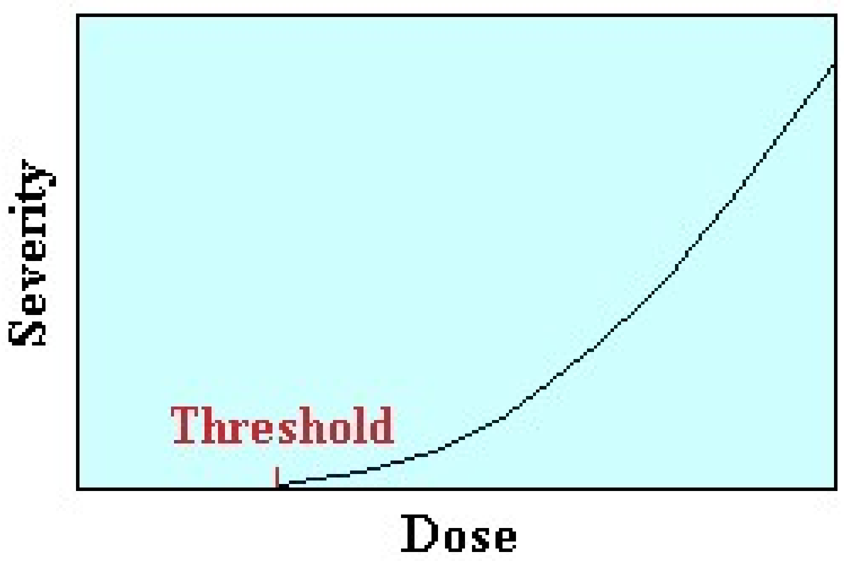


Radiation Risk Models



Deterministic Effects (tissue/organ)

- Dose response once threshold is reached
- Severity of effect increases with dose
- Effect occurs within hours to months
  - Short term or immediate effects



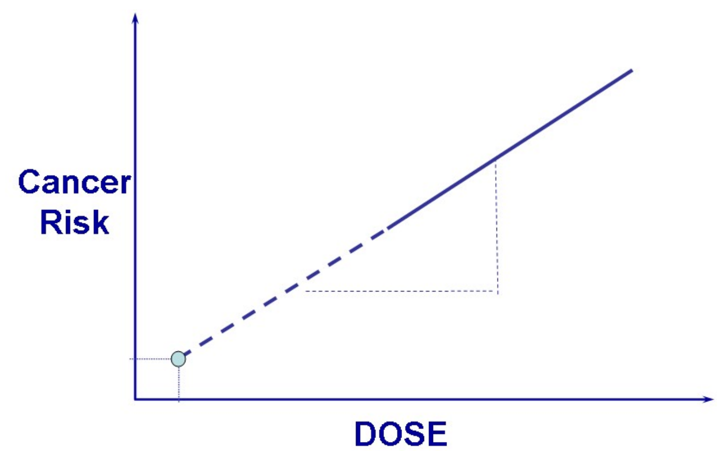
http://www.hko.gov.hk/education/dbcp/rad_health/eng/r4_1.htm

Summary of Acute Radiation Syndromes

Dose Range (Sv)	First Stage Symptoms	Manifestation of illness	Prognosis (without Treatment)
0.5 - 1	Mild	Slight decrease in blood cell counts	Almost certain survival
1.0 – 2.0	Mild to moderate	Early signs of bone marrow damage	Highly probable survival (>90%)
2.0 – 3.5	Moderate	Moderate to severe bone marrow damage	Probable survival
3.5 – 5.5	Severe	Severe bone marrow damage, slight GI damage	Death within 3.5 – 6 weeks (50% of vics.)
5.5 – 7.5	Severe	Drop in all blood cell counts and moderate GI damage	Death probable within 2-3 weeks
7.5 – 10.0	Severe	Marked GI and bone marrow damage, hypotension	Death probable within 1 – 2.5 weeks
10.0 – 20.0	Severe	Severe GI damage, Inflammation of lung tissue, altered mental status	Death certain within 5 – 12 days
20.0 – 30.0	Severe	Cerebrovascular collapse, fever, shock	Death certain within 2 – 5 days

Stochastic Effects

- Probability of occurrence increases with dose
- Delayed effect, generally from lower doses (long term effects)
- Effects include cancer and hereditary effects
  - Improperly repaired DNA damage
- Lowest dose to show an excess cancer ~100 mSv
  - New research is beginning to challenge this statement



Summary of Radiation Effects

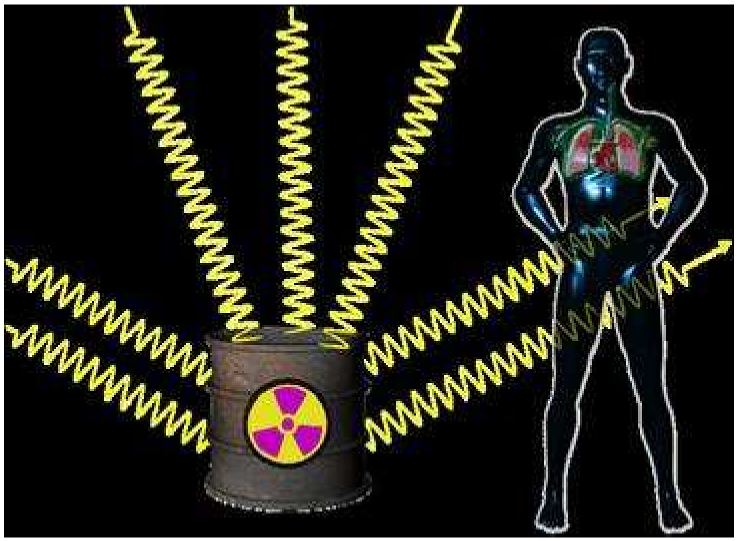
- Know that high doses can cause significant damage: Deterministic effects and Stochastic effects
- Think that low doses may cause stochastic effects
- Impossible to differentiate low dose effects from baseline cancer rates
- Baseline cancer incidence (Canada 2007): 46% men - 41% women
- Risk of fatal cancer ~ 0.005% per mSv (ICRP 60)

Radiation Protection Principles

Radiation Protection – ALARA Principle

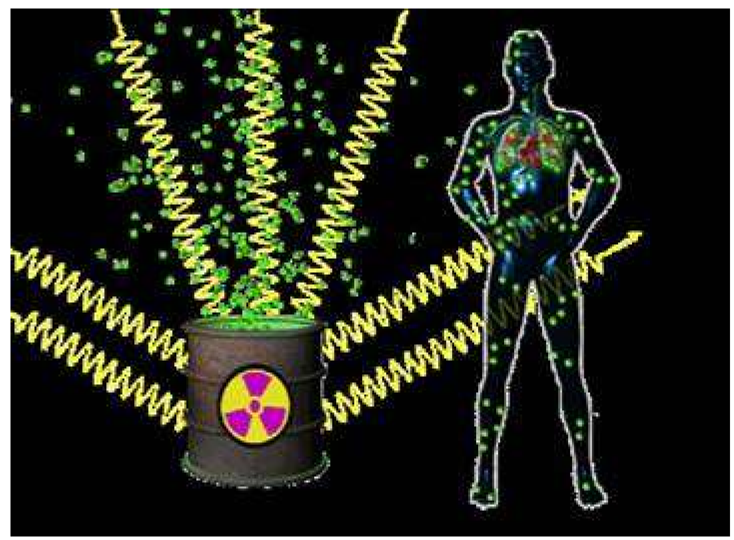
- ALARA is an acronym that means **As Low As Reasonably Achievable**
- The goal is to keep exposure to radiation as low as reasonably achievable. This will keep the dose received, and the chance of potential harmful effects, to a minimum

Radioactive Contamination vs Exposure



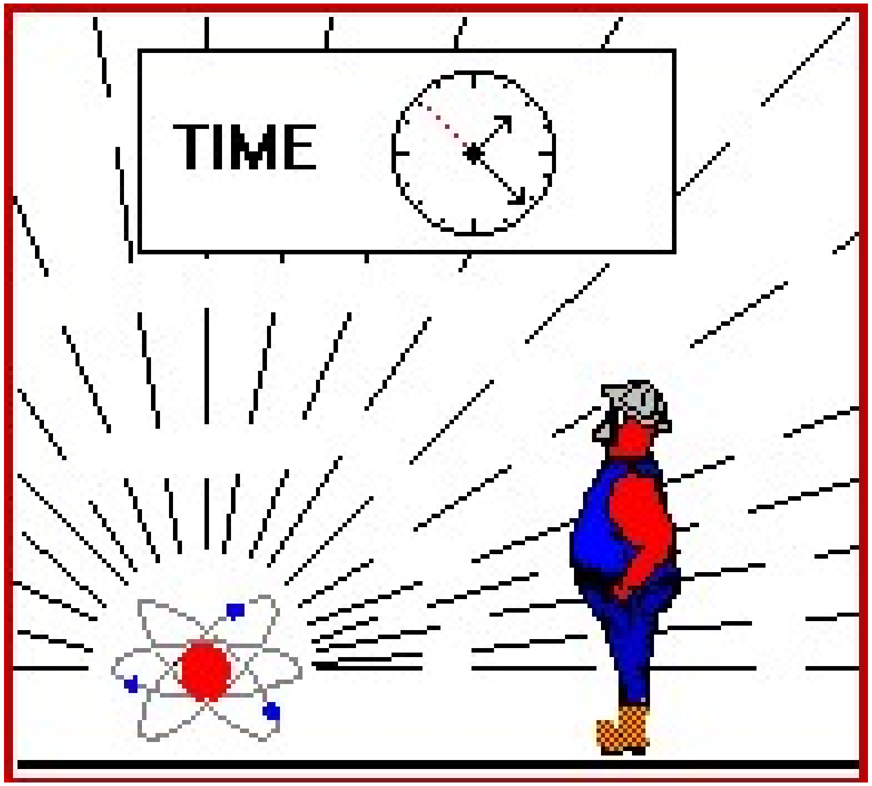
Contamination and internal dose: Radioactive material can be on a person (contamination) or in a person (internal dose)

Exposure (external dose) : Irradiation of the body when in the presence of a radioactive source



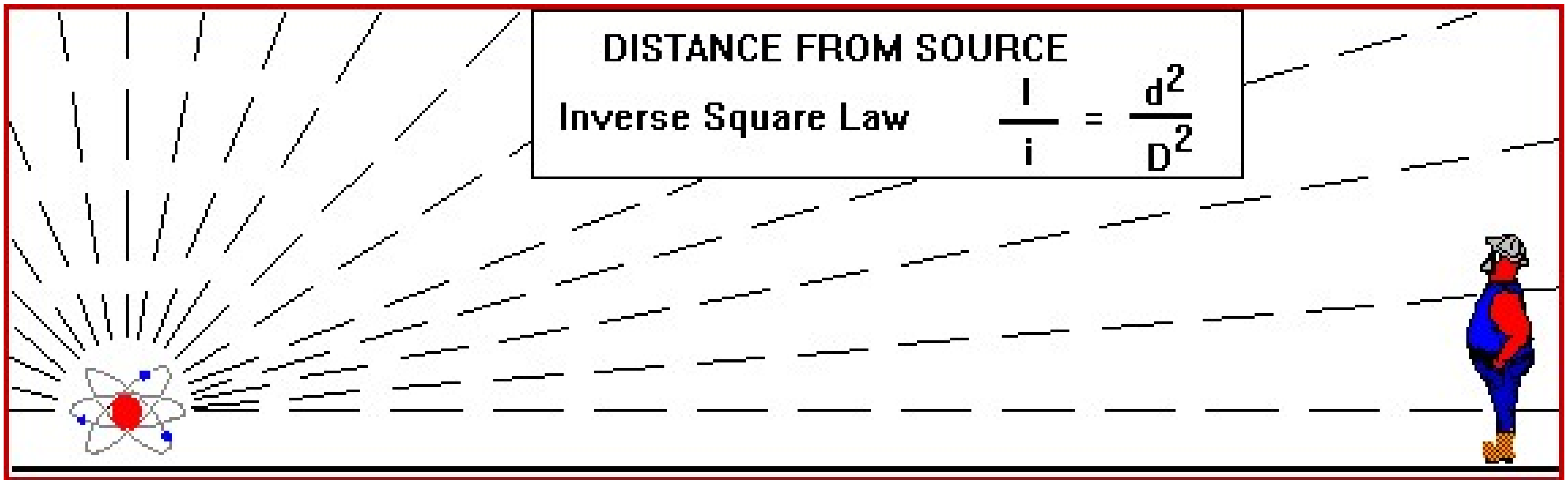
Radiation Protection - Time

Reducing the time spent in the area of radiation will reduce the radiation dose received



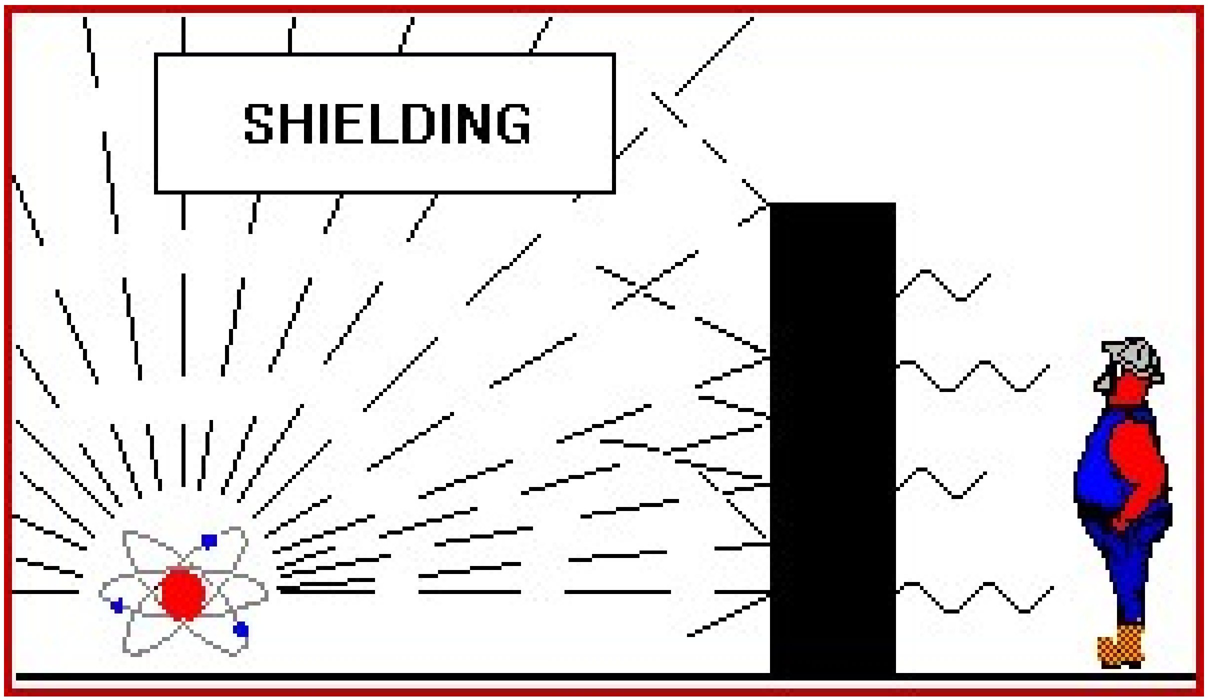
Radiation Protection - Distance

The effects of radiation decreases as you move away from the radiation source in accordance with the inverse square law



Radiation Protection - Shielding

Substances referred to as shielding can also be placed between you and the radioactive material as a protective measure

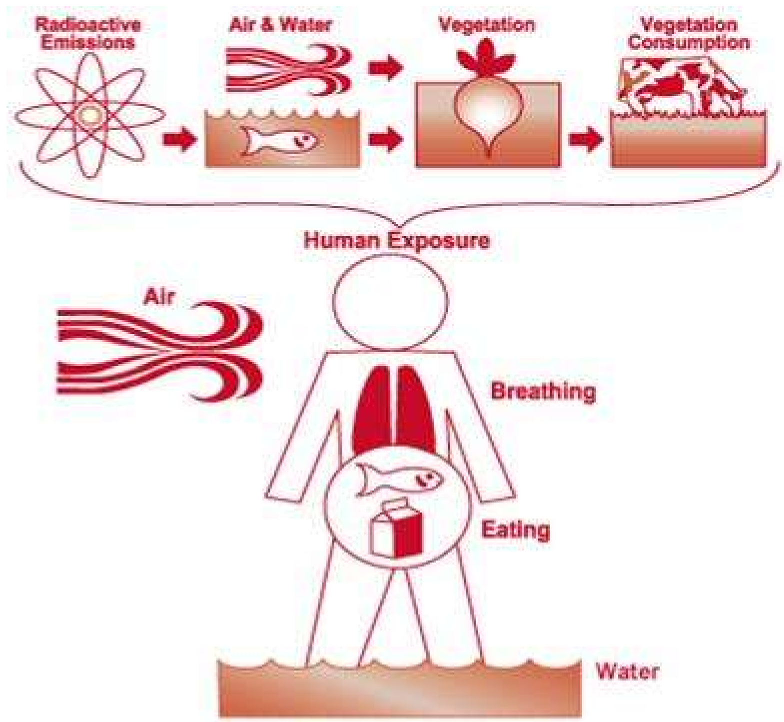


Shielding




Internal Contamination

- Entry into the body by:
  - Inhalation
  - Ingestion
  - Injection
  - Absorption



Internal Radiation Protection

- By utilizing the following equipment and procedures, one can protect against internal radiation hazards:
  - –Respirators
  - –PPE
  - –Upwind
  - –Protocols
  - –Hygiene
  - –Containment
  - –Segregation

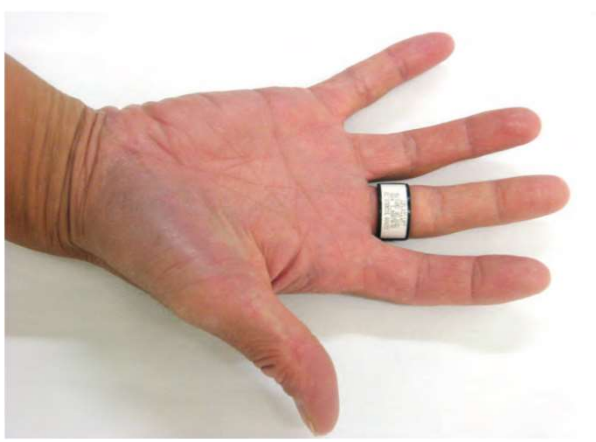
Internal and External Dosimetry

- Internal Dosimetry = Measuring doses from radioactive materials inside the body

- External Dosimetry = Measuring doses from sources outside the body

Personal Dosimetry: External

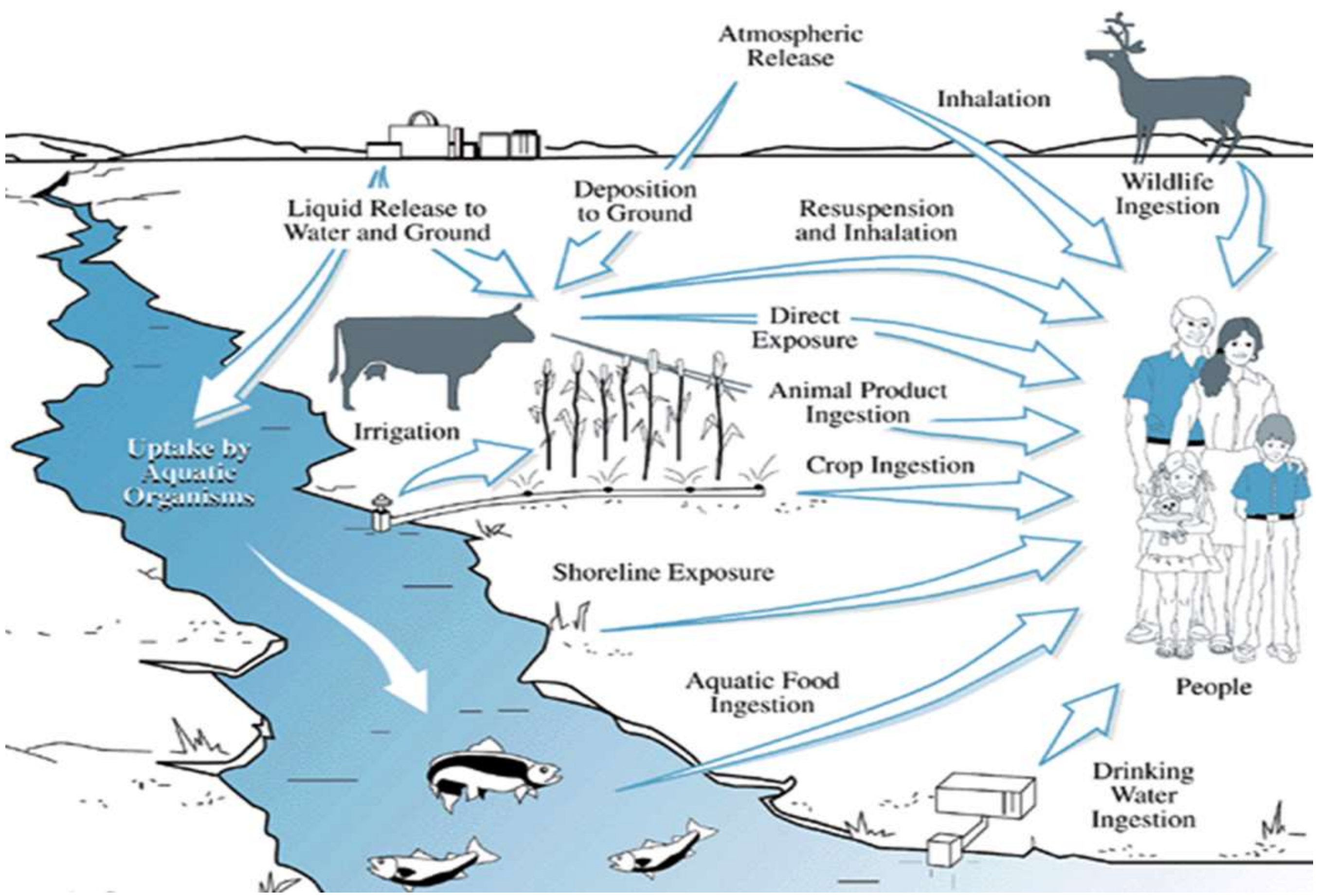
- ***External Dosimetry***: measurement or determination of dose when the radiation source is outside of the body
- ***Dosimeter***: a device worn on the body that is capable of measuring dose deposited



Internal Dosimetry
Purpose and General Approach

- Purpose: to determine the dose that results when nuclear substances are in the body
- Consists of determining:
  - quantity and type of nuclear substances in a person and
  - radiation energy absorbed within the body

Modelling Doses for Members of the Public



Dose Reporting

- CNSC licensees must ascertain and record doses to workers
- Doses measured by licensed dosimetry service must be submitted to the National Dose Registry
  - National repository for dose records
  - Owned and Operated by Health Canada
  - Used for compliance activities, trend reporting and health studies

Radiation Sources in Canadian Industry

- Power plants
- Research Reactors
- Fixed Nuclear gauges (Mining, Mills, etc)
- Portable gauges (Civil Engineering)
- Various isotopes in medical diagnosis and treatment
- Industrial radiography
- Oil and gas industry
- Universities and laboratories

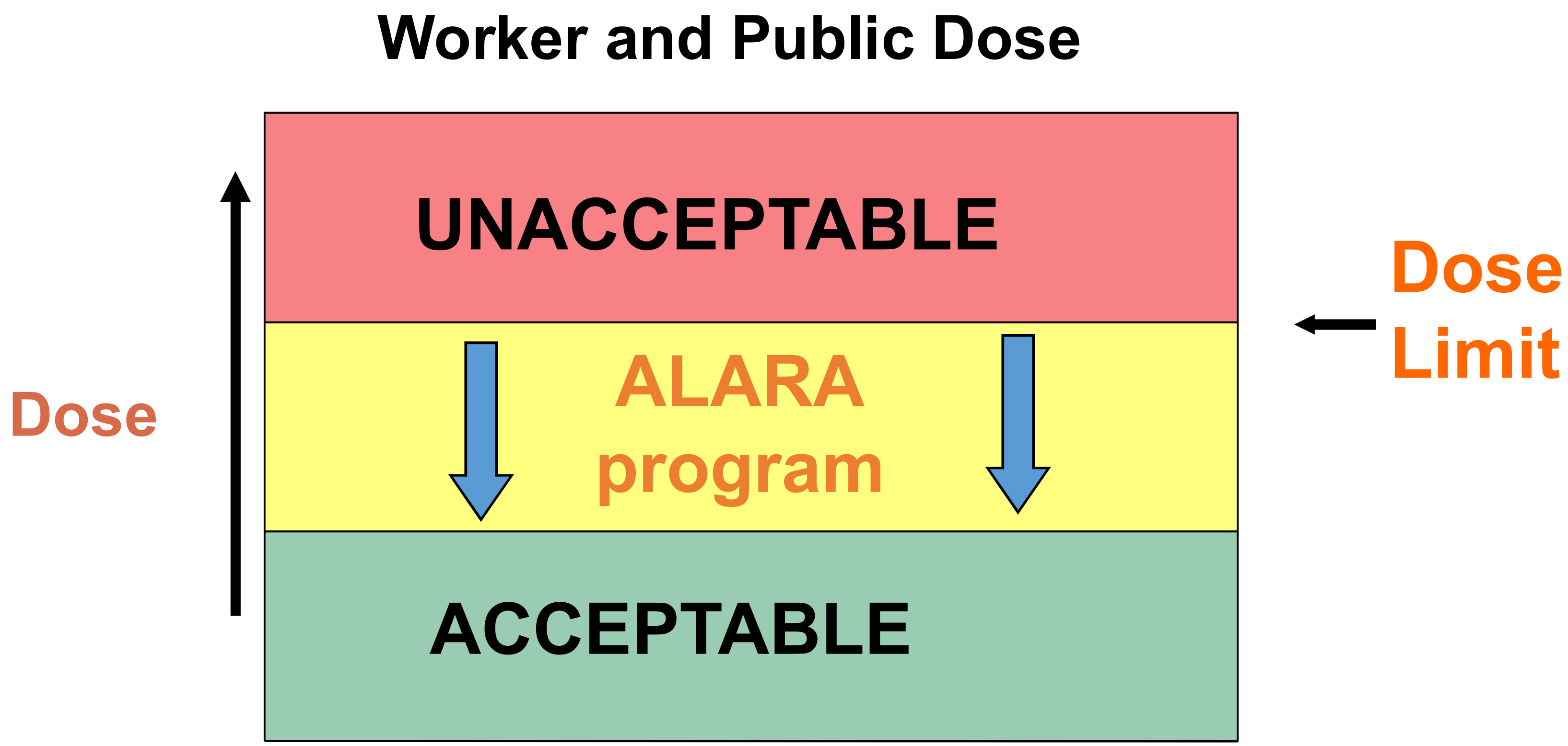
Radiation Protection Regulations

- Enforced under the *Nuclear Safety and Control Act*
  - the CNSC regulates all nuclear activities in Canada in order to protect the health and safety of workers and the public from ionizing radiation
  - the RP regulations play an important role in achieving this goal by
    - placing limits on radiation doses to workers and members of the public, and
    - by requiring all CNSC licensees to implement radiation protection programs

Radiation Protection Program

- Requirements of the RP program:
  - (i) management control over work practices
  - (ii) personnel qualification and training
  - (iii) control of occupational and public exposure to radiation, and
  - (iv) planning for unusual situations
- Ascertain the quantity and concentration of any nuclear substance released as a result of the licensed activity

Radiation Dose Limitation Framework



Dose Limits

Person	Period of Time	Effective Dose (mSv)
Nuclear energy worker	One-year dosimetry period	50
	Five-year dosimetry period	100
Pregnant nuclear energy worker	Balance of the pregnancy	4
Any other person	One calendar year	1

From the Radiation Protection Regulations, Section 13(1)

Choosing a Worker Dose Limit

- International Commission of Radiation Protection (ICRP) judged that the dose limit should be set so the total effective dose received in a working life would be prevented from exceeding 1 Sv received moderately uniformly year by year

- Annual and five year dose limits are used to ensure doses are distributed fairly uniformly over the occupational age range