Health Physics Fundamentals

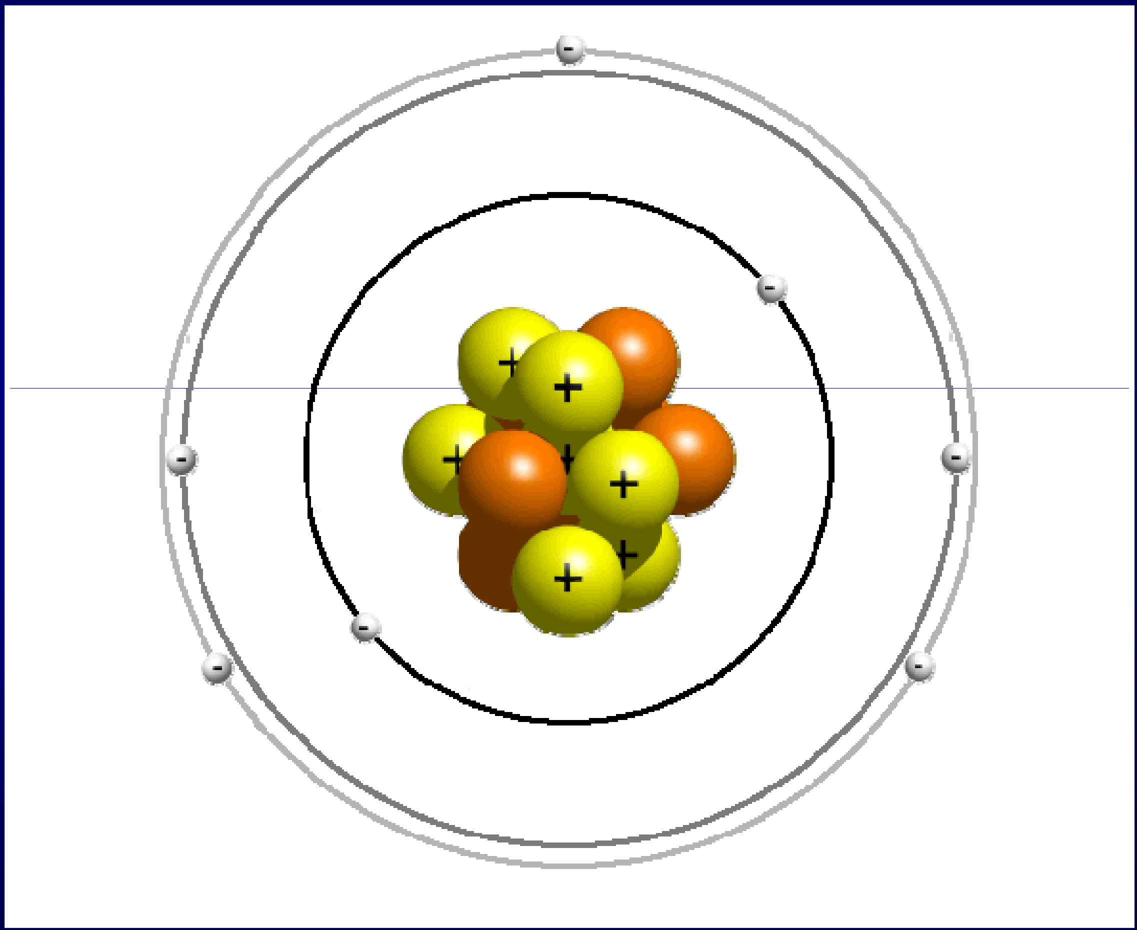
Objectives of this Brief Overview

- Review basic atomic structure
- Discuss radiological definitions, terms and units
- Discuss radioactive decay and characteristics of radiation
- Discuss differences between external and internal radiation exposure

Objectives of this Brief Overview

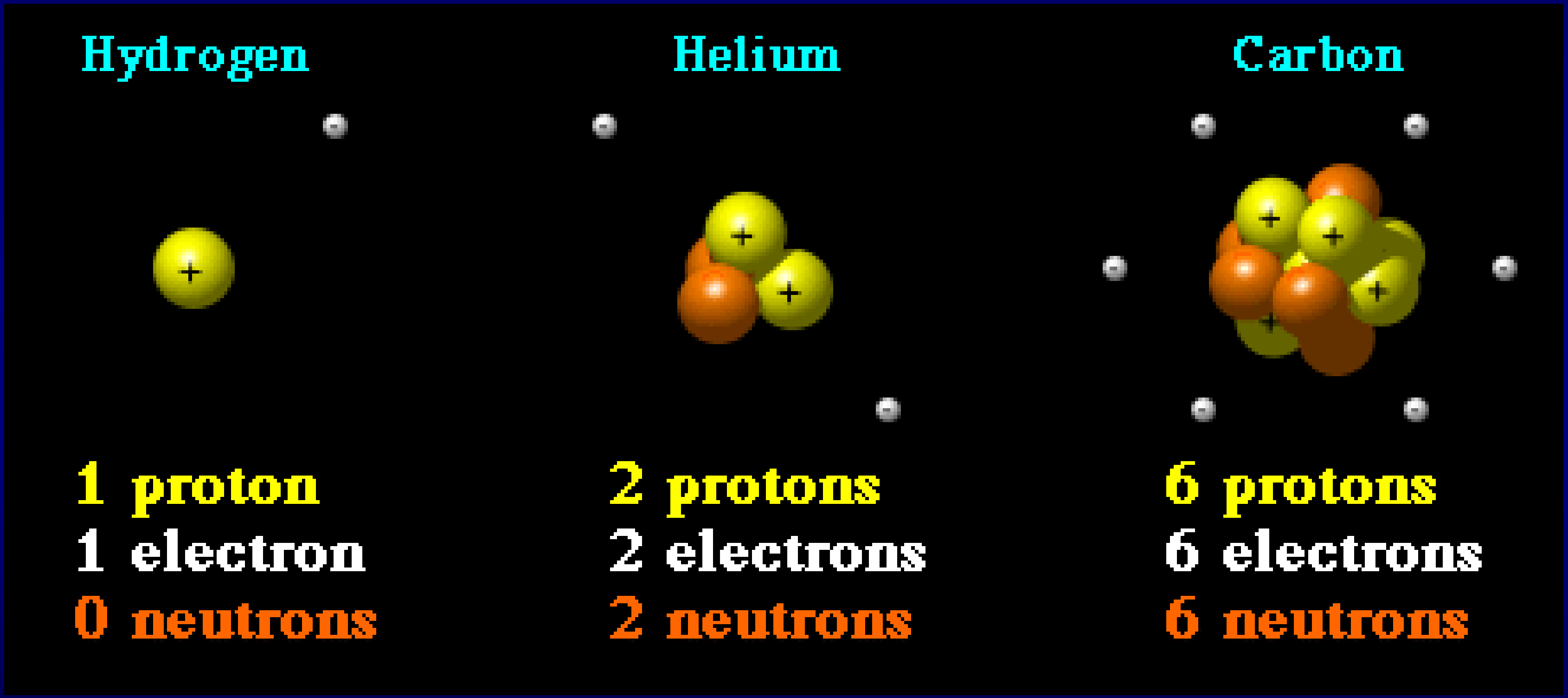
- Discuss NRC dose limits for radiation workers and members of the public
- Summarize sources of radiation exposure
- Discuss biological effects of high levels of radiation
- Discuss biological effects and estimated risks from low levels of radiation

Atomic Structure

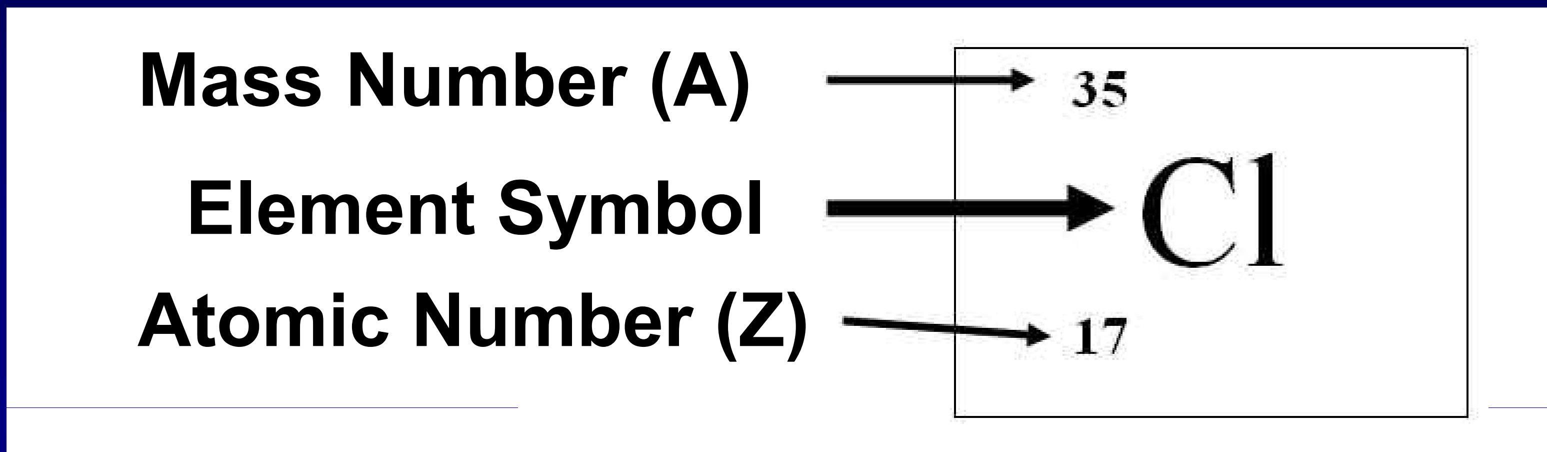


- Nucleus contains protons (+) and neutrons
- Electrons (-) exist in orbital shells outside of the nucleus

Atomic Structure

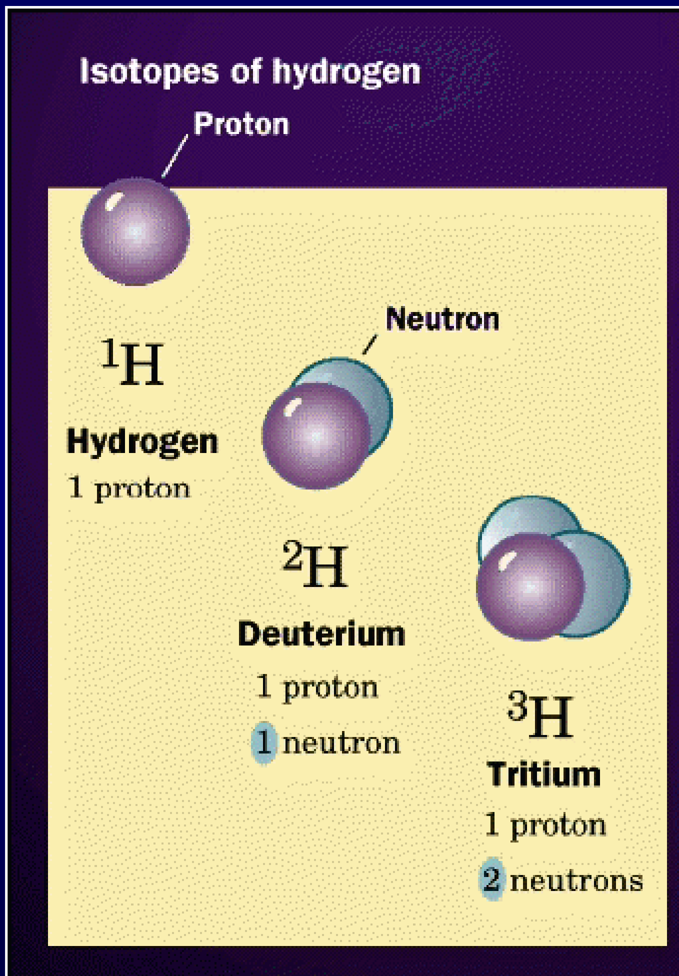


Atomic Notation

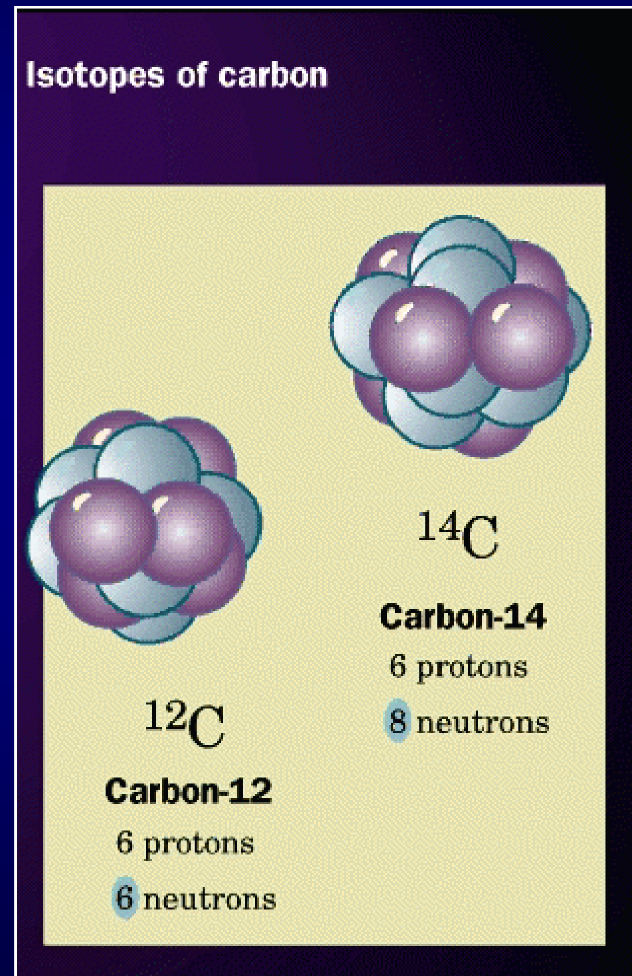


- The atomic mass, A, is the total number of protons and neutrons in the atom's nucleus
- Elements are determined by the number of protons in the nucleus or the Atomic Number, Z
- Example above is commonly written as Cl-35

Isotopes



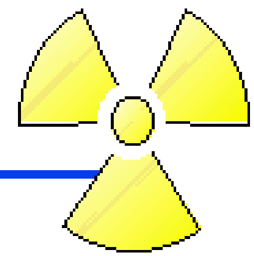
Isotopes of hydrogen
Proton
Neutron
^{1}H
Hydrogen
1 proton
^{2}H
Deuterium
1 proton
1 neutron
^{3}H
Tritium
1 proton
2 neutrons



Isotopes of carbon
^{14}C
Carbon-14
6 protons
8 neutrons
^{12}C
Carbon-12
6 protons
6 neutrons

Definitions

Radiation and Radioactivity



- Radiation: Energy in transit, either as particles or electromagnetic waves
- Radioactivity: The characteristic of various materials to emit ionizing radiation
- Ionization: The removal of electrons from an atom. The essential characteristic of high energy radiations when interacting with matter.

Radioactivity and Radiation

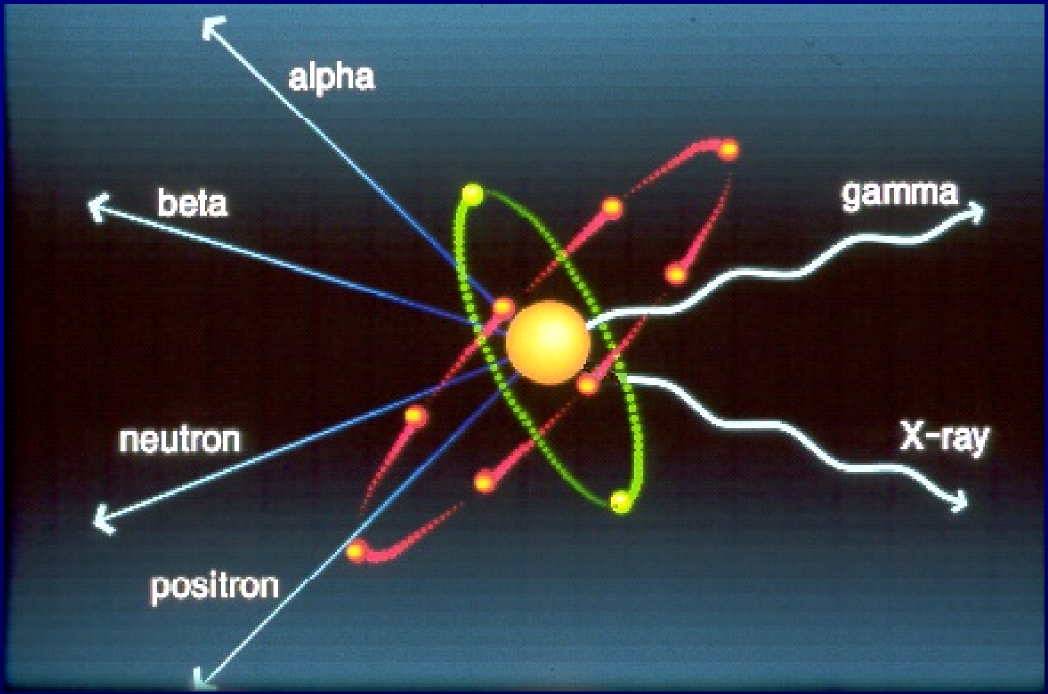
Particle emission

α

β^-

${}_0n^1$

$\beta+$

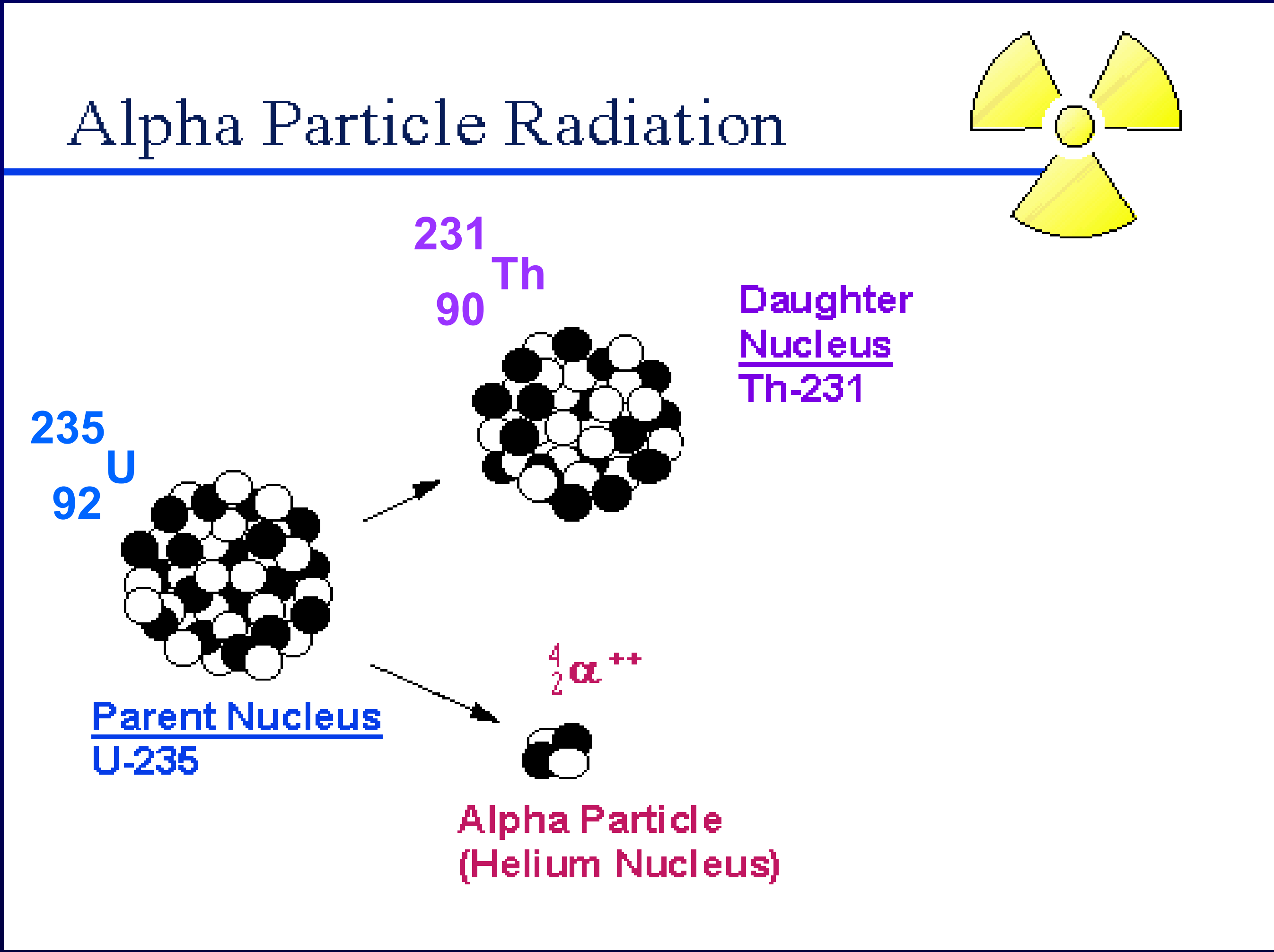


Photon emission

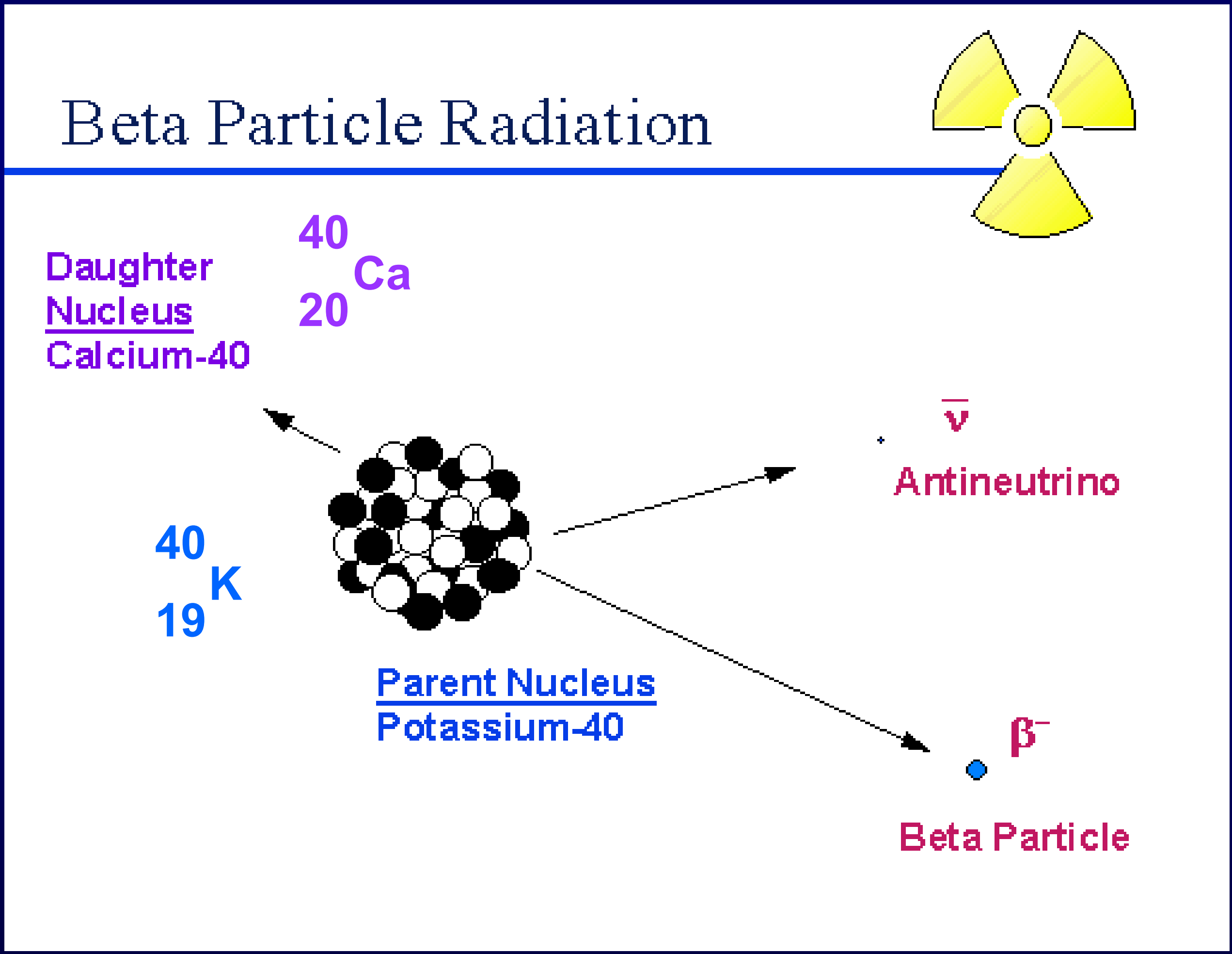
γ

x-ray

Radioactive Decay

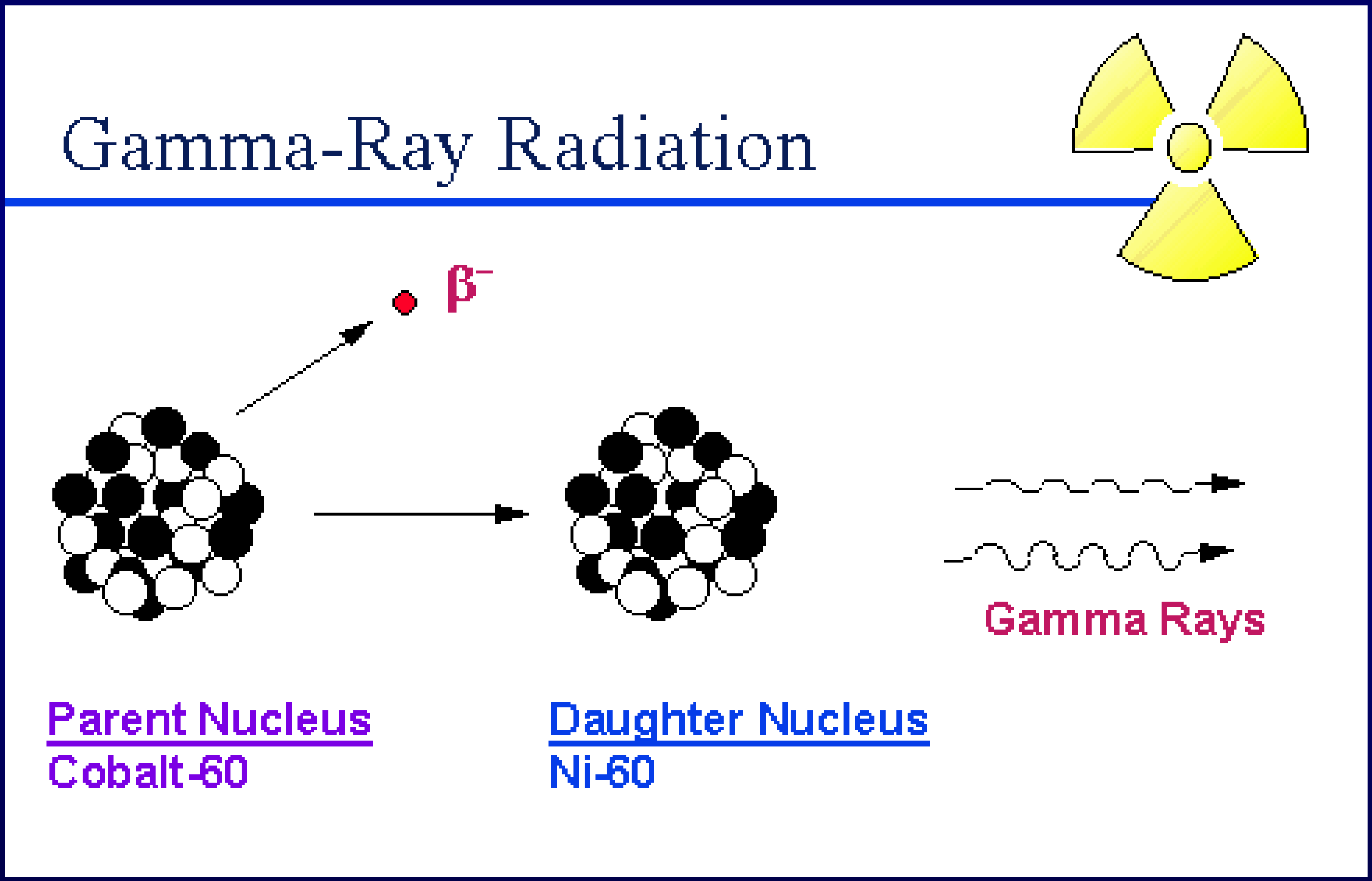


Radioactive Decay

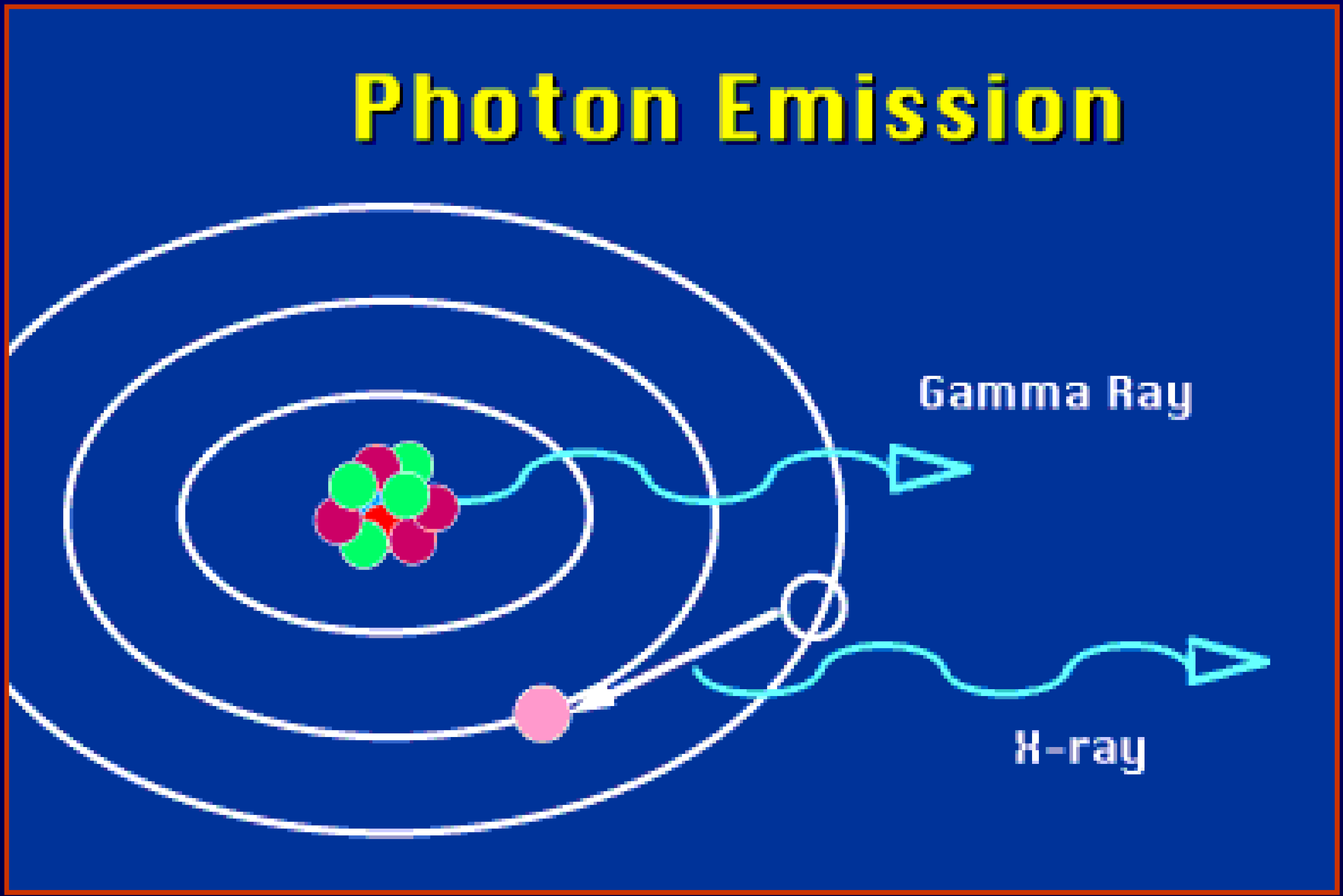


$n \rightarrow p^+ + \beta^- + \bar{\nu}$

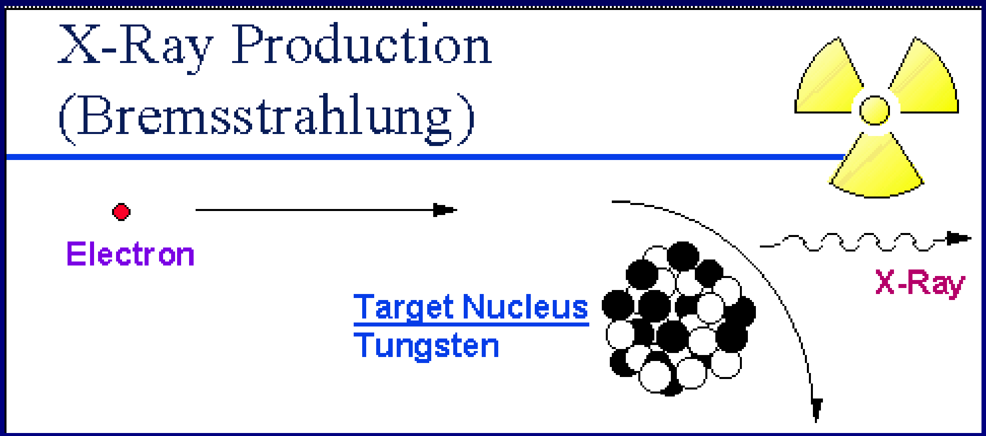
Gamma Ray Emission

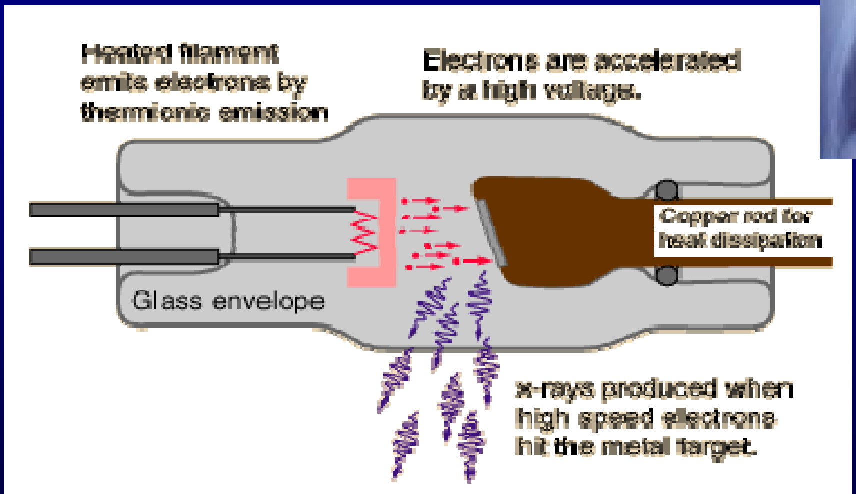


The Difference Between X-Rays and Gamma Rays

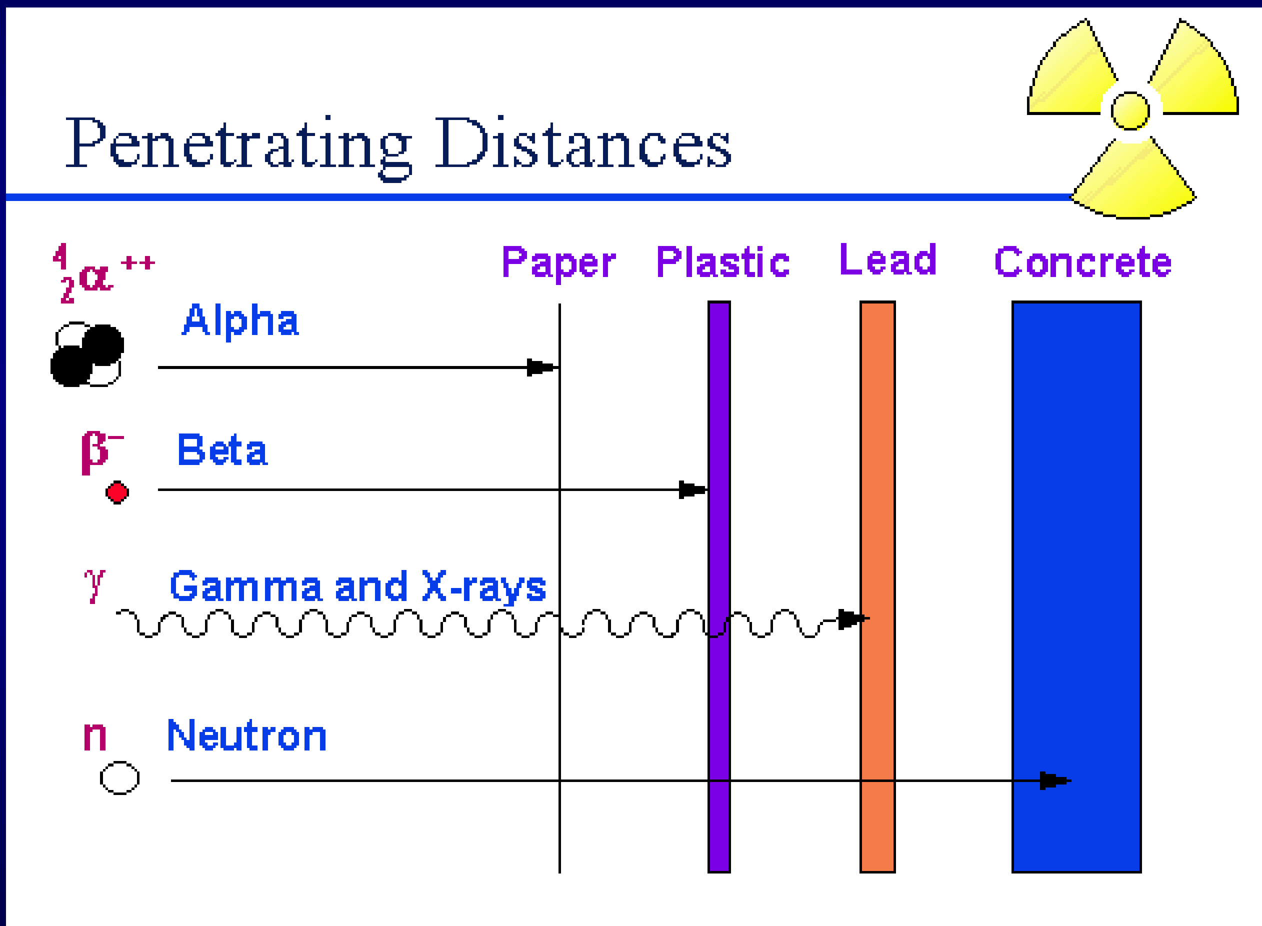


X-Ray Production - Bremsstrahlung

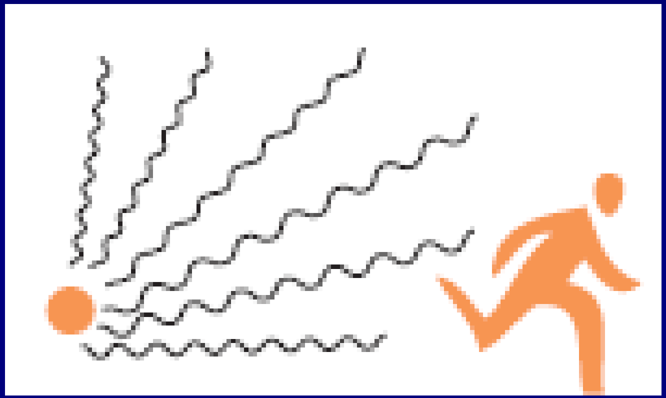




Radiation Penetration



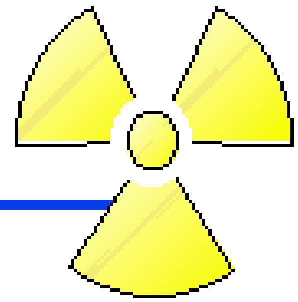
(Depends on energy & thickness of material)



Radiation vs. Contamination

Activity

Measures of Radioactivity



Activity: The quantity of radioactive material present at a given time:

- Curie (Ci) : 3.7×10^{10} disintegration per second (dps)

or

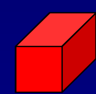
- Becquerel (Bq): 1 dps

Mass vs Activity

0.001 g

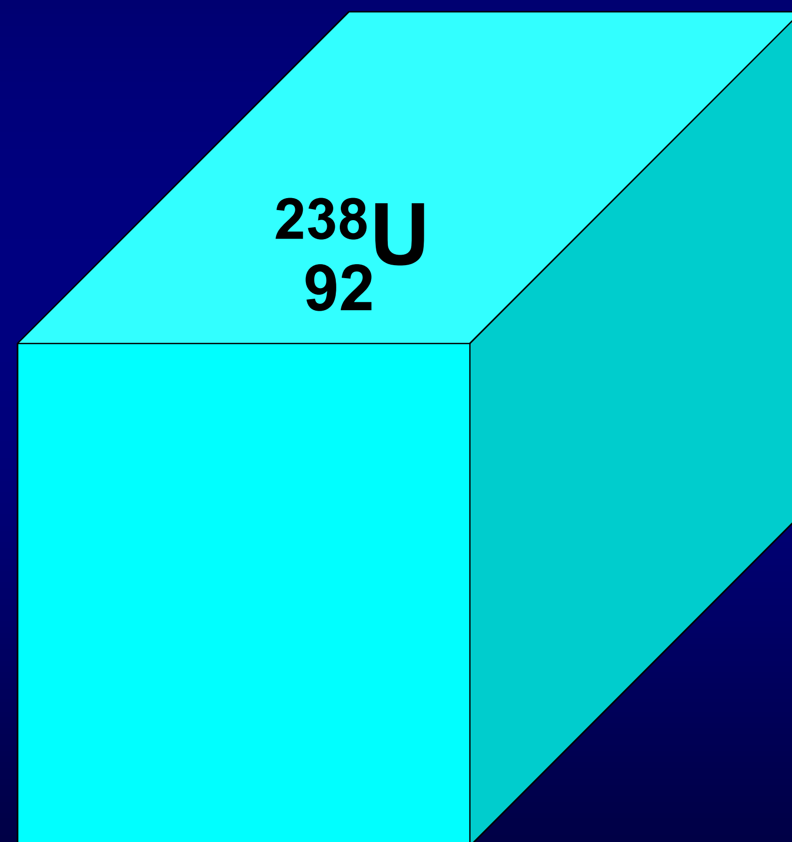
$^{60}_{27}Co$

1 g



$^{226}_{88}Ra$

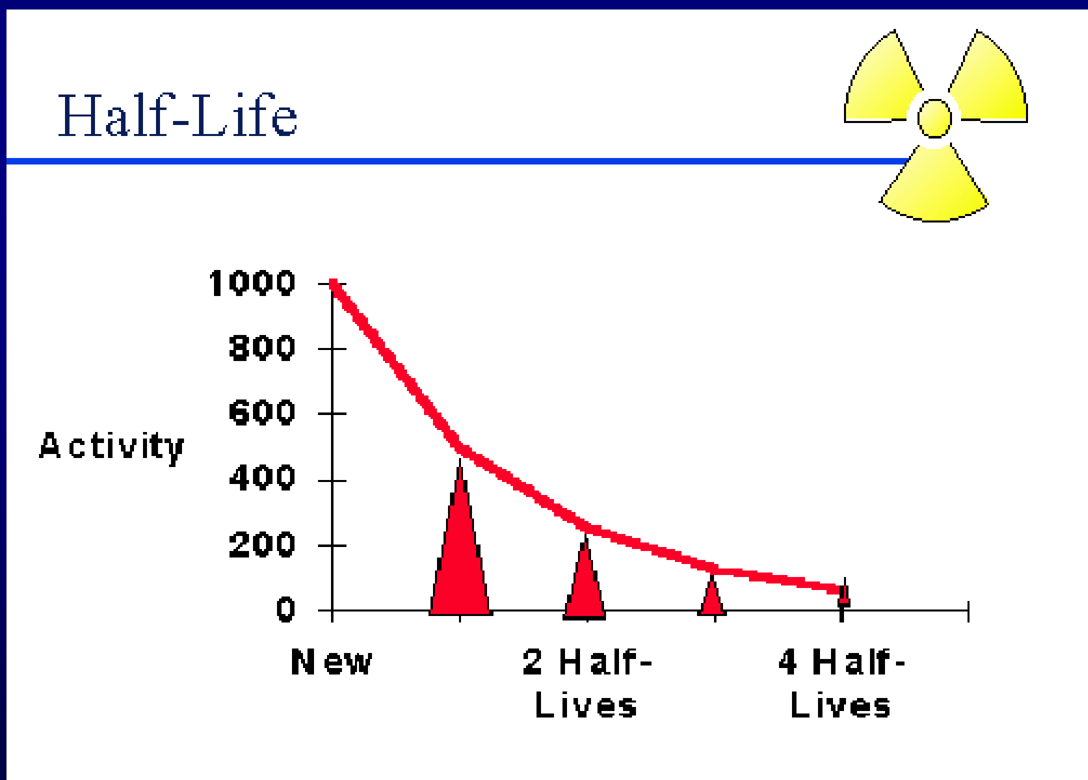
635,600 g



Amount in grams of each isotope equaling one curie of activity

Half-Life

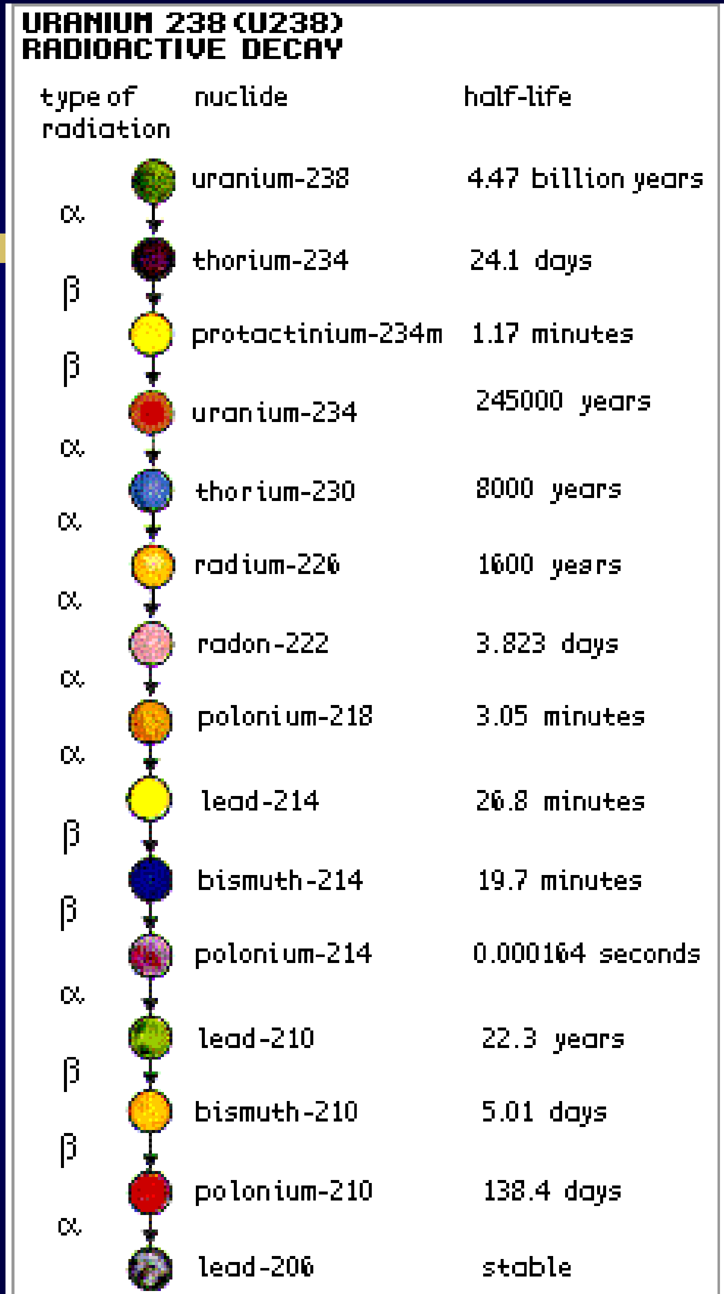
- Amount of time for half of the activity to decay
- Unique to each radionuclide



- N-16 is 7 sec
- Co-60 is 5.3 yrs
- U-238 = 4.47 billion yrs

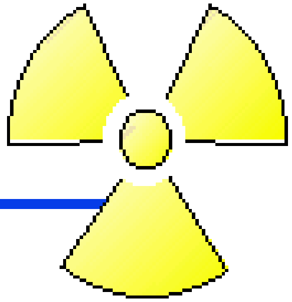
Serial Decay

- Some radioisotopes decay into daughter products that are also radioactive. An example is the U-238 decay series.
- As seen within the U-238 series, decay can occur via alpha, beta and gamma.
- Each isotope within a series has its own unique half-life which can vary from fractions of a second to billions of years.



Radiation Units

Radiation Units



- Roentgen: A unit for measuring the amount of gamma or X rays in air
- Rad: A unit for measuring absorbed energy from radiation
- Rem: A unit for measuring biological damage from radiation

Radiation Units

rad - unit of absorbed dose

rem - unit of dose equivalent

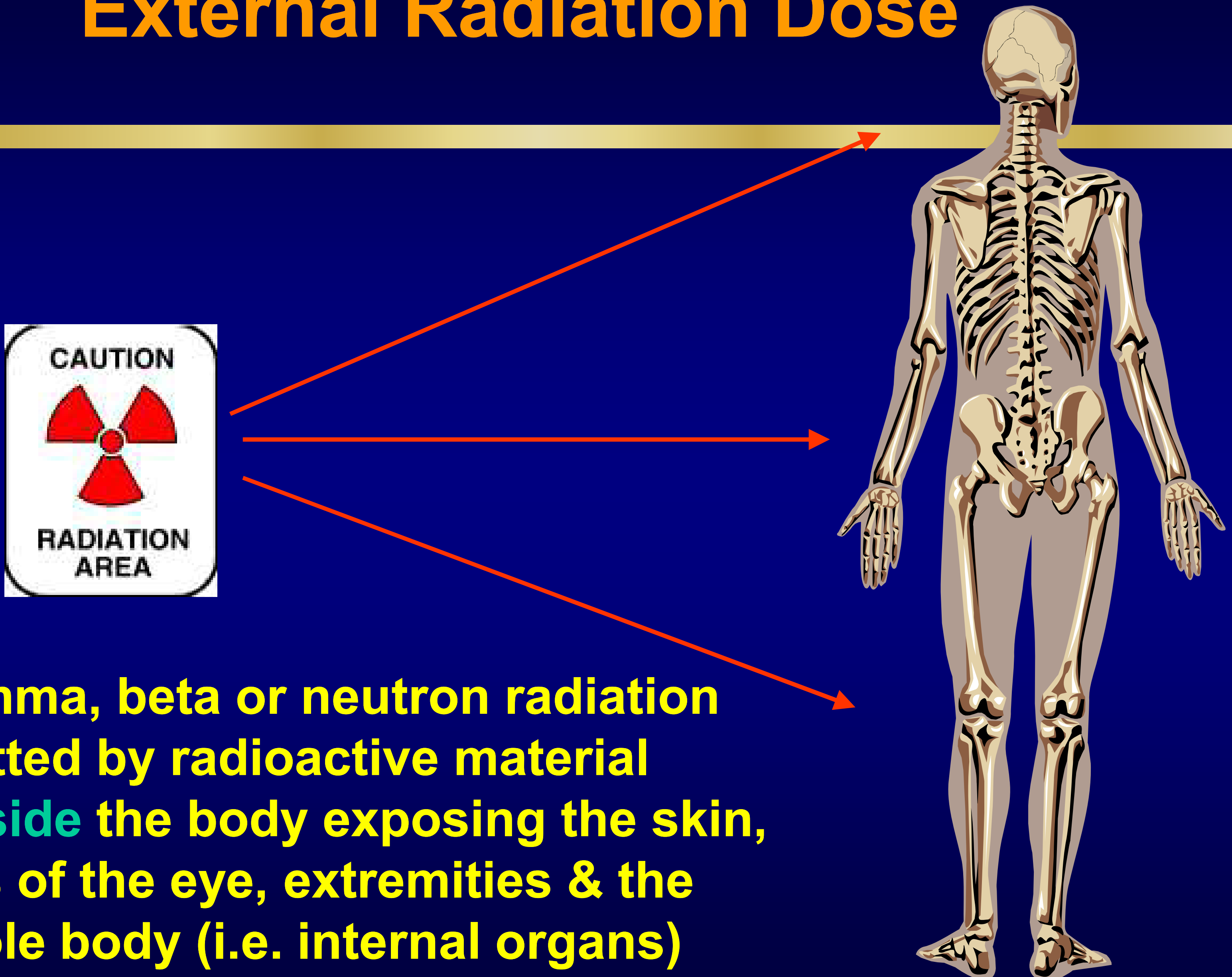
rem = rad x Q

Q = 1 for beta and gamma	(1 rad = 1 rem)
Q = 10 for neutrons*	(1 rad = 10 rem)
Q = 20 for alpha	(1 rad = 20 rem)

Radiation Units

Quantity	Traditional Unit	SI Unit	Conversion Factor
Absorbed Dose	rad	gray (Gy)	1 Gy = 100 rad
Dose Equivalent	rem	Sievert (Sv)	1 Sv = 100 rem
Activity	curie (Ci)	Becquerel (Bq)	1 Ci = 3.7×10^{10} Bq

External Radiation Dose



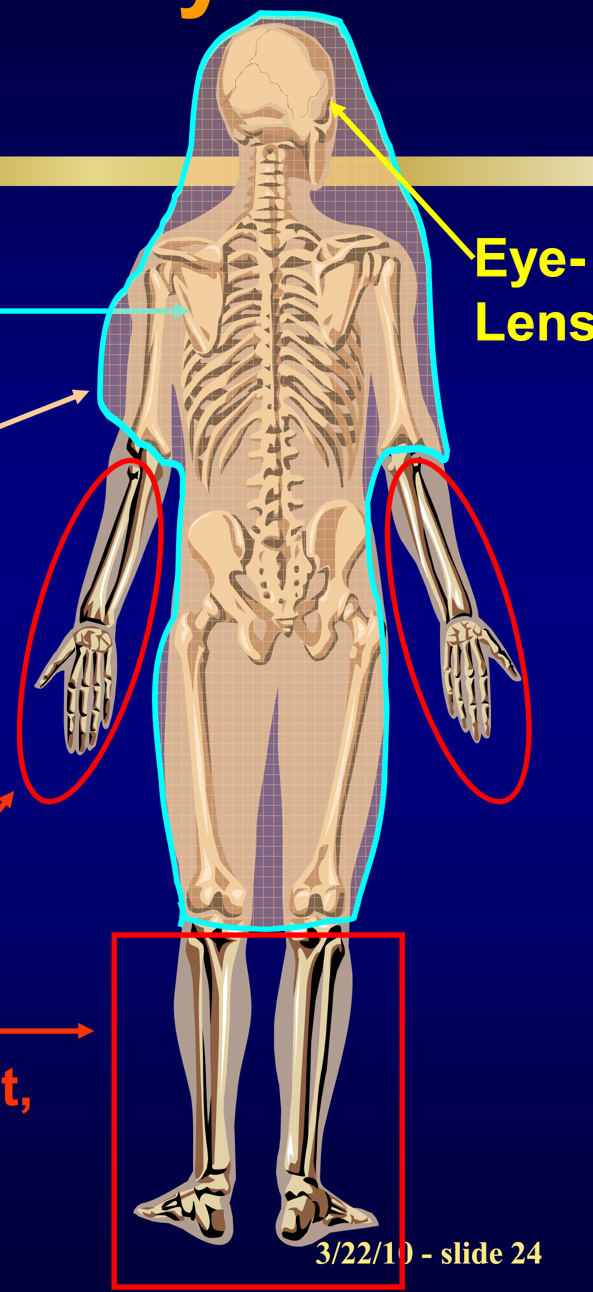
Gamma, beta or neutron radiation emitted by radioactive material outside the body exposing the skin, lens of the eye, extremities & the whole body (i.e. internal organs)

"Skin," "Extremities," "Eye" and "Whole Body"

Whole Body -
everything except extremities

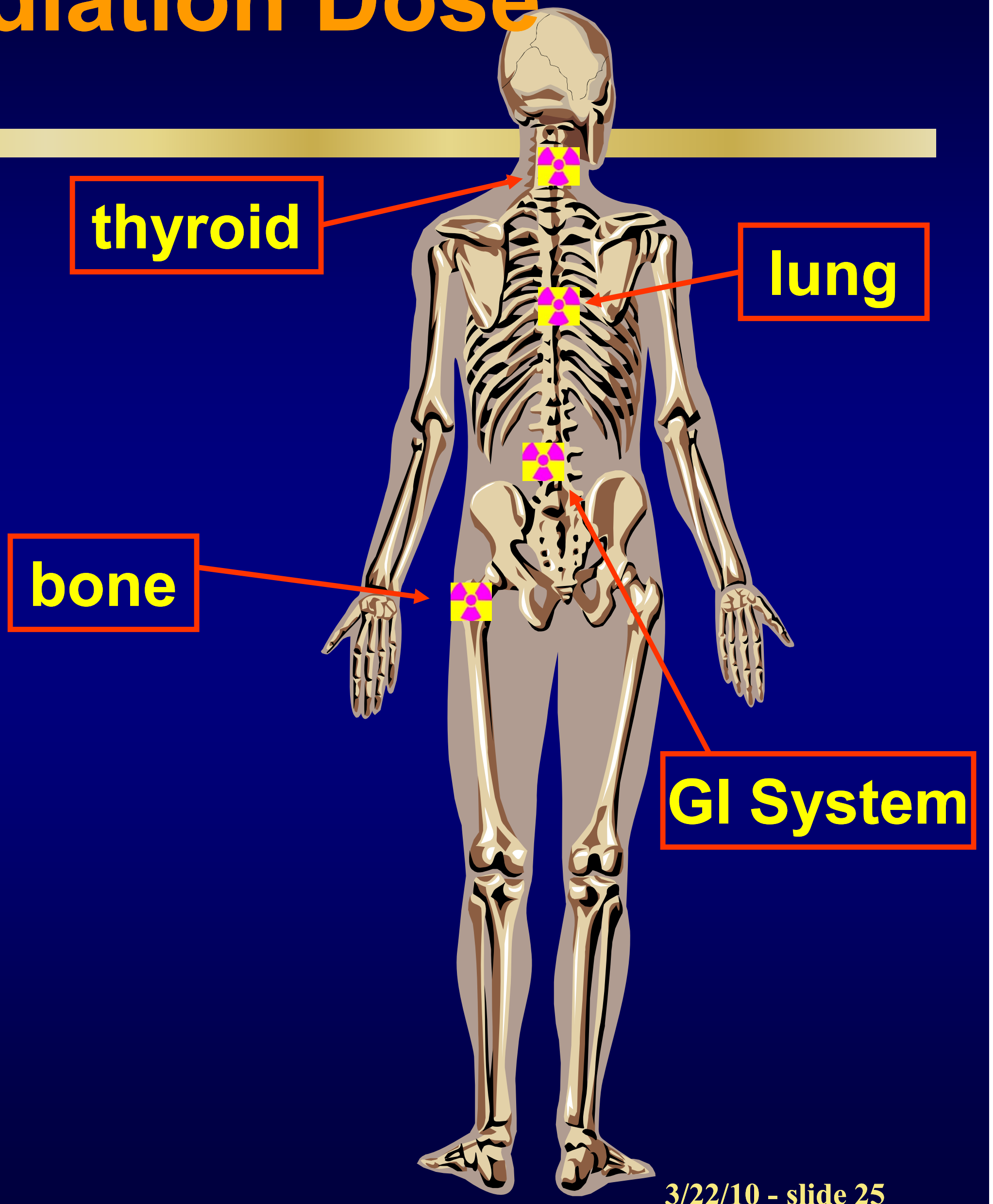
Skin of the Whole Body -
skin covering everything except the extremities

Extremities -
Hands, elbow, and arm below elbow, foot, knee, or leg below knee



Internal Radiation Dose

Alpha, beta or gamma radiation emitted by radioactive material inside the body can expose internal organs such as:



Radiation Hazards to the Human Body

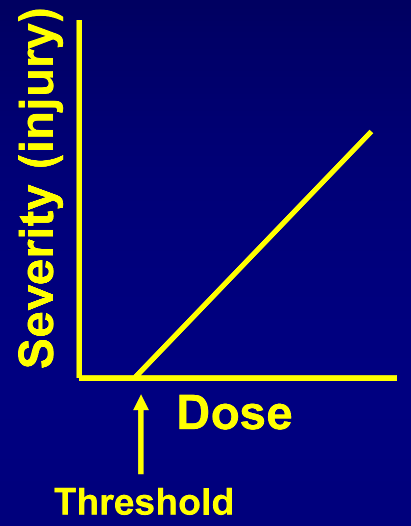
Radiation	External	Internal
Alpha		X
Beta	X	X
Photons	X	X
Neutrons	X	

Internal Radiation Hazards

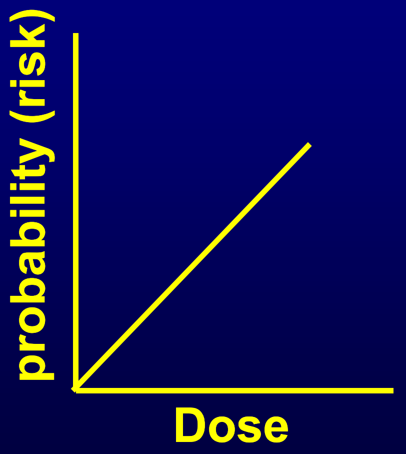
Radiation	Radionuclide	Inhalation Limit (microcuries)
Alpha	Polonium-210	0.6
Beta	Phosphorus-32	900
Gamma	Technetium-99m	200,000

Dose Limits Based on Two Types of Radiation Effects

- **Deterministic (non-stochastic)** - have a threshold, severity increases with dose, e.g., cataracts, reddening of skin, acute radiation syndrome (high-level)



- **Stochastic (probabilistic)** - probability increases with dose, e.g., cancer and genetic effects (low level); no known threshold - ALARA



NRC Occupational Dose Limits

Whole Body (TEDE)	5 rem/yr
Any Organ (TODE)	50 rem/yr
Skin (SDE)	50 rem/yr
Extremity (SDE)	50 rem/yr
Lens of Eye (LDE)	15 rem/yr
Embryo/Fetus of DPW	0.5 rem or 500 mrem

DPW = Declared Pregnant Woman

TOTAL ORGAN DOSE EQUIVALENT (TODE)
(Avoidance of Deterministic Risk)

TODE = external dose + internal organ dose

$TODE_T$ = DDE + CDE_T

where

DDE = Deep-Dose Equivalent from external radiation

CDE_T = Committed Dose Equivalent to an organ (Tissue) from internally deposited radioactivity

TOTAL EFFECTIVE DOSE EQUIVALENT (TEDE)
(Limitation of Stochastic Risk)

TEDE = external dose + weighted internal organ dose

TEDE = DDE + $\Sigma(CEDE_T)$
= EDE + $\Sigma(CEDE_T)$

DDE = Deep-Dose Equivalent from external radiation

$CEDE_T$ = Committed Effective Dose Equivalent from internally deposited radioactivity ($CDE_T \times w_T$)

EDE = Effective Dose Equivalent from external radiation (weighted average)

NRC Dose Limits
Members of the Public

TEDE limit of 100 mrem/year (from each licensee)

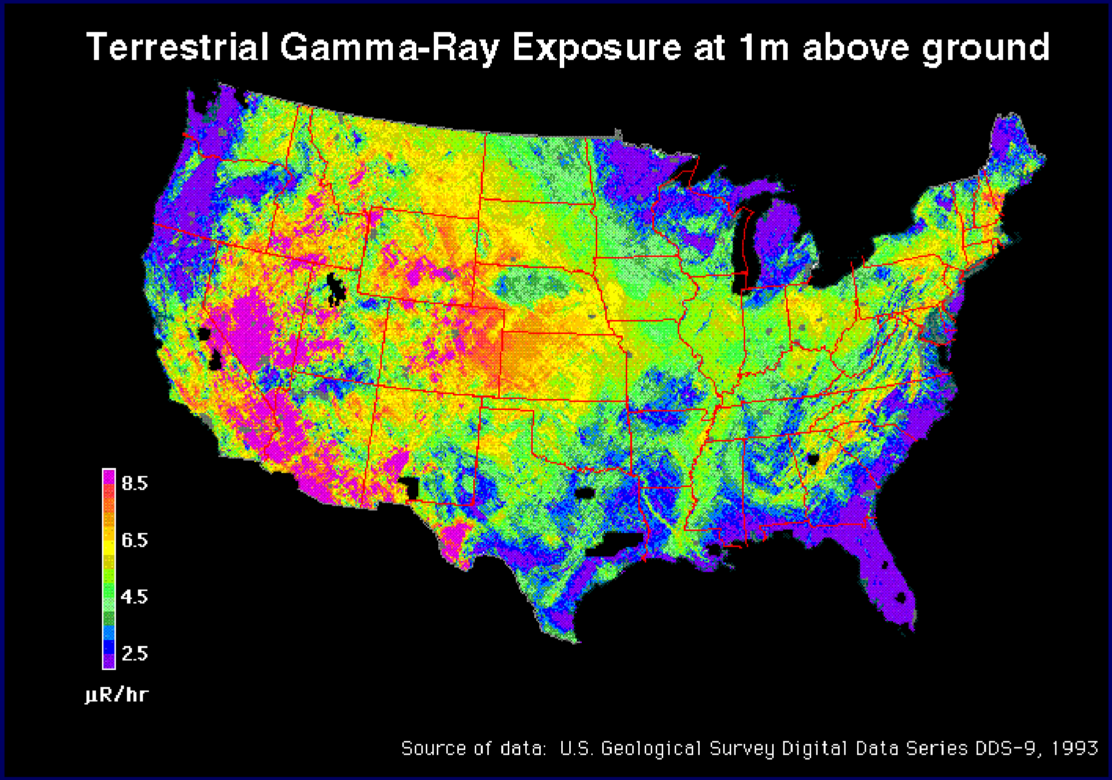
AND

2 mrem in any one hour from external sources of radiation in an unrestricted area

Sources of Radiation Exposure

Terrestrial Gamma Radiation

- **The dose rates from natural radioactivity in the soil vary throughout the country.**
- **Higher dose rates are in magenta.**
- **Note that 8.5 μR/hr is equal to about 75 mrem/yr.**

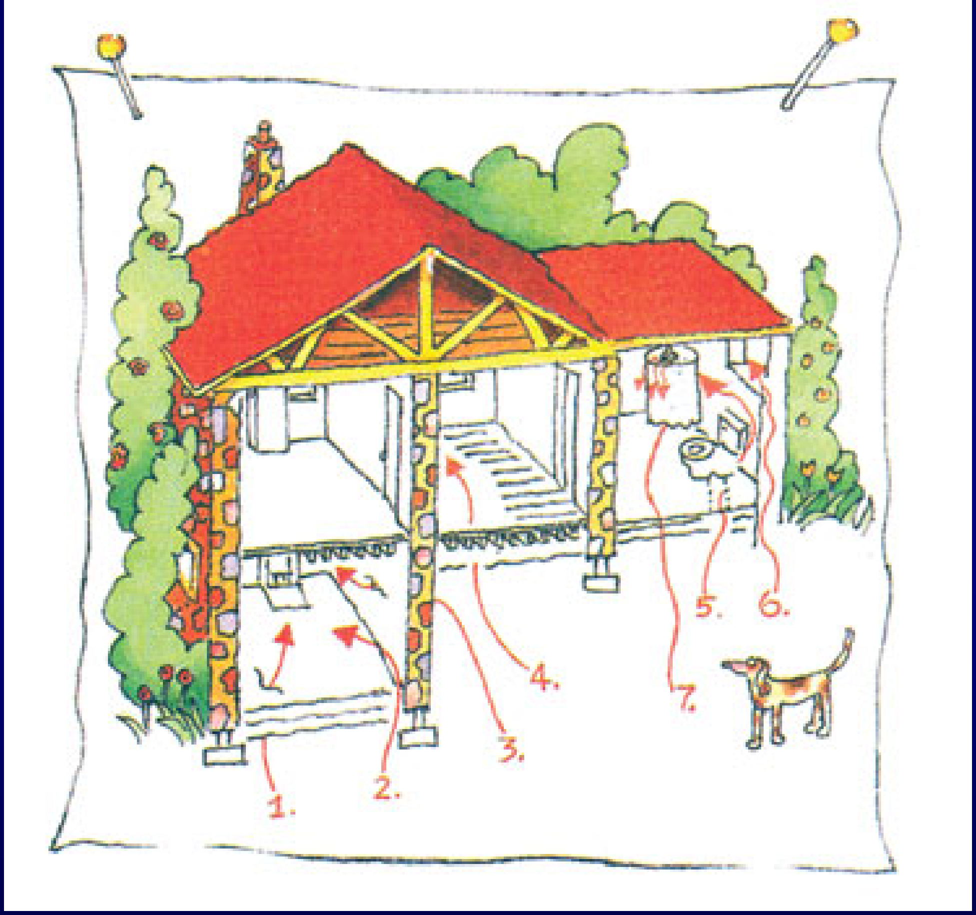


Uranium Ore

Radon

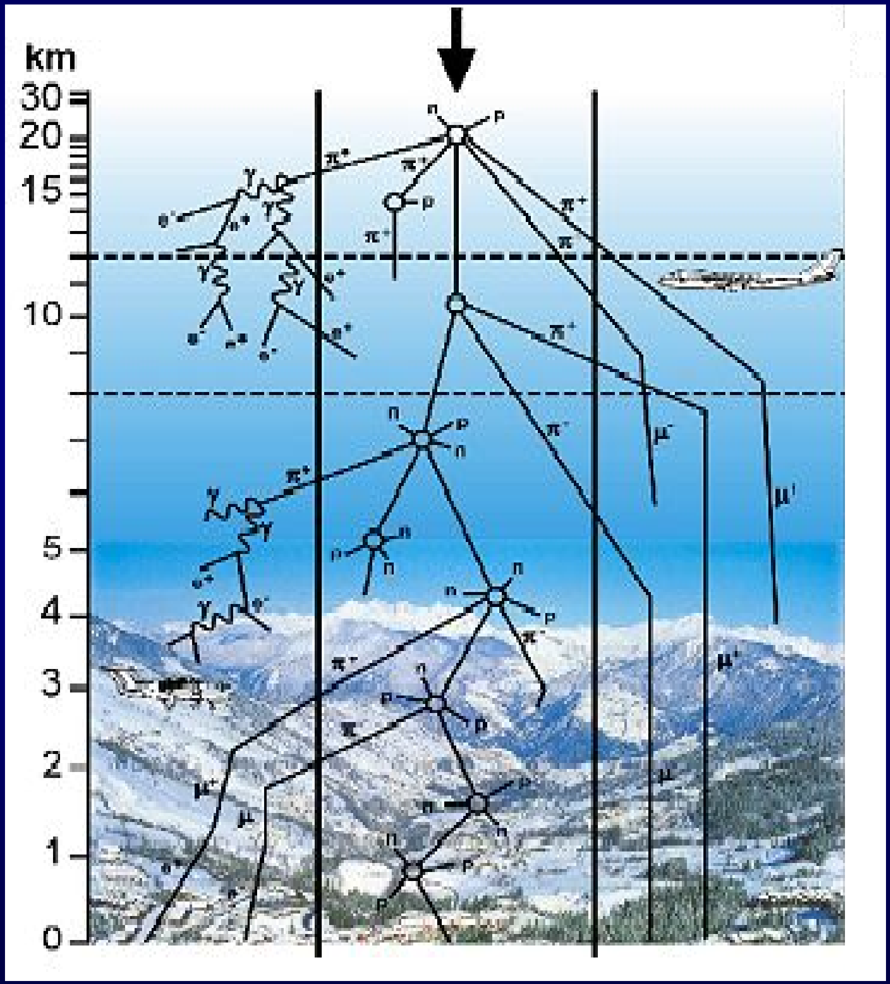
- Radon (Rn-222) is produced by the radioactive decay of uranium-238 found naturally in the soil. Radon is a noble gas that readily diffuses through soil into homes.

- Radon and its radioactive decay products are the largest contributors to natural background dose.



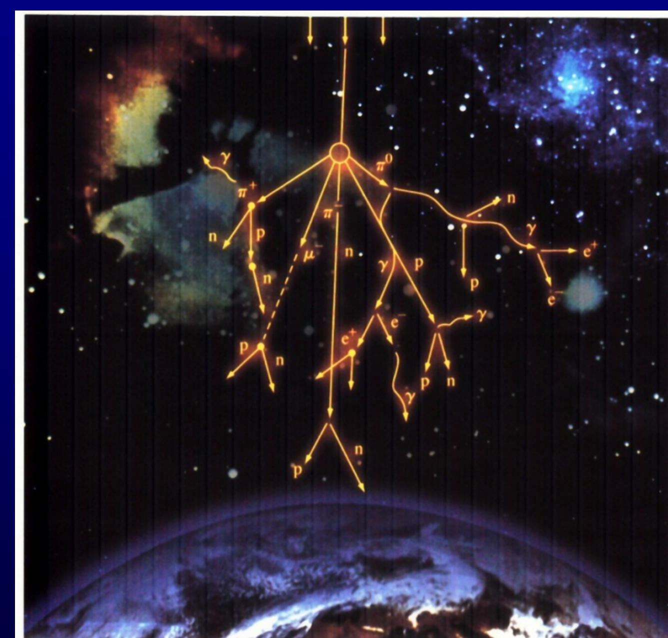
Cosmic Radiation

- Cosmic radiation is composed of high-energy charged particles from space
- Particles interact with molecules in our atmosphere to create secondary neutrons, electrons and gamma rays
- The primary and secondary radiation created is reduced by the earth's atmosphere. Thus, higher altitudes result in higher doses



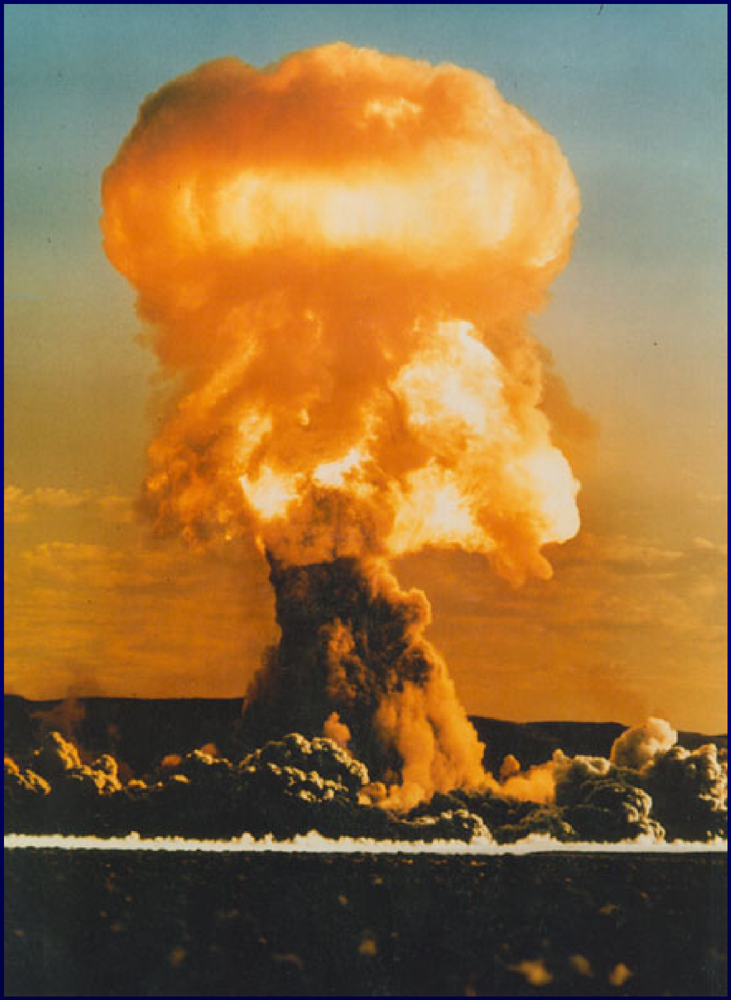
Cosmic Radiation

- **Cosmic radiation interacts with molecules of nitrogen in the upper atmosphere of the earth to produce radioactive materials that are part of our environment.**
- **Carbon-14, a radioactive isotope with a half-life of 5,730 years, is produced in this manner.**

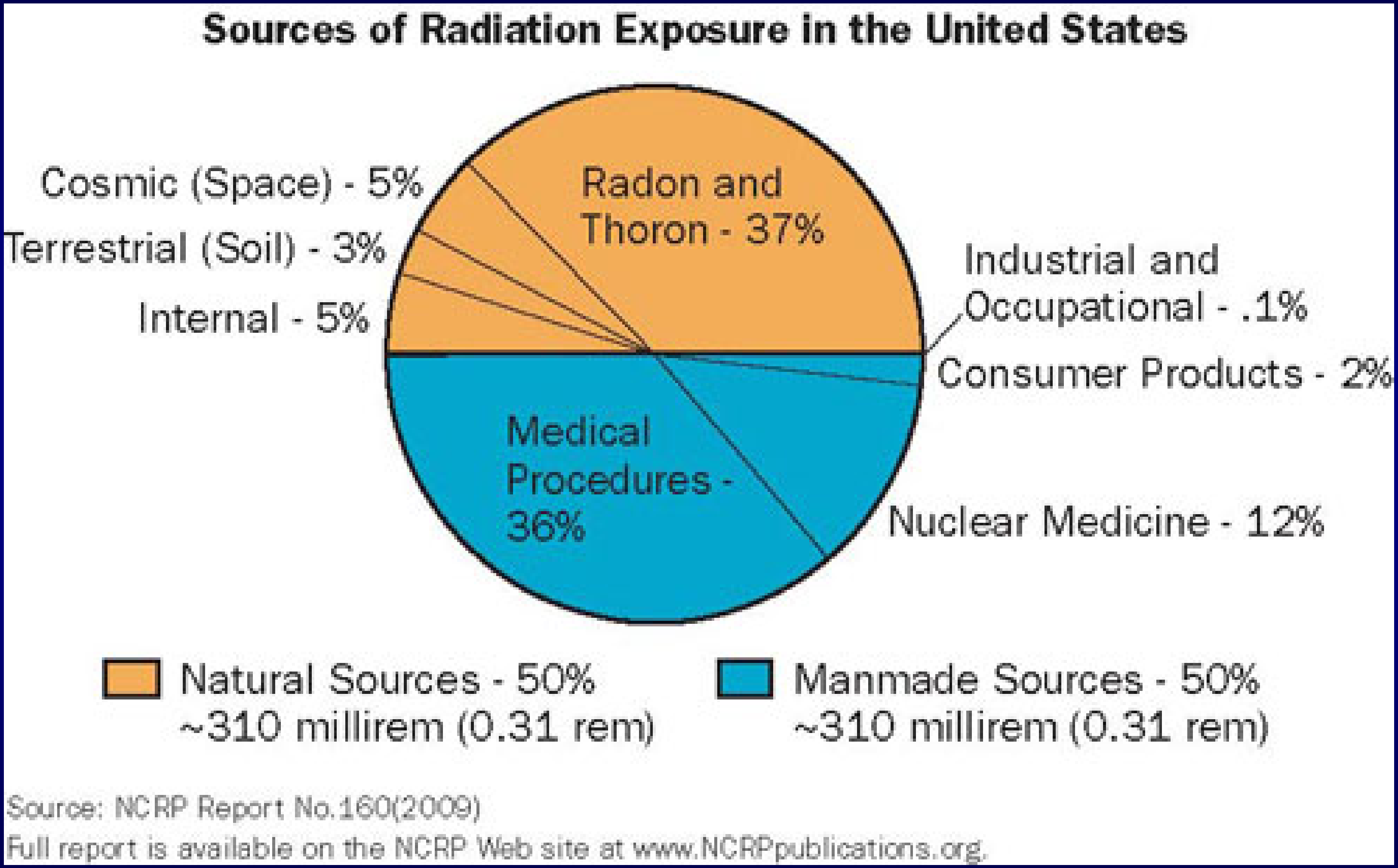


Fallout

- Nuclear weapons testing during the 1950's and 1960's resulted in fission products being dispersed in the environment.
- Most fission products have short half-lives and are no longer present in the environment (e.g., I-131 with an 8 day half-life). However, isotopes with long half-lives such as Cs-137 (half-life of about 30 years) are still present.



Sources of Average Annual Dose

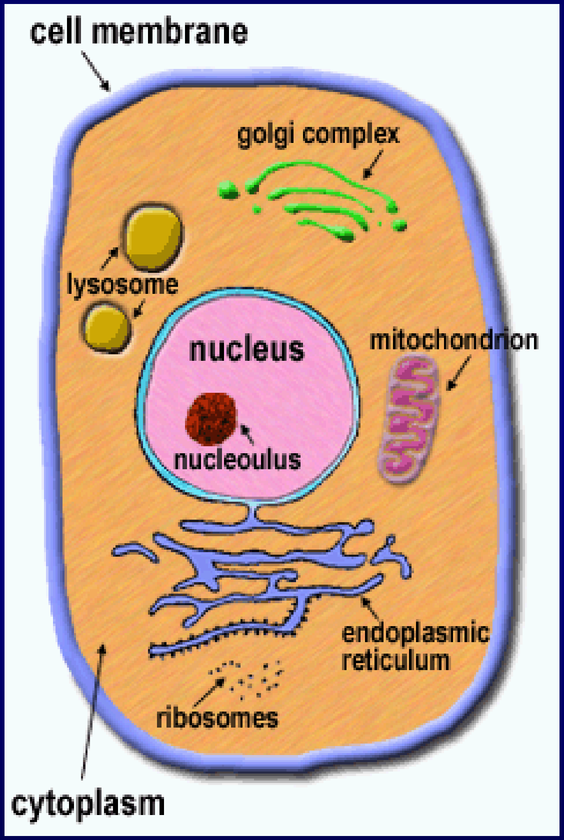


The average annual dose from all sources of radiation is about 620 mrem.

Biological Effects of Ionizing Radiation

The Human Cell

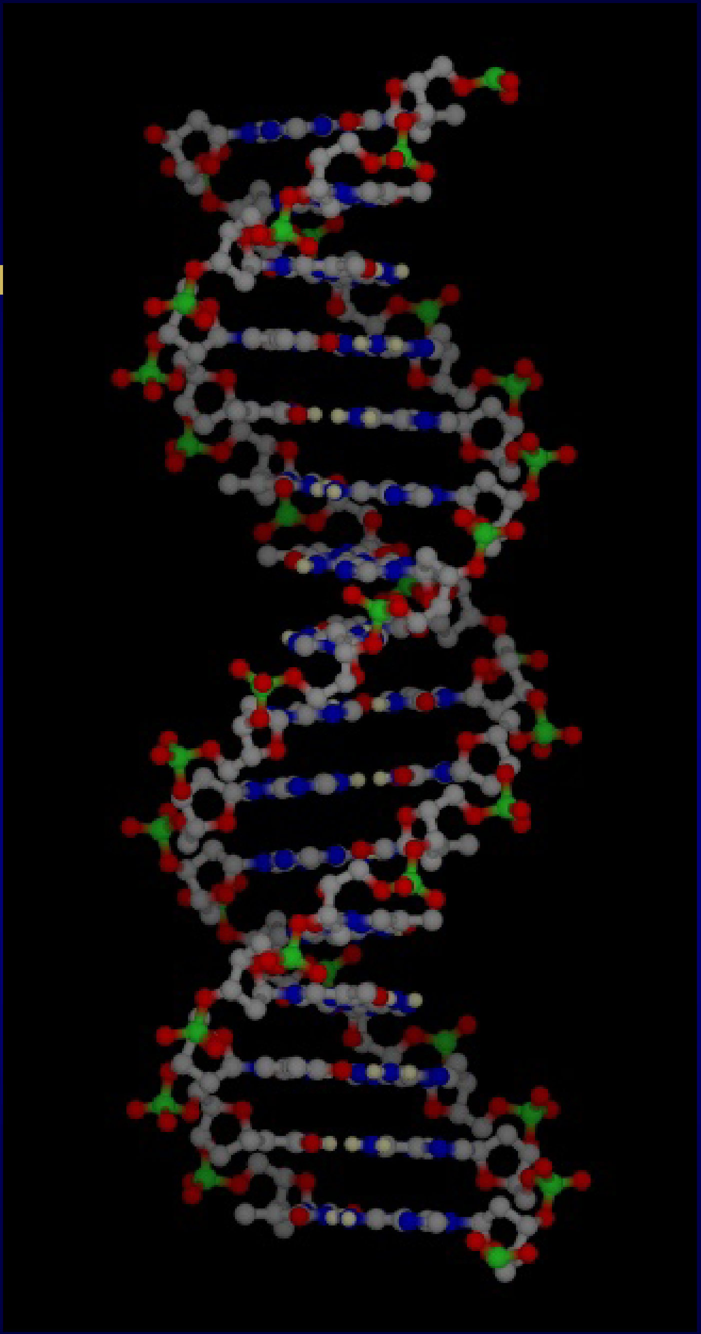
- Cell is basic building block of life
- Has basic structures that allow cell to function and reproduce
- Cell function is determined through DNA within the cell nucleus



DNA

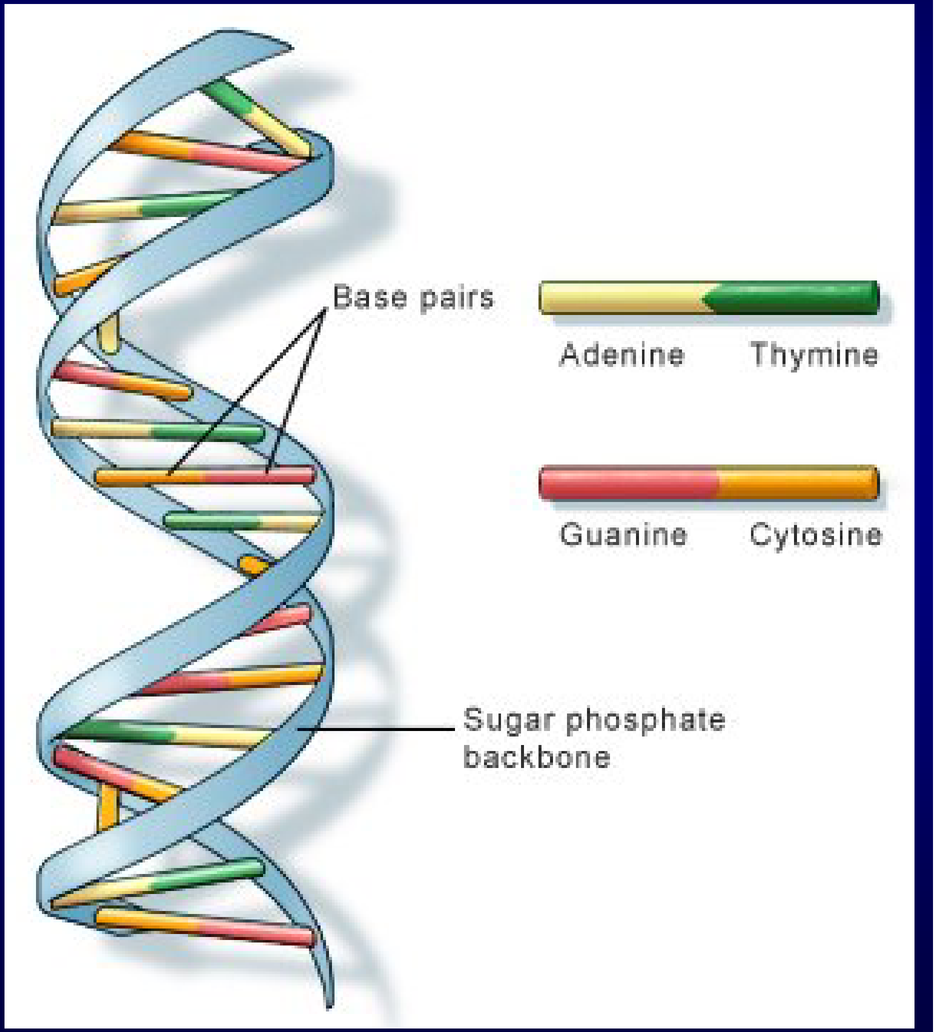
- DNA is a vast chemical database found in the nucleus of each of the body's trillions of cells. It contains the genetic instructions required for cellular development and function.

- The DNA found in every human cell is identical.



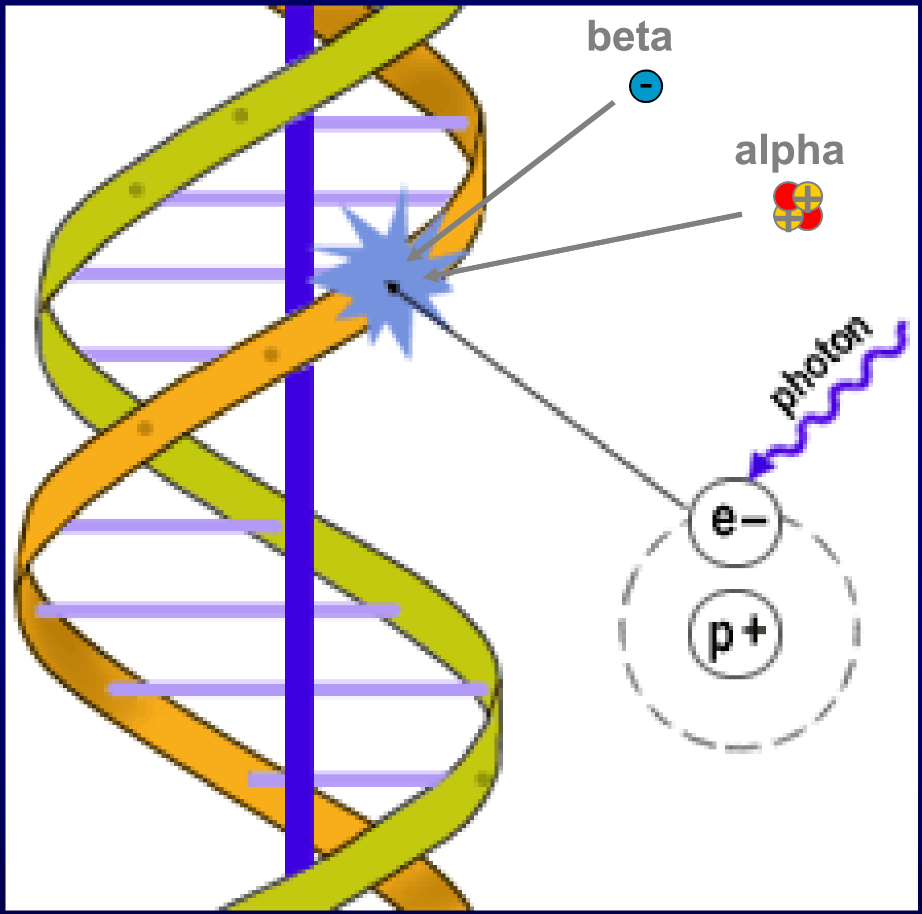
DNA Molecular Structure

- DNA exists as two long, paired strands spiraled into the famous double helix.
- The strands are joined by chemical bases that can be arranged in countless ways. The order of the bases determines the messages to be conveyed, much as specific letters of the alphabet combine to form words and sentences.



Direct Biological Effect

- When ions directly damage critical biological molecules in human cells
- DNA within the cell nucleus is believed to be the critical biological target for radiation damage

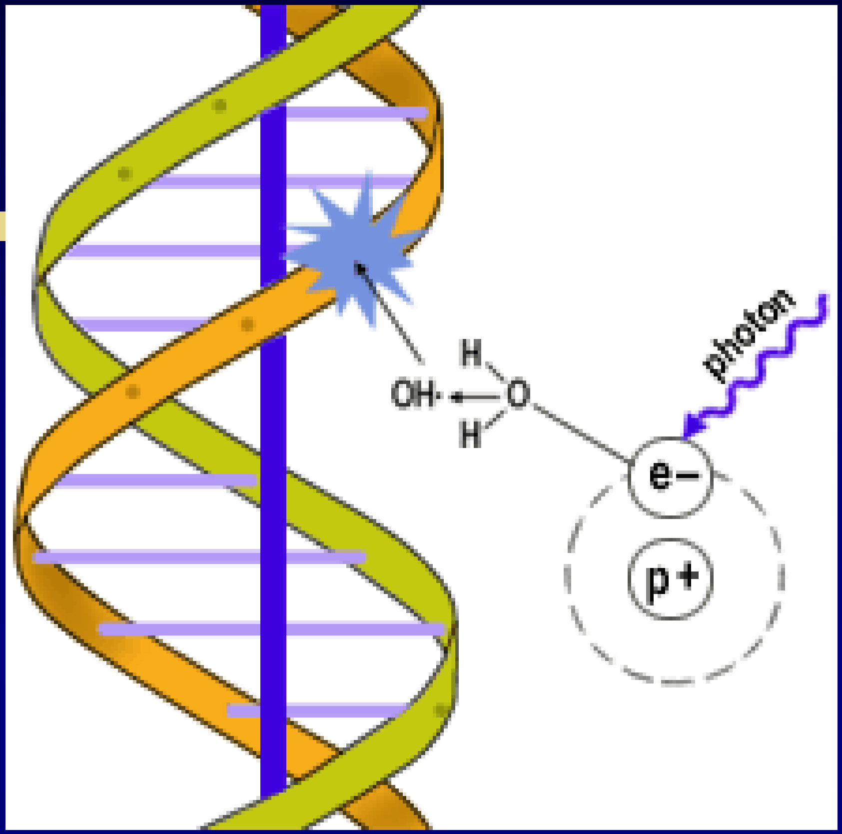


Indirect Effect

Radiation interacts with body water to produce free radicals and other reactants.

Free radicals are very reactive agents that can damage biological molecules.

One important free radical is the hydroxyl ion (OH). Two of these radicals combine to form hydrogen peroxide ($OH + OH \rightarrow H_2O_2$), a powerful oxidizing agent that can attack and damage biological molecules by breaking chemical bonds.



Since the human body is mainly water, the indirect effect is believed to be predominant.

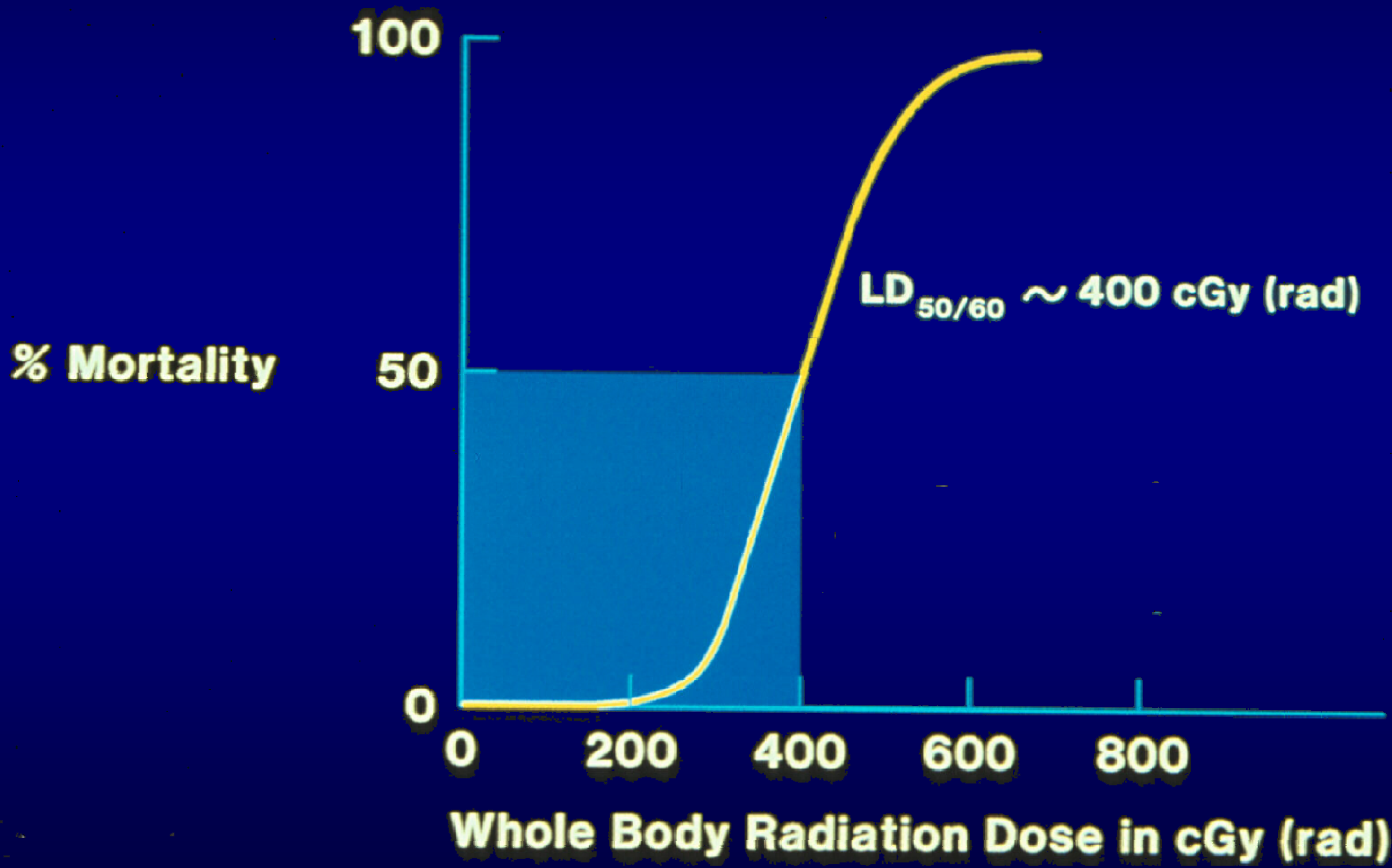
Biological Effects: High Levels of Radiation

Thresholds for three Acute Radiation Syndromes:

- 100 rad - Hematopoietic (blood)
- 500 rad - Gastrointestinal
- 2,000 rad - Central Nervous System

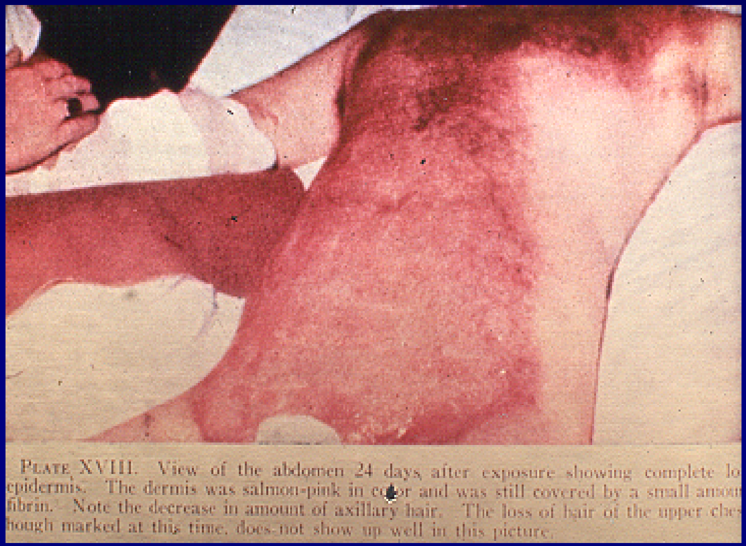
* **LD 50/60** - lethal dose for 50% of people exposed within 60 days - approximately 400 rad (whole body exposure - no medical intervention)

LD50/60

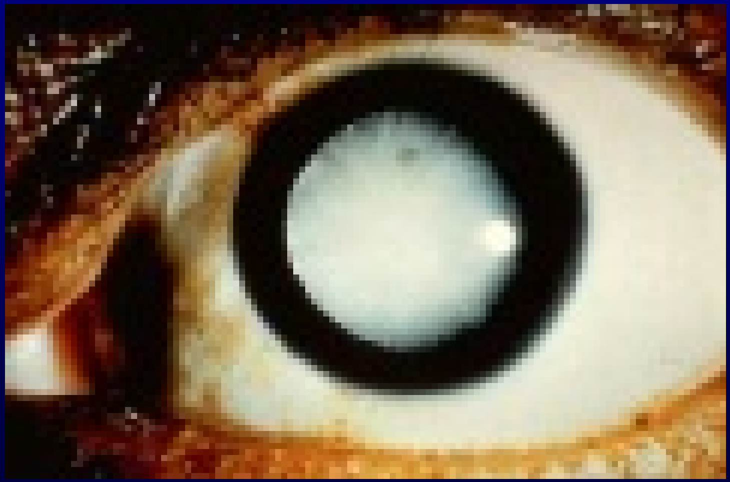


100
50
0
% Mortality
LD 50/60 ~ 400 cGy (rad)
0
200
400
600
800
Whole Body Radiation Dose in cGy (rad)

Biological Effects:
High Doses of Radiation



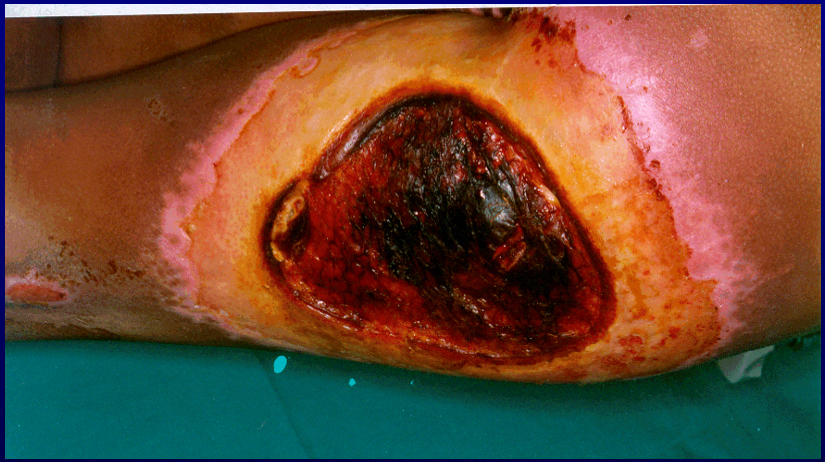
Skin Effects



Cataracts

Biological Effects: High Doses of Radiation

- Ir-192 radiography source not properly secured
- Loss of source not apparent until 6 hours later



- Skin dose at 1cm estimated at 10 kGy
- Right leg amputated
- Workers wife and children also exposed

Biological Effects: Low Doses of Radiation

- Most low dose effects are stochastic (i.e., statistical in nature) and include:

  - Cancer
  - Hereditary genetic effects (not proven in humans)

- Stochastic effects take years to manifest

Biological Effects: Low Dose Radiation Risks

ICRP-60 quantifies cancer risk due to radiation exposure:

- 5 fatal cancers are expected in a population of 10,000 people exposed to 1 rem

  or

- 5 x 10^{-4} / person-rem or 0.05% / person-rem

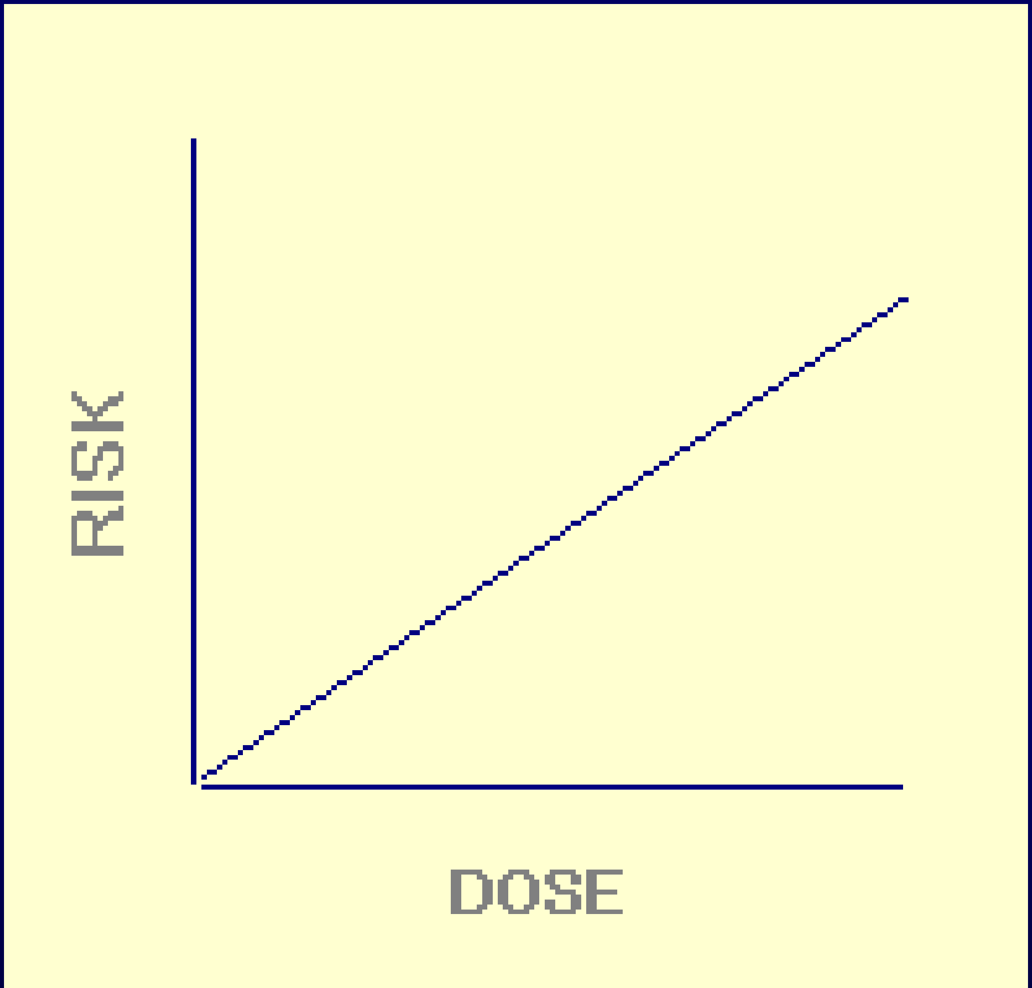
NOTE: About 20% of the population will die from cancer in the absence of radiation (baseline cancer mortality risk of 1 in 5).

Other Ways of Thinking About Low Dose Radiation Risk

Since baseline cancer mortality risk is about 20%:

- **An exposure of 1 rem could increase the overall risk to 20% + 0.05% = <u>20.05%</u>**
- **If 10,000 people are unexposed, we might see about 2,000 cancer deaths - after the 10,000 are exposed, we might see about 2,005**

Dose-Response Relationship for a Stochastic Effect



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