Health Physics Fundamentals

Objectives

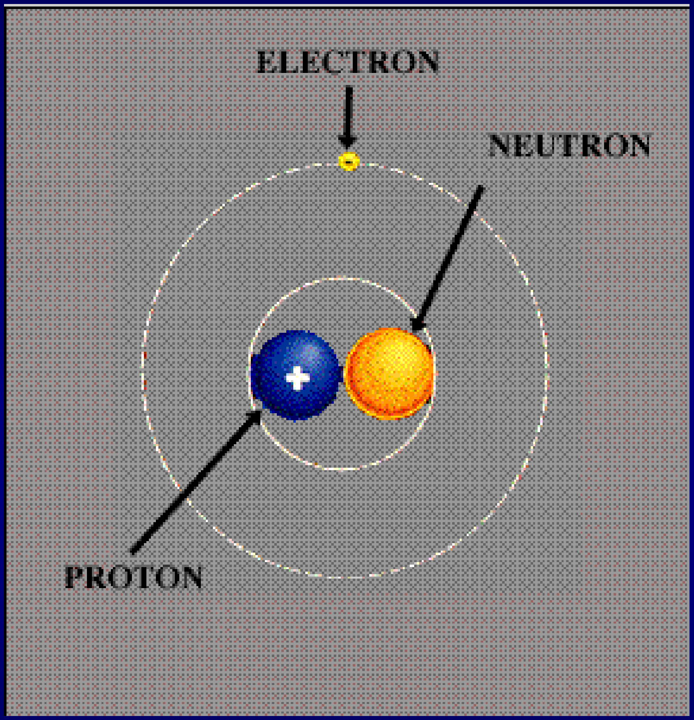
- Review basic atomic structure
- Discuss radiological definitions, terms and units
- Discuss radioactive decay and characteristics of radiation
- Discuss differences between external and internal radiation exposure

Objectives

- 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

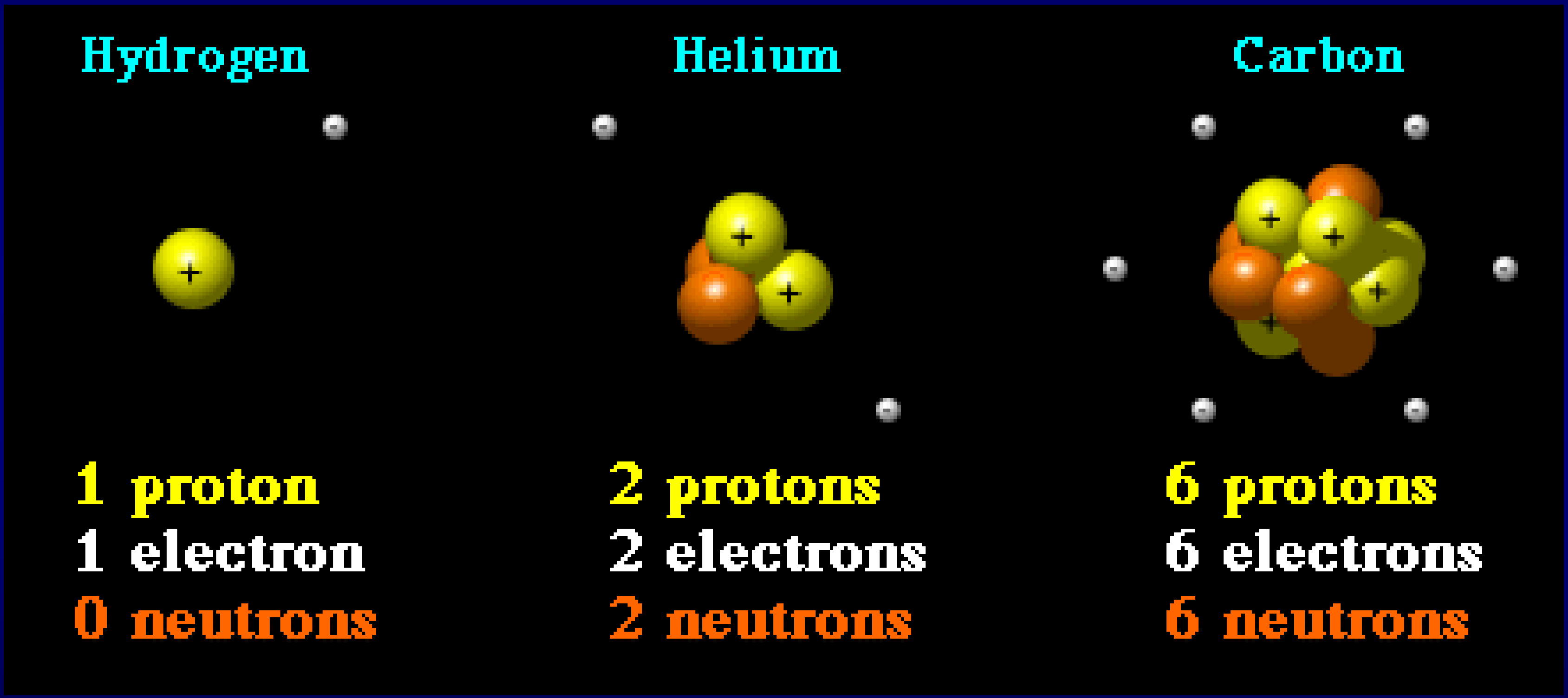
Atomic Structure

- Atoms have orbital electrons, which have a negative charge, and a nucleus comprised of neutrons and protons.
- Protons have a positive charge. Typically there is an orbital electron for each proton in the nucleus.

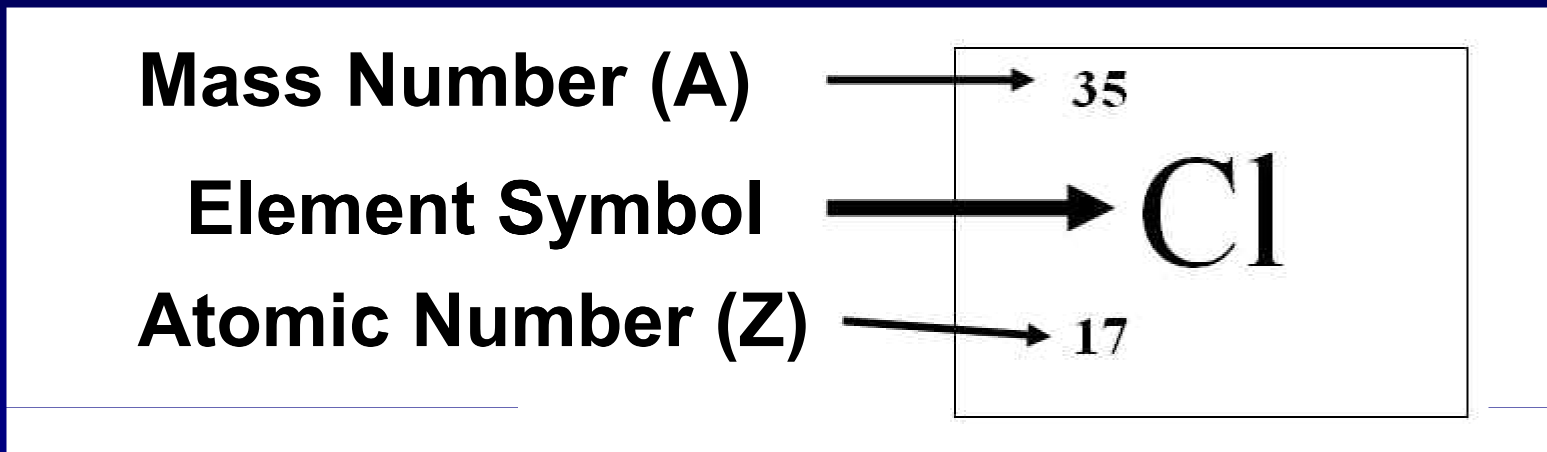


- The element is determined by the number of protons in the nucleus.

Atomic Structure

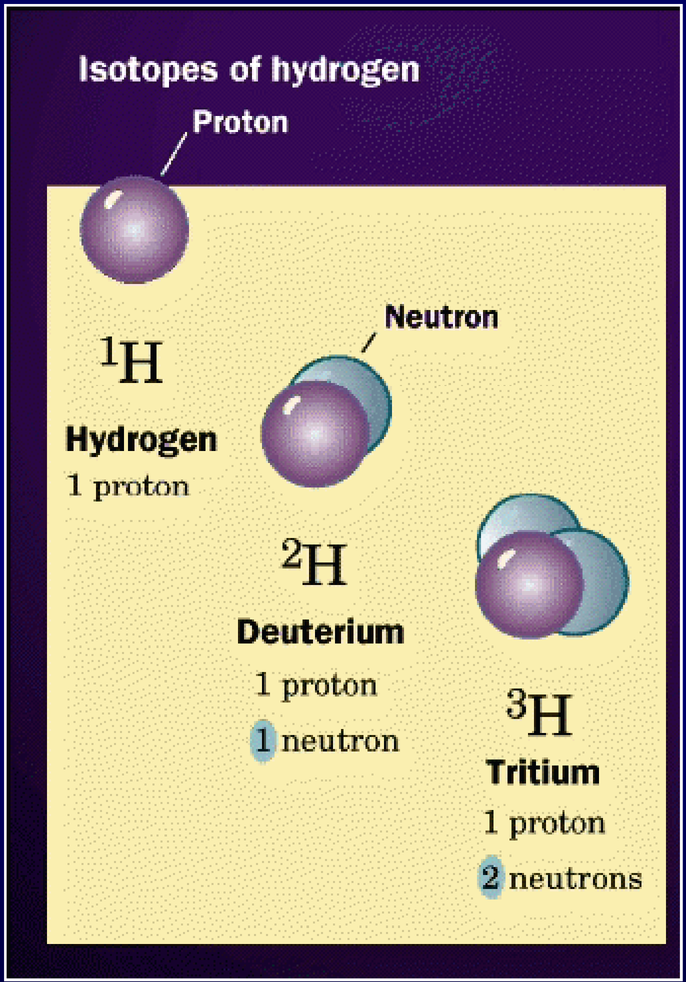


Atomic Notation



- The Mass Number, 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 and Radioactivity

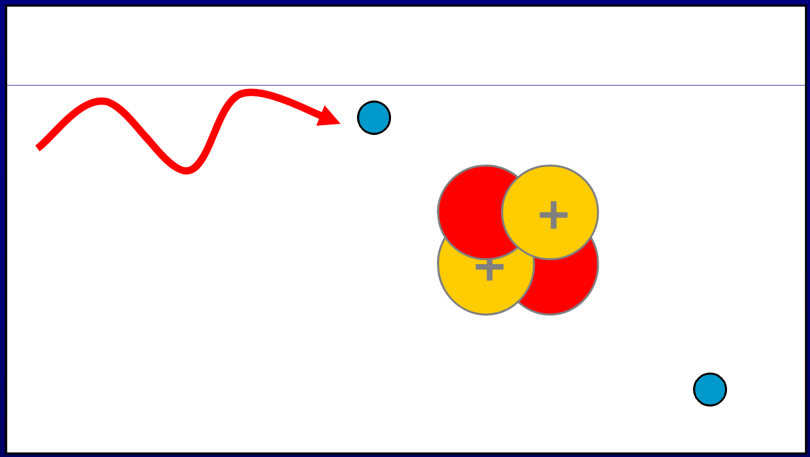


- **Atoms with the same number of protons but a different number of neutrons are called isotopes.**
- **Some isotopes have an unstable nucleus. They try to rearrange themselves into a more stable configuration by emitting energy or particles which we call radiation.**
- **Isotopes that emit ionizing radiation are called radioactive.**
- **This slide shows isotopes of hydrogen. Of these, H-3, or tritium, is radioactive.**

Ionizing Radiation

- Radioactive decay releases ionizing radiation

- Ionizing radiation is energetic enough to remove orbital electrons from atoms or molecules with which it interacts.



- Non-ionizing radiation (e.g., visible light, microwaves) does not have sufficient energy to remove orbital electrons from the atoms with which it interacts.

Radioactivity and Radiation

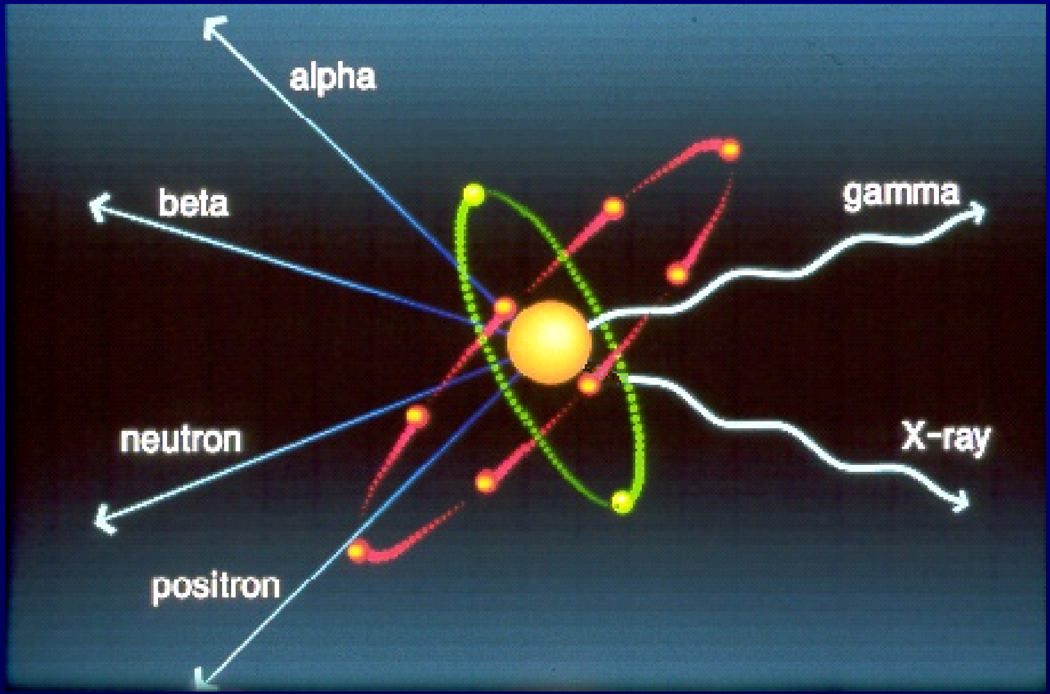
Particle emission

α

β-

n

β+

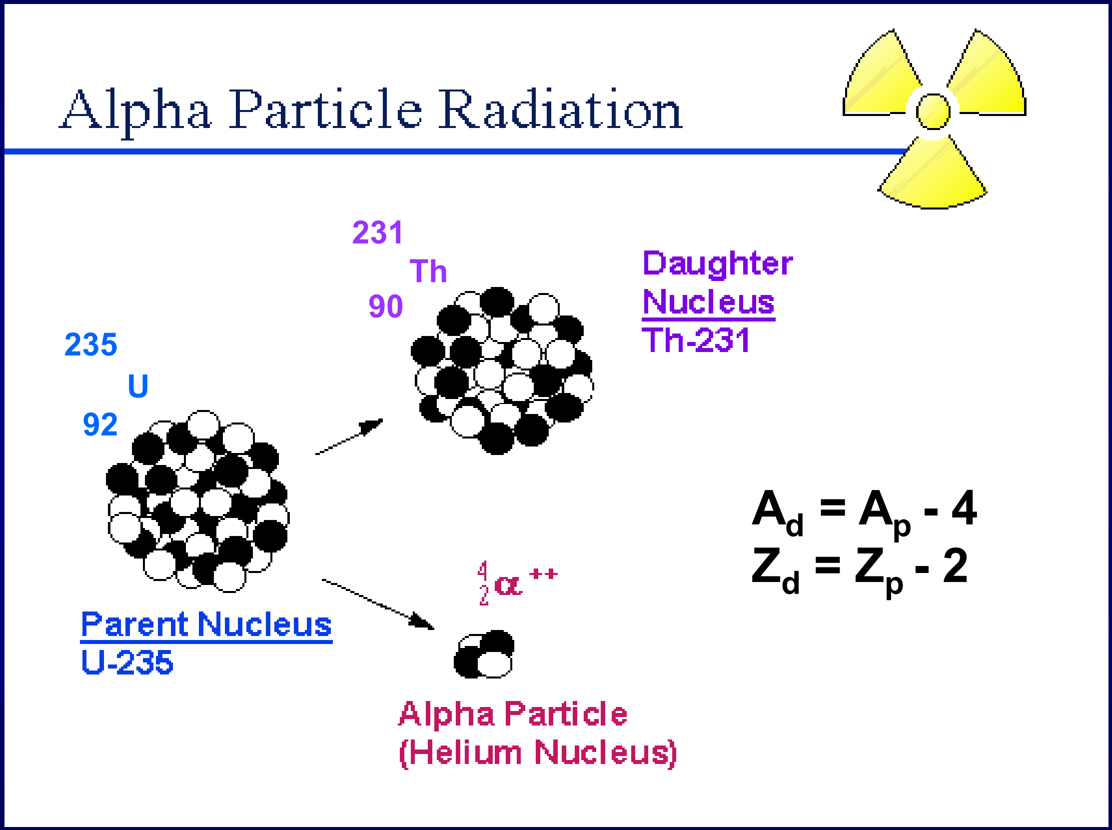


Photon emission

γ

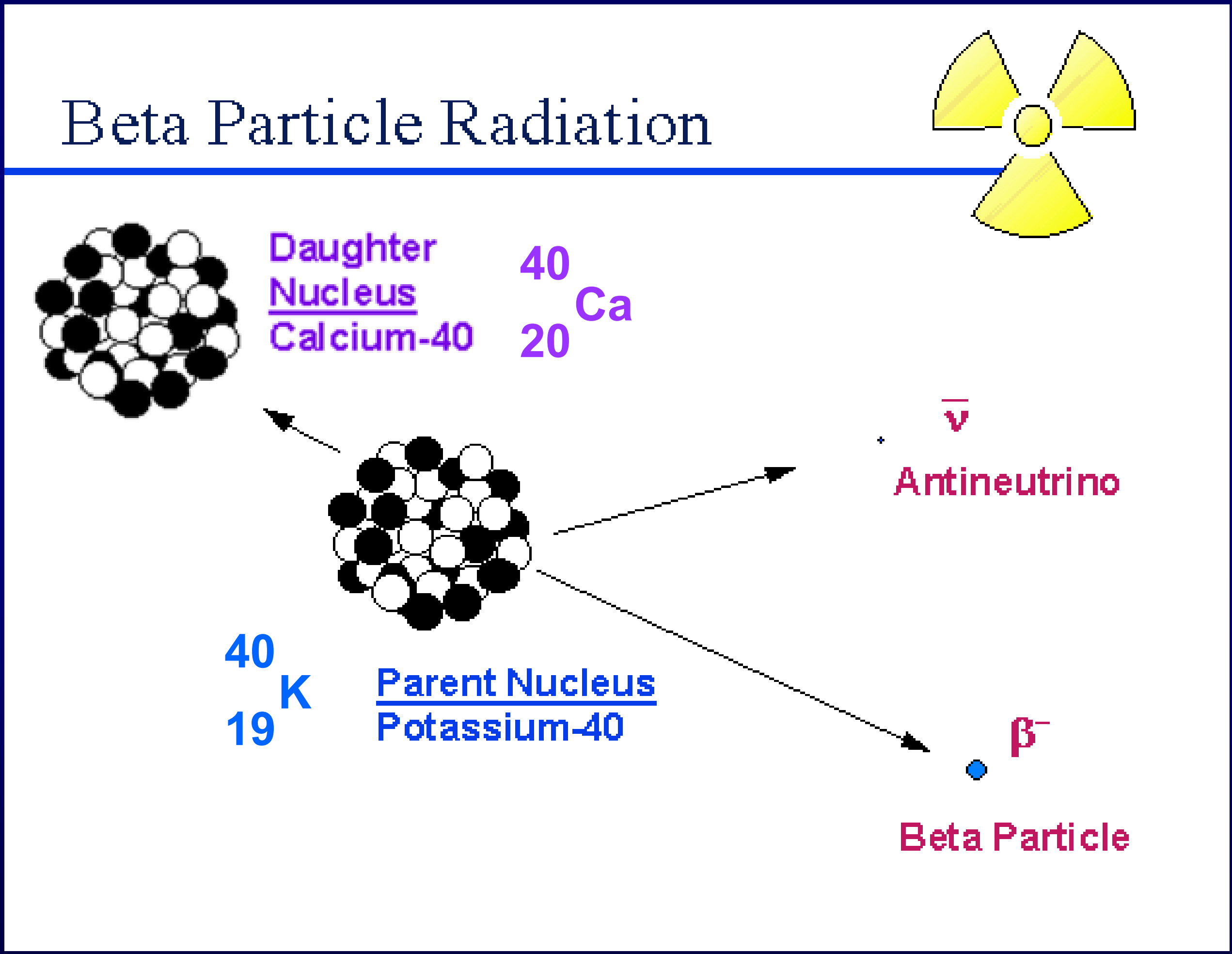
X-ray

Alpha Decay



$$^{235}_{92}U \rightarrow \, ^{231}_{90}Th + \, ^{4}_{2}He^{++}$$

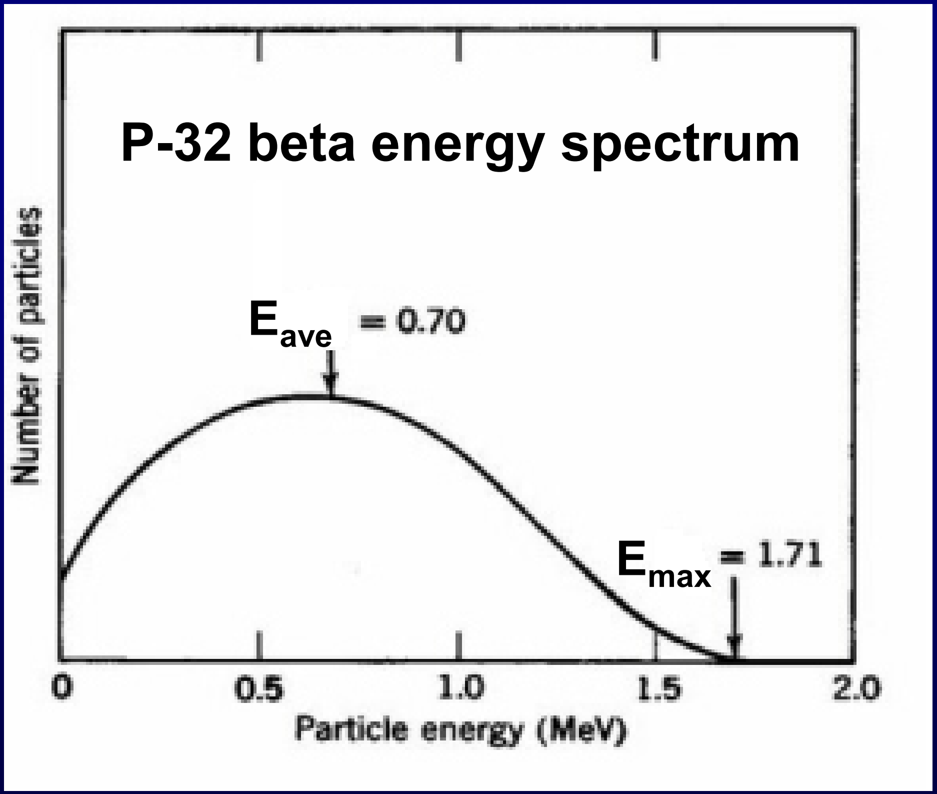
Beta (β^-) Decay



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

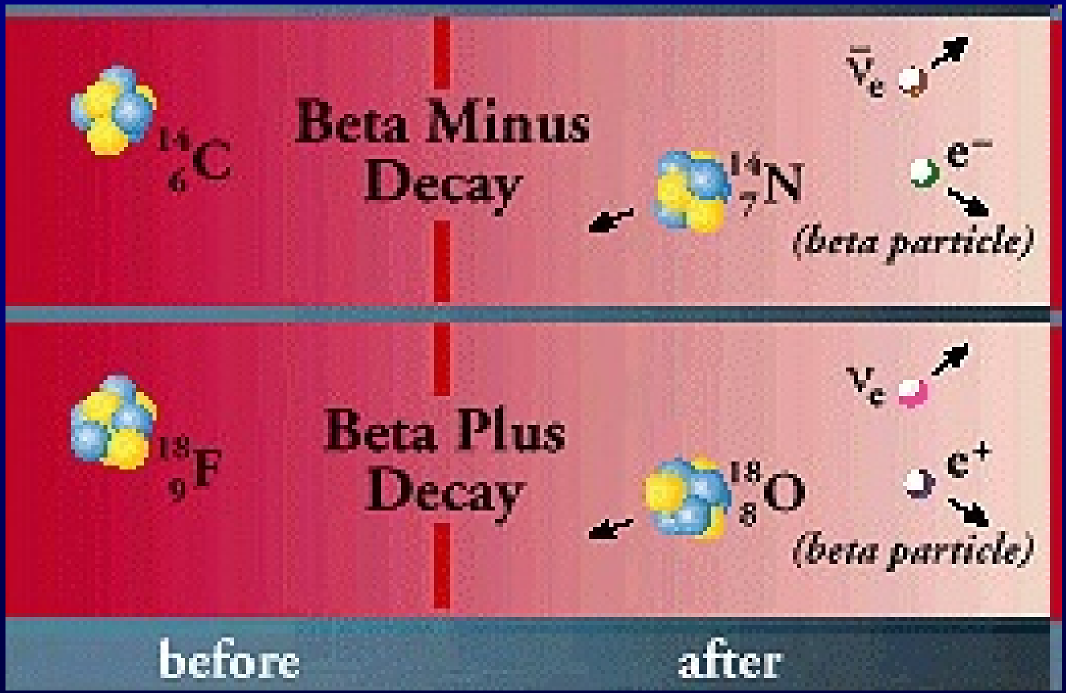
Beta Energy Spectrum

Beta particles are emitted with a spectrum of energies (unlike alpha particles) since their energy is shared with an antineutrino.

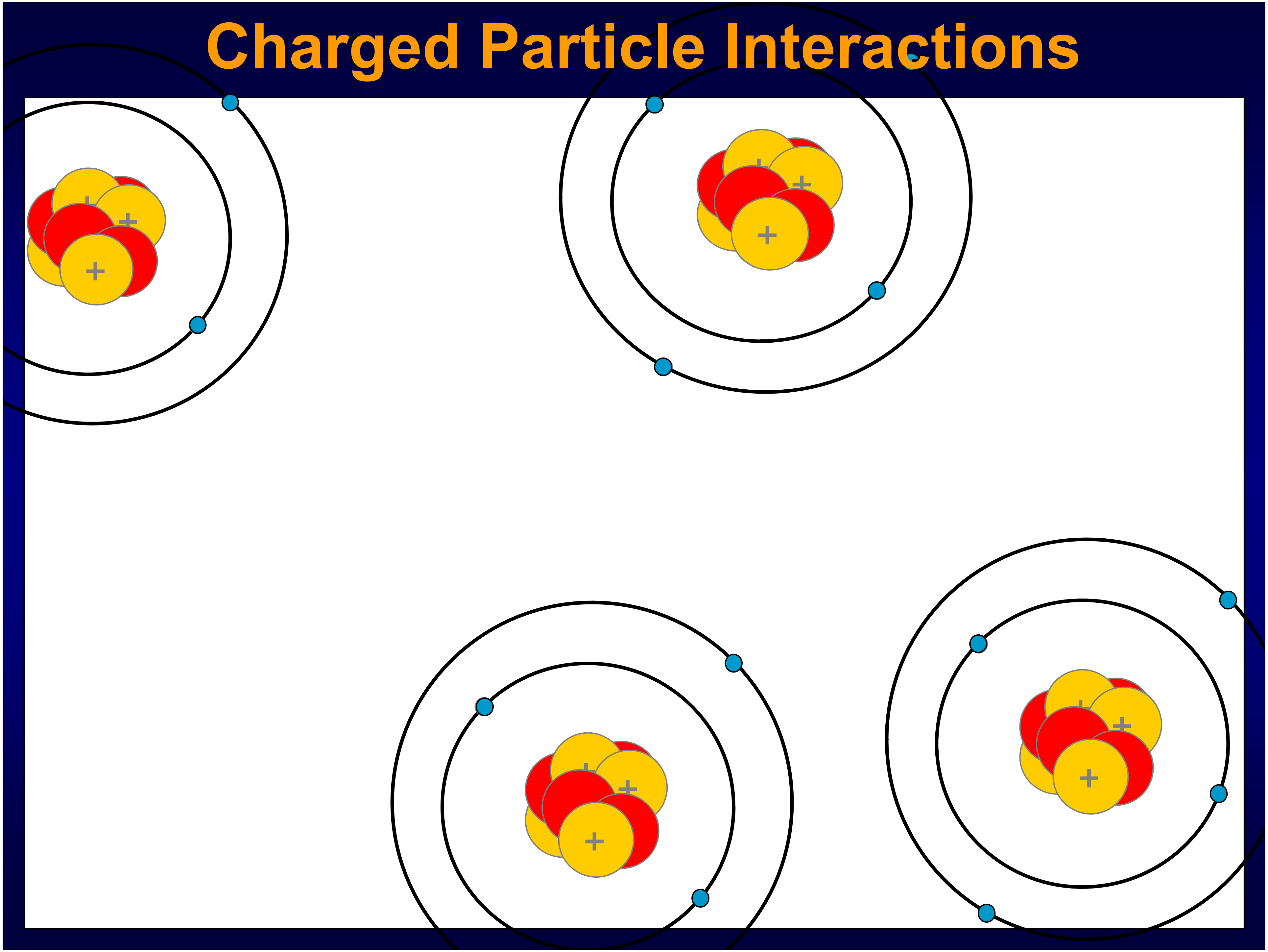


Positron (β^+) Emission

- Occurs when the nucleus contains too many protons (neutron to proton ratio is too low)
- Nucleus emits a positron (a beta particle with a positive charge) and a neutrino $p^+ \rightarrow n + \beta^+ + \nu$

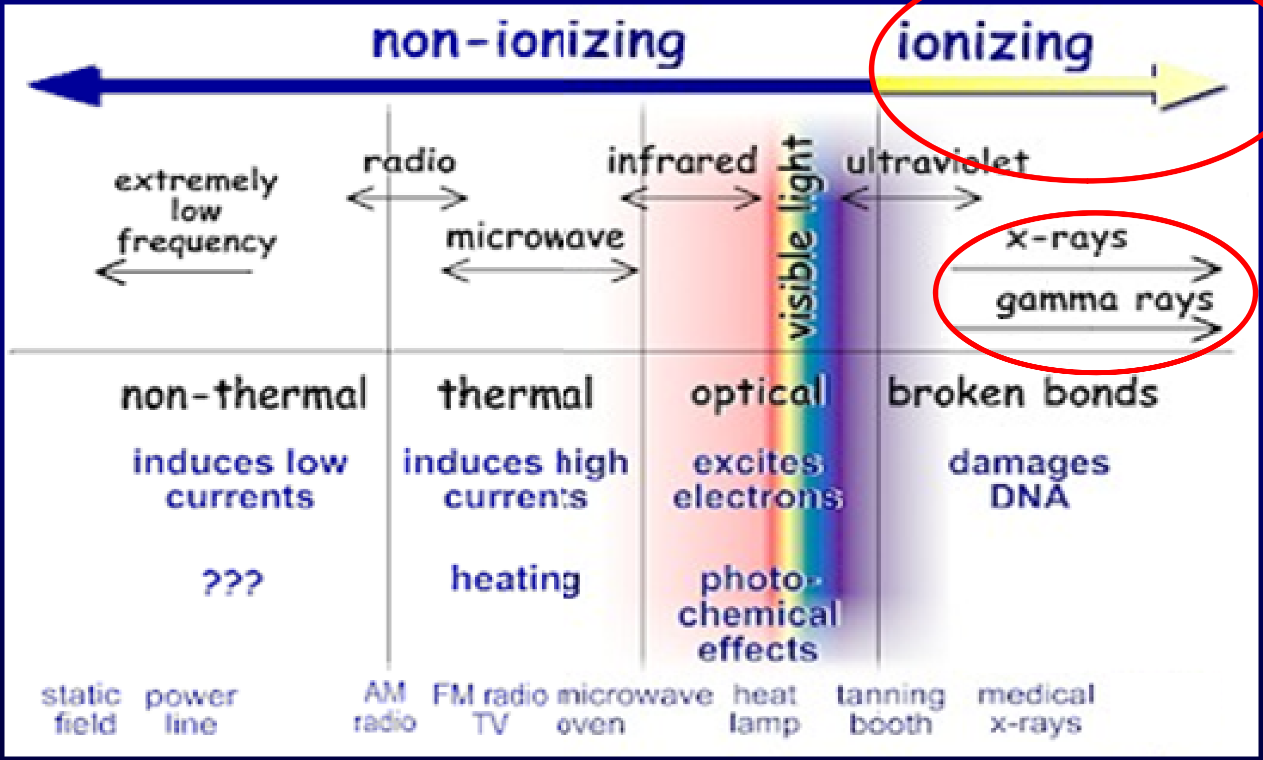


Charged Particle Interactions

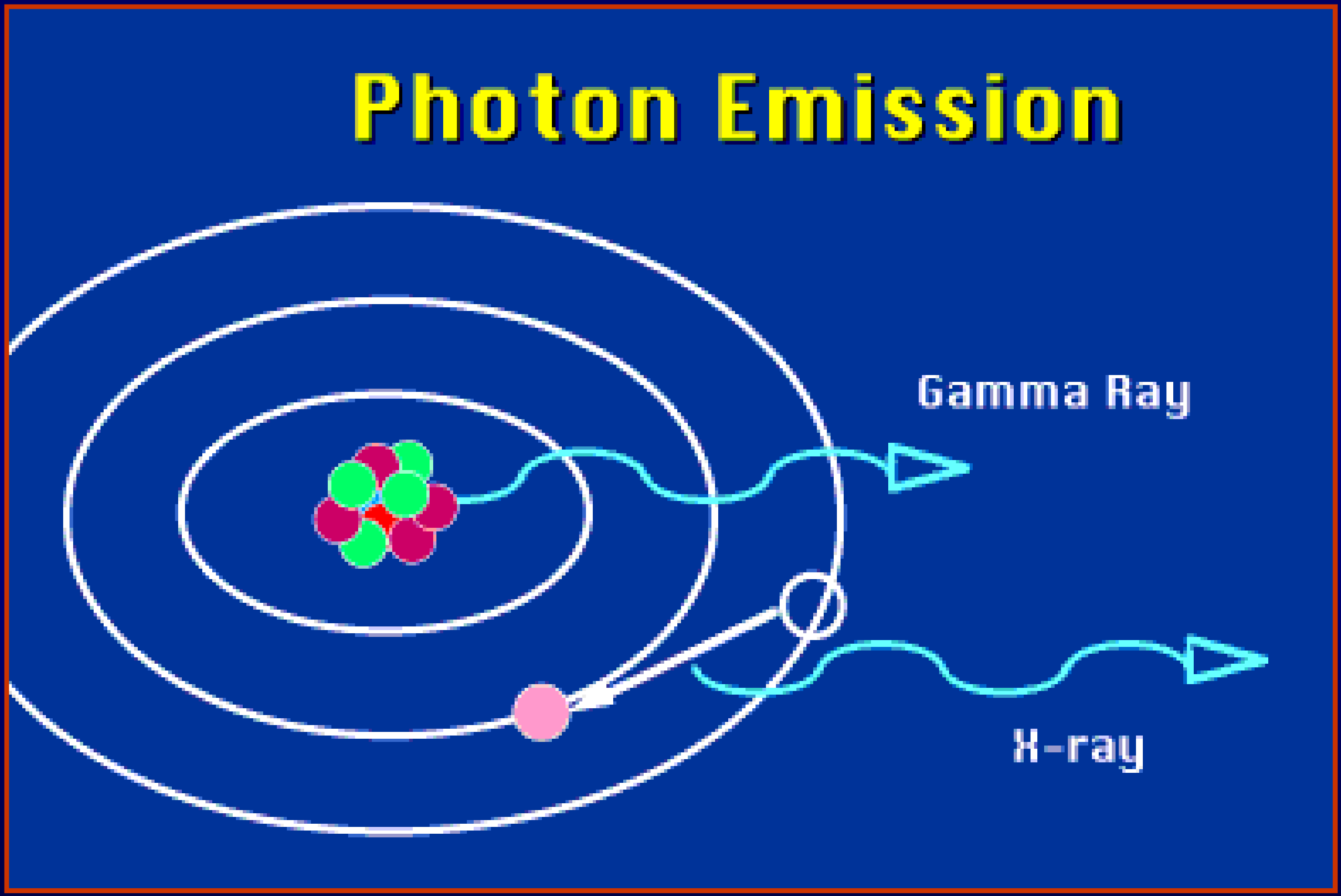


Gamma and X-ray radiation (Photons)

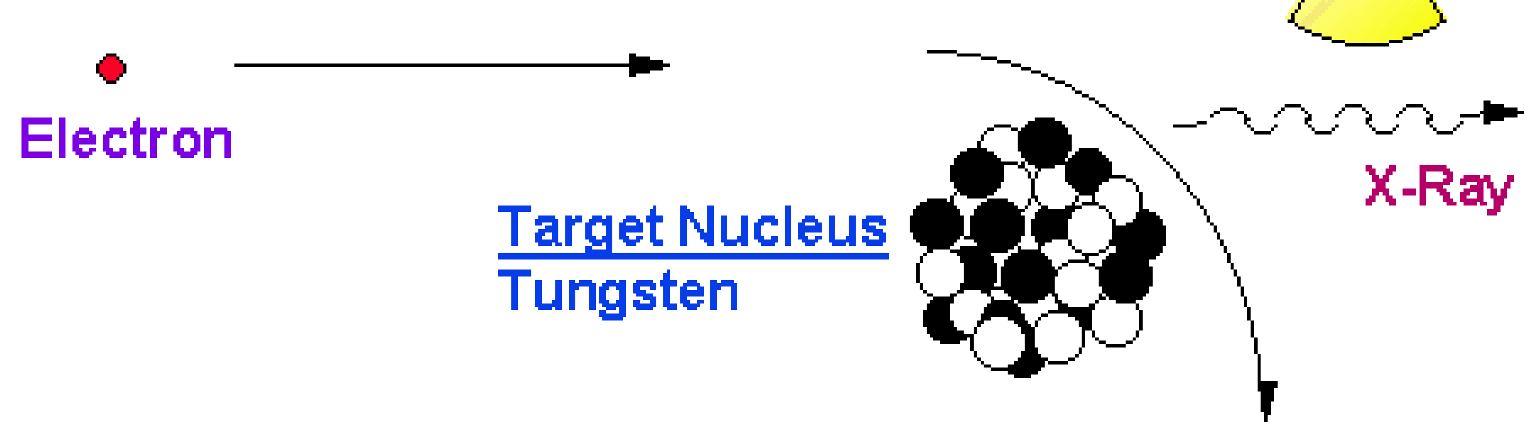
- Photons (electromagnetic radiation) are grouped by wavelength. The shorter the wavelength, the higher the energy.
- Not all forms of radiation are ionizing.

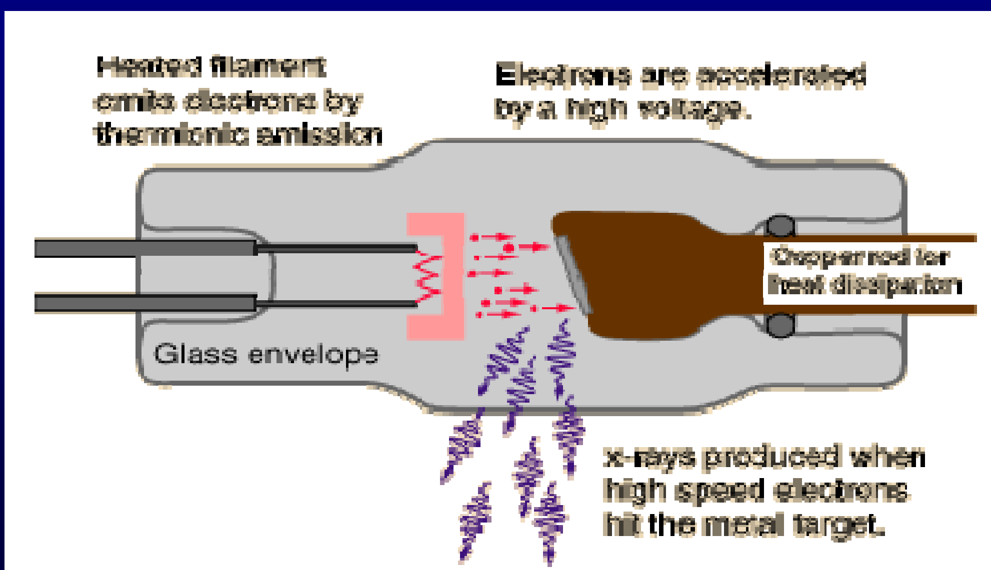


Gamma Rays and X-rays

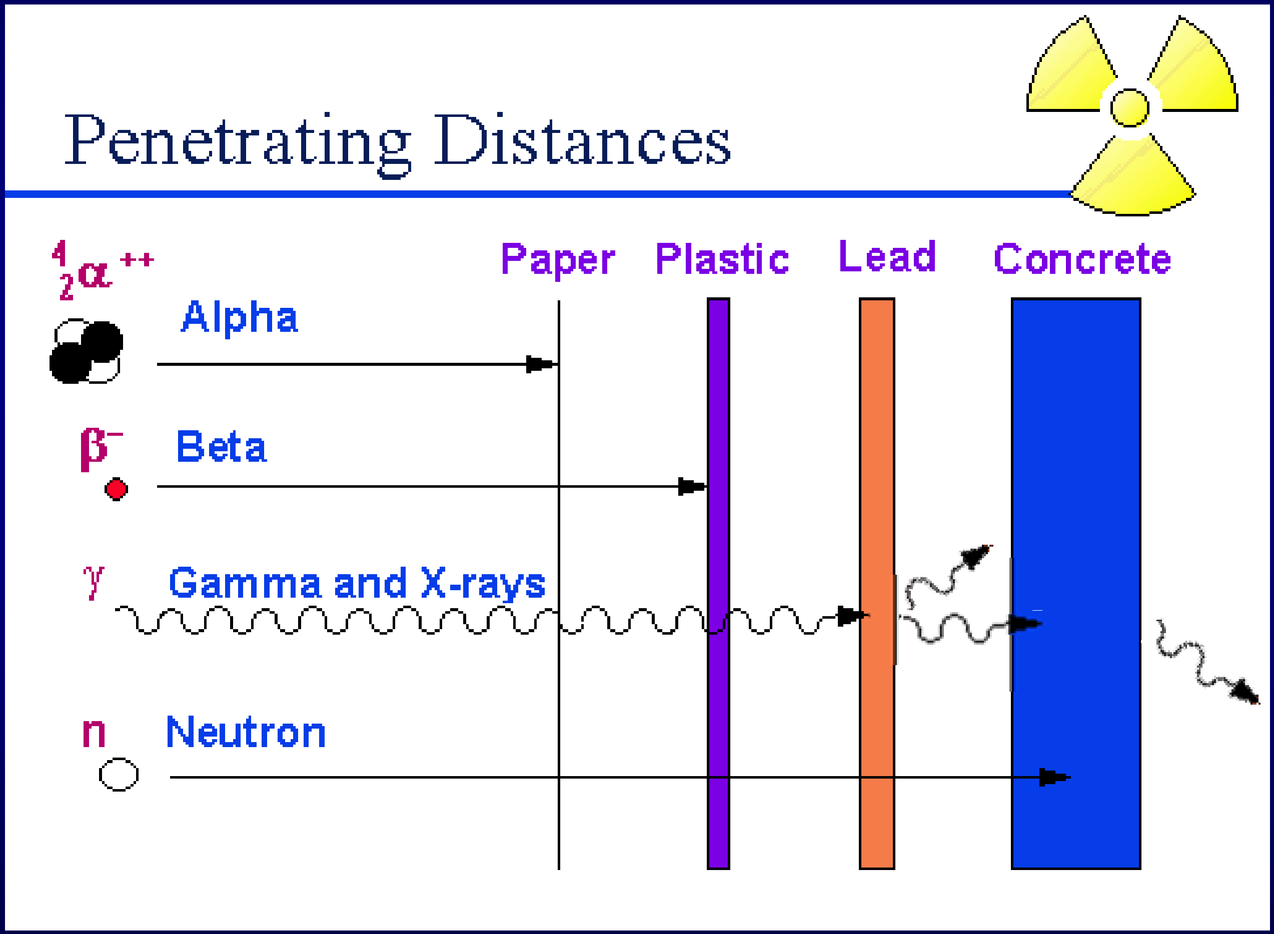


X-Ray Production (Bremsstrahlung)

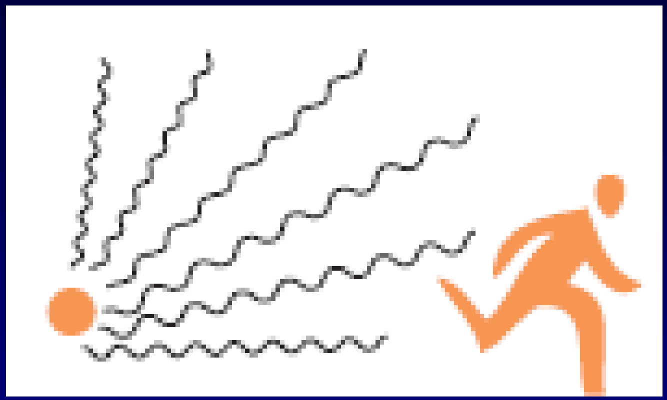




Radiation Shielding



(Depends on energy of radiation & thickness of material)

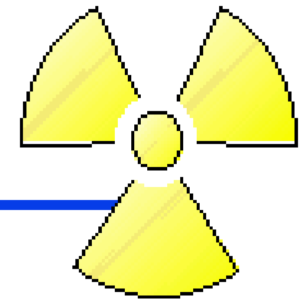


Radiation vs. Contamination

(show examples)

Activity

Measures of Radioactivity



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

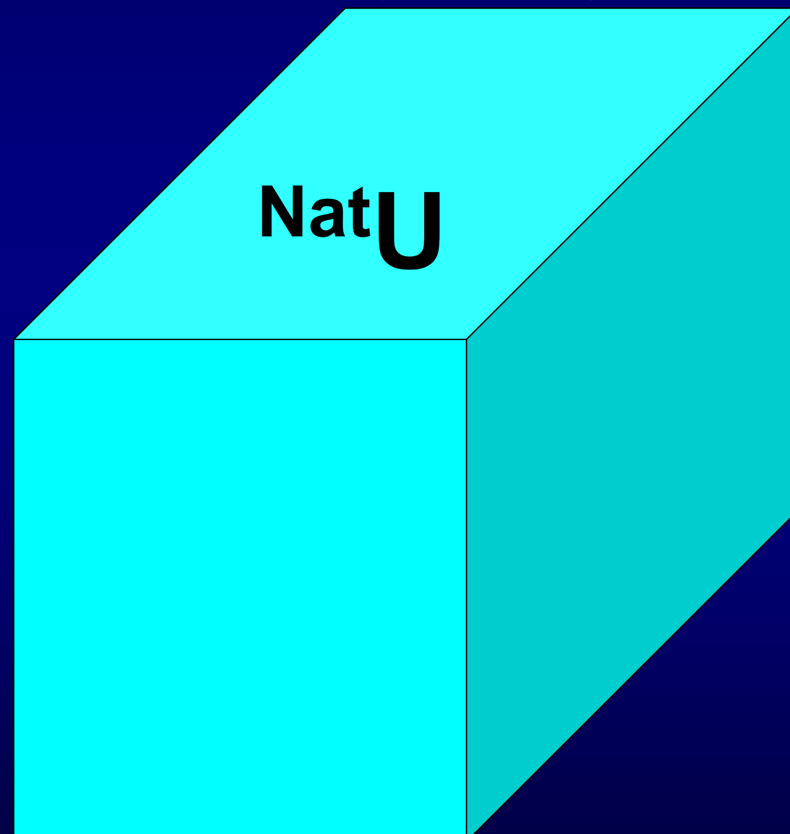
– Curie (Ci) : 3.7×10^{10} disintegration per second (dps)

or

– Becquerel (Bq): 1 dps

Mass vs Activity

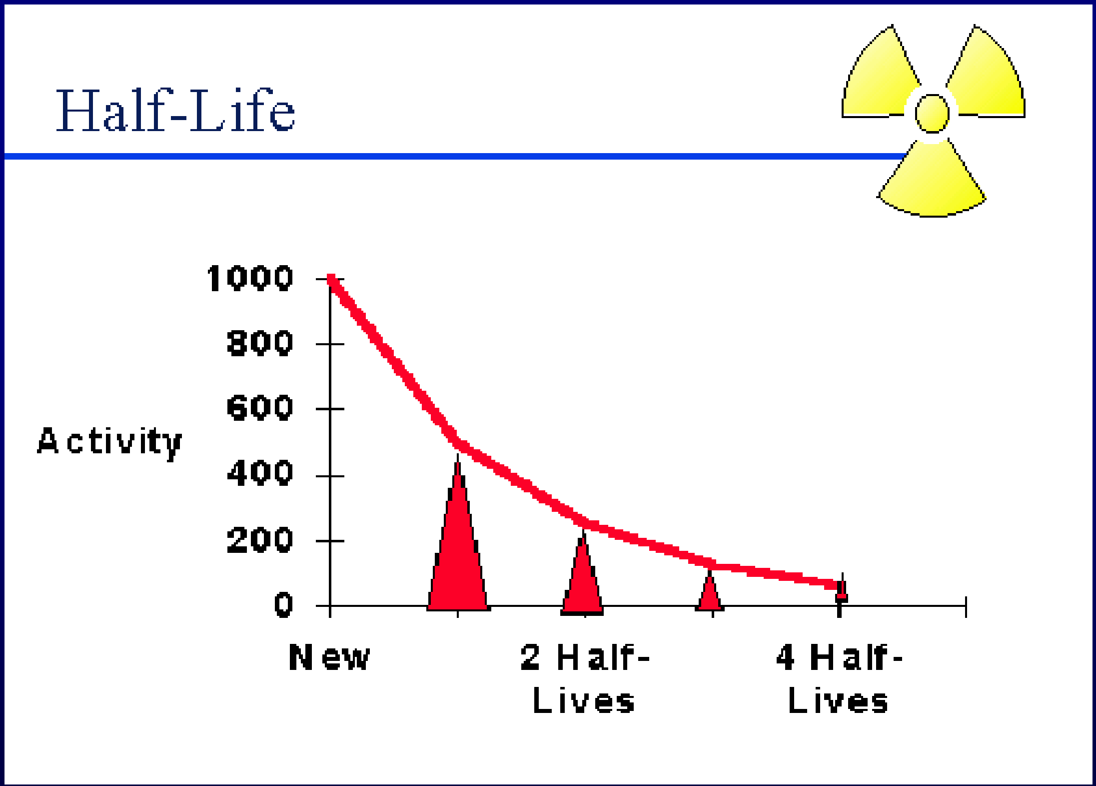
0.001 g	1 g	1,428,571 g
$^{60}_{27}Co$	$^{226}_{88}Ra$	^{Nat}U



Amount in grams of each isotope equaling one curie of activity

Half-Life

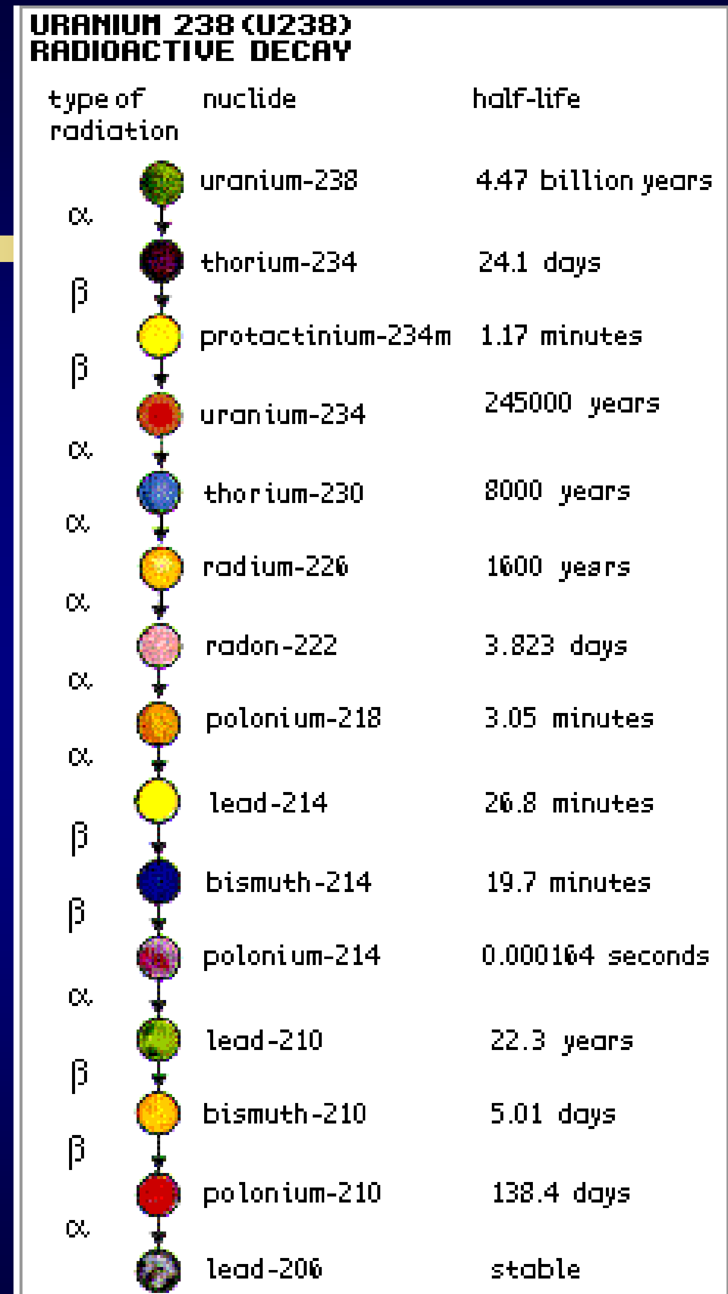
- Amount of time for half of the activity to decay
- Unique to each radionuclide



- **N-16: 7 seconds**
- **Co-60: 5.3 years**
- **Ra-226: 1600 yrs**
- **U-238: 4.47 billion years**

Serial Decay

- Some radioisotopes decay into daughter products that are also radioactive.
  (e.g. U-238 decay series)
- Decay can occur with alpha, beta and/or gamma emissions
- Each isotope within a series has its own unique half-life which can vary considerably



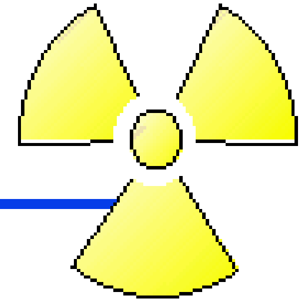
URANIUM 238 (U238) RADIOACTIVE DECAY

type of radiation	nuclide	half-life
	uranium-238	4.47 billion years
α		
	thorium-234	24.1 days
β		
	protactinium-234m	1.17 minutes
β		
	uranium-234	245000 years
α		
	thorium-230	8000 years
α		
	radium-226	1600 years
α		
	radon-222	3.823 days
α		
	polonium-218	3.05 minutes
α		
	lead-214	26.8 minutes
β		
	bismuth-214	19.7 minutes
β		
	polonium-214	0.000164 seconds
α		
	lead-210	22.3 years
β		
	bismuth-210	5.01 days
β		
	polonium-210	138.4 days
α		
	lead-206	stable

Radiation Units and Dose Limits

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 (any material)

rem - unit of dose equivalent (tissue only)

rem = rad x Q (Quality Factor)

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

* Q for neutrons varies with energy level. See 10CFR20.1004, Tables (b).1 and .2

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

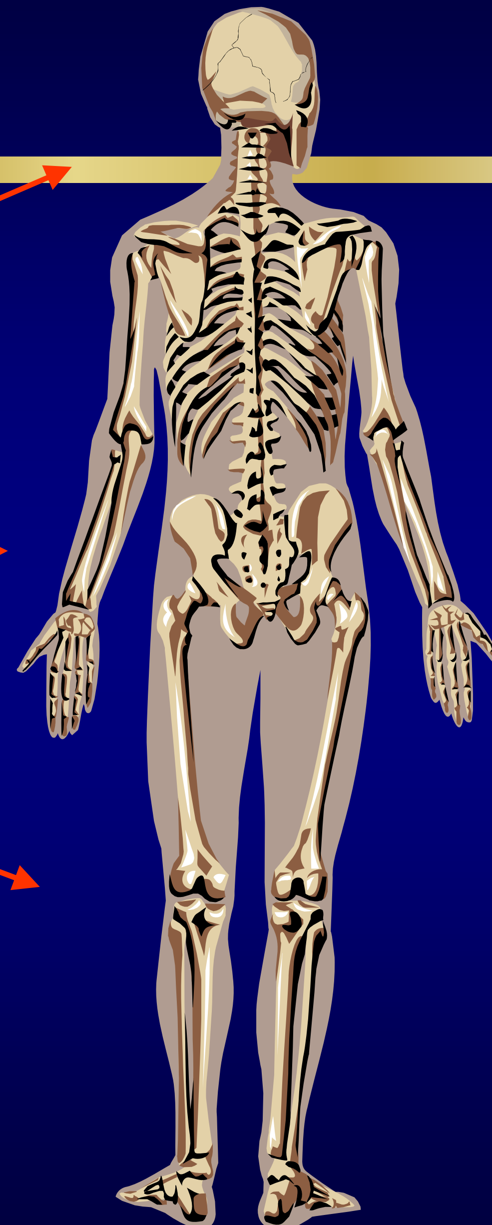
Unit Prefixes

Tera	1E12	TBq
Giga	1E9	GBq
Mega	1E6	MBq
kilo	1E3	kBq
milli	1E-3	mCi
micro	1E-6	µCi
nano	1E-9	nCi
pico	1E-12	pCi

Radiation Hazards to the Human Body

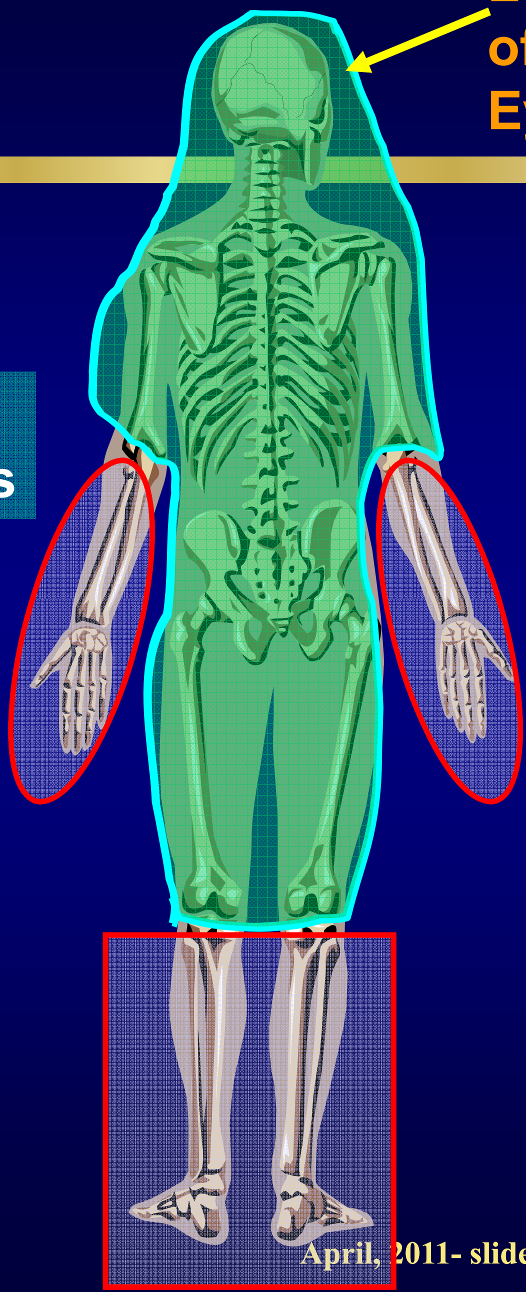
Radiation	External	Internal
Alpha		X
Beta	X	X
Photons	X	X
Neutrons	X	

External Dose



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

Dose Limit Application



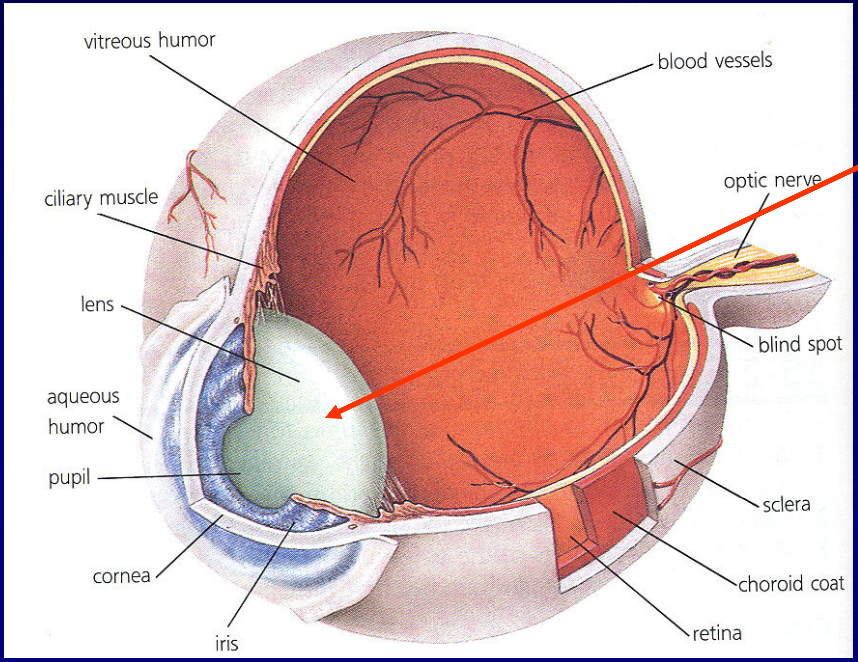
Whole Body -
everything except extremities

Skin of the Whole Body -
skin covering everything except extremities

Skin of the Extremities -
skin covering extremities

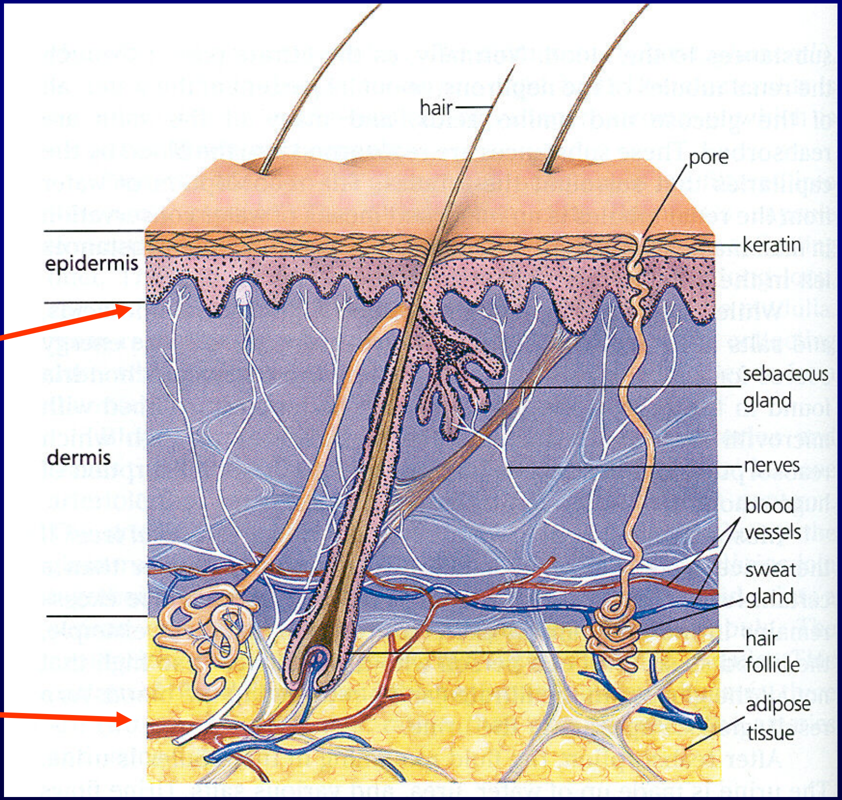
Extremities -
Elbows, and arms below elbows
knees, and legs below knees

External Dose Measurements



The dose to the lens of the eye is measured at a depth of 0.3 cm

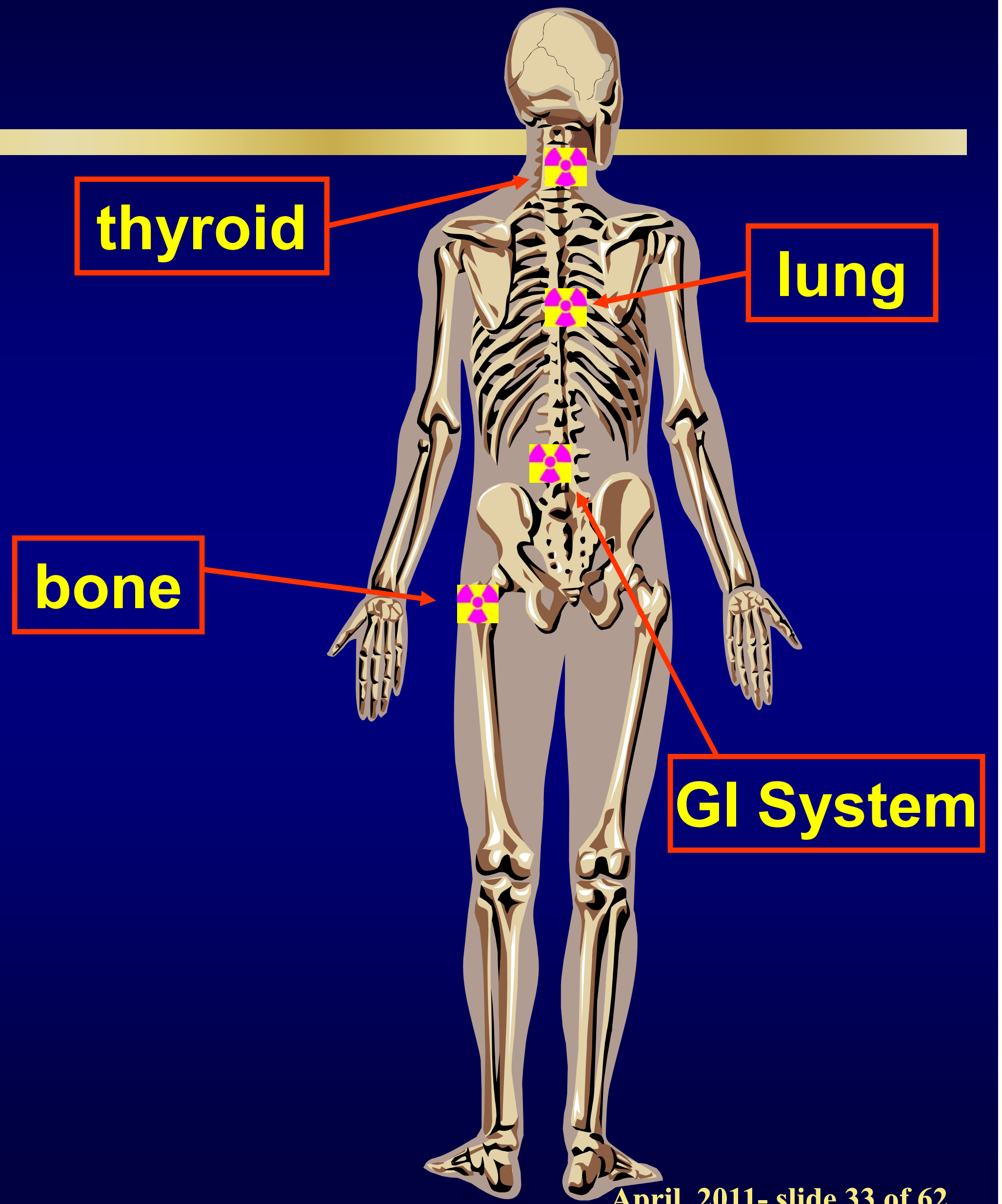
The shallow (skin) dose is measured at a depth of 0.007 cm



The deep (whole body) dose is measured at a depth of 1 cm

Internal Dose

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

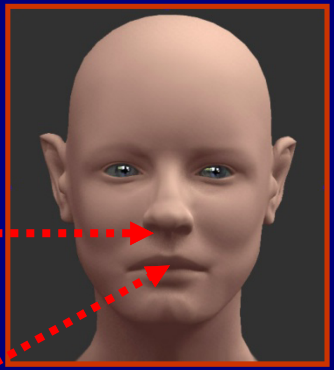


Internal Dose

- Internal dose is defined as dose from radiation released by radioactive materials deposited inside the body

- Radioactive materials enter the body through:

Inhalation



Ingestion

Absorption
(through skin or wounds)

Inhalation
ALI (Annual Limit on Intake)
DAC (Derived Air Concentration

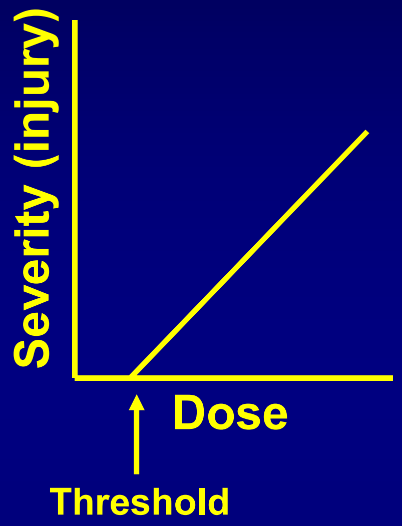
Ingestion
ALI (Annual Limit on Intake)

Internal Radiation Hazards

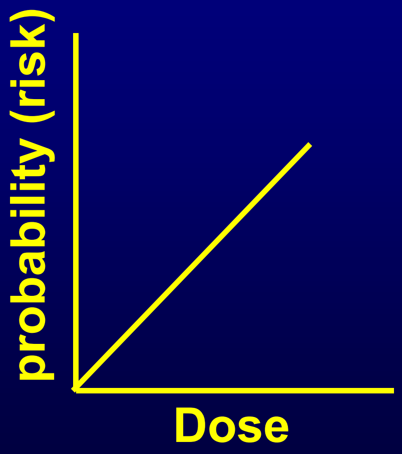
Radiation	Radionuclide	Inhalation Limit (microcuries)
Alpha	Polonium-210	0.6
Beta	Phosphorus-32	900
Gamma	Technetium-99m	200,000

Dose Limits Based on Two Types of Radiation Effects

Non-stochastic (deterministic):
threshold above which severity increases with dose (e.g., cataracts, reddening of skin, epilation)



Stochastic (probabilistic):
no known threshold (ALARA!); probability increases with dose (e.g., cancer and genetic effects)



	Dose Term	Annual Limit
OCCUPATIONAL	LDE	15 rem
	SDE_{ME}	50 rem
	SDE_{WB}	50 rem
	TODE	50 rem per organ
	TEDE	5 rem
	Minor	10% of adult limits
	Dose to E/F of DPW	0.5 rem pregnancy
	Public TEDE	0.1 rem = 100 mrem

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 or 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 + $\Sigma(CEDE_T)$

where

DDE = Deep Dose Equivalent from external radiation

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

$CEDE_T$ = Committed Effective Dose Equivalent from internally-deposited radioactivity (CDE_T x w_T)

Limits to Members of the Public

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

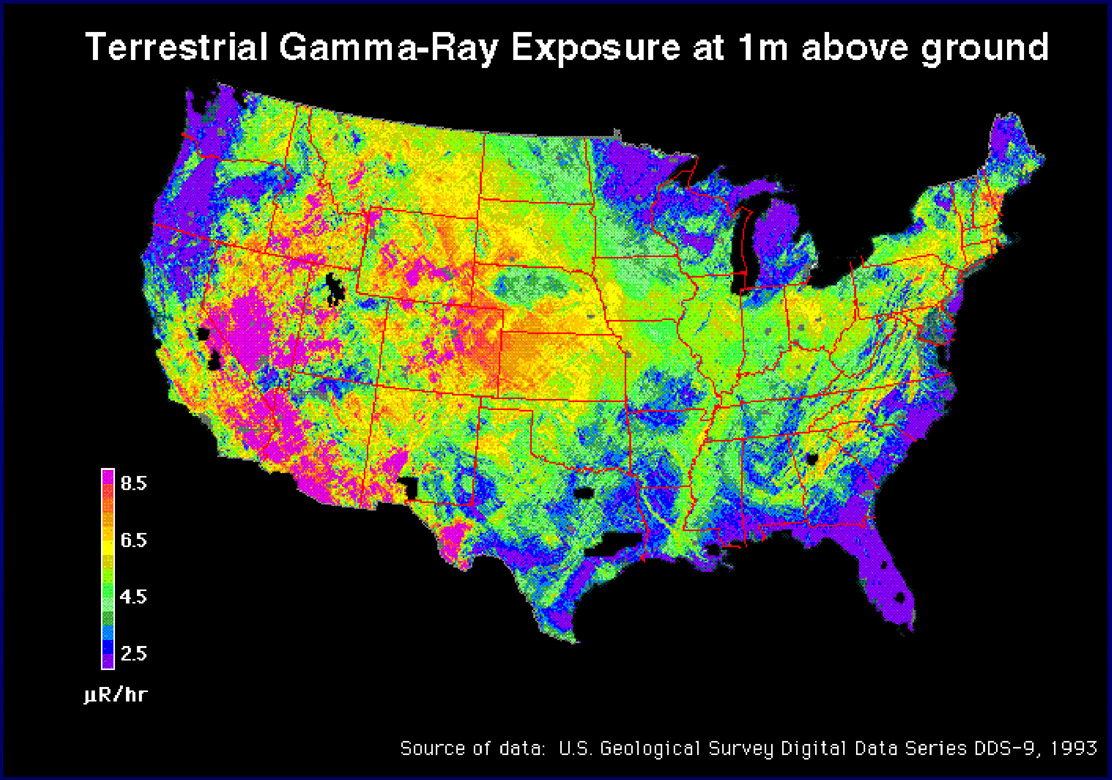
AND

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

Sources of Radiation Exposure

Terrestrial Gamma Radiation

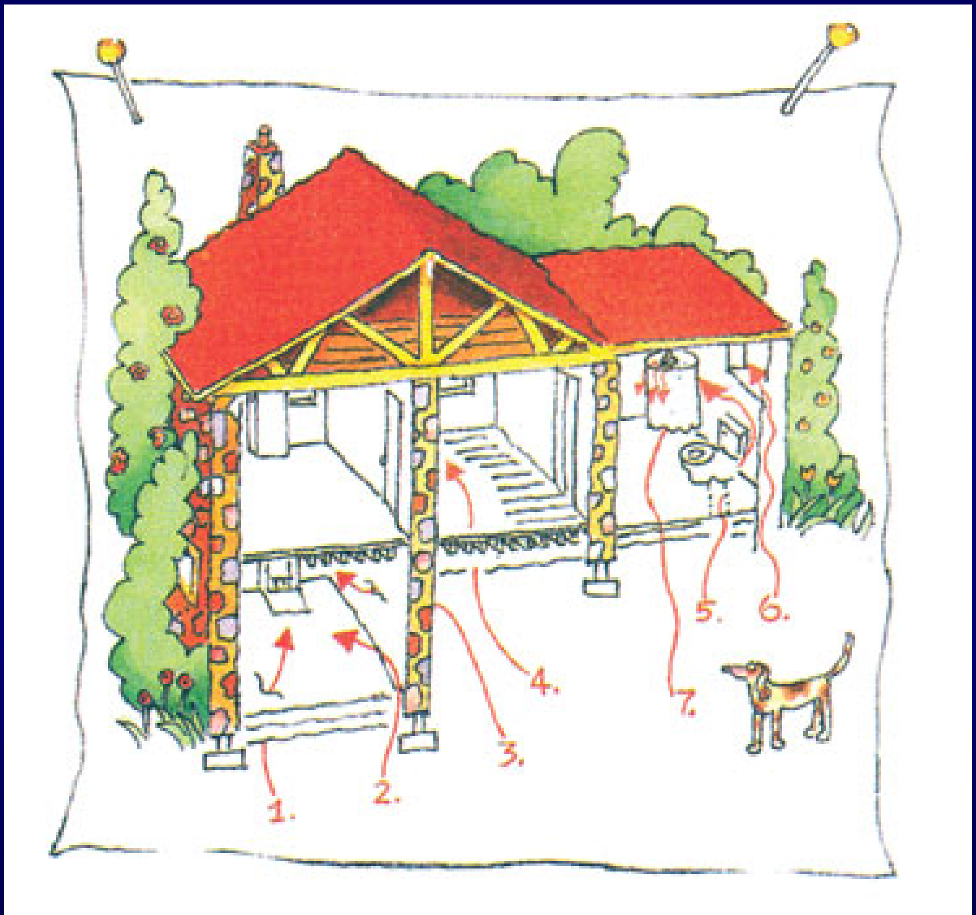
- The dose rates from natural radioactivity in the soil vary throughout the country
- Higher dose rates are in magenta
- Note that exposure to 8.5 μR/hr for a year equals about 75 mrem



Uranium Ore

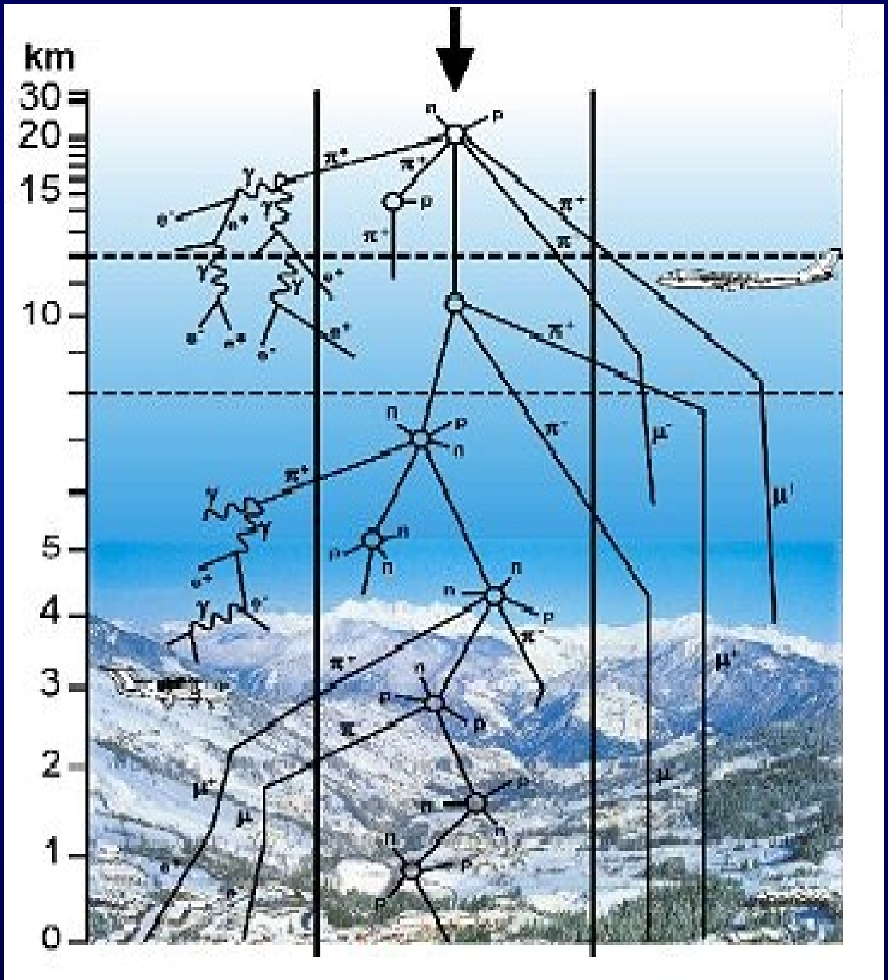
Radon

- 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



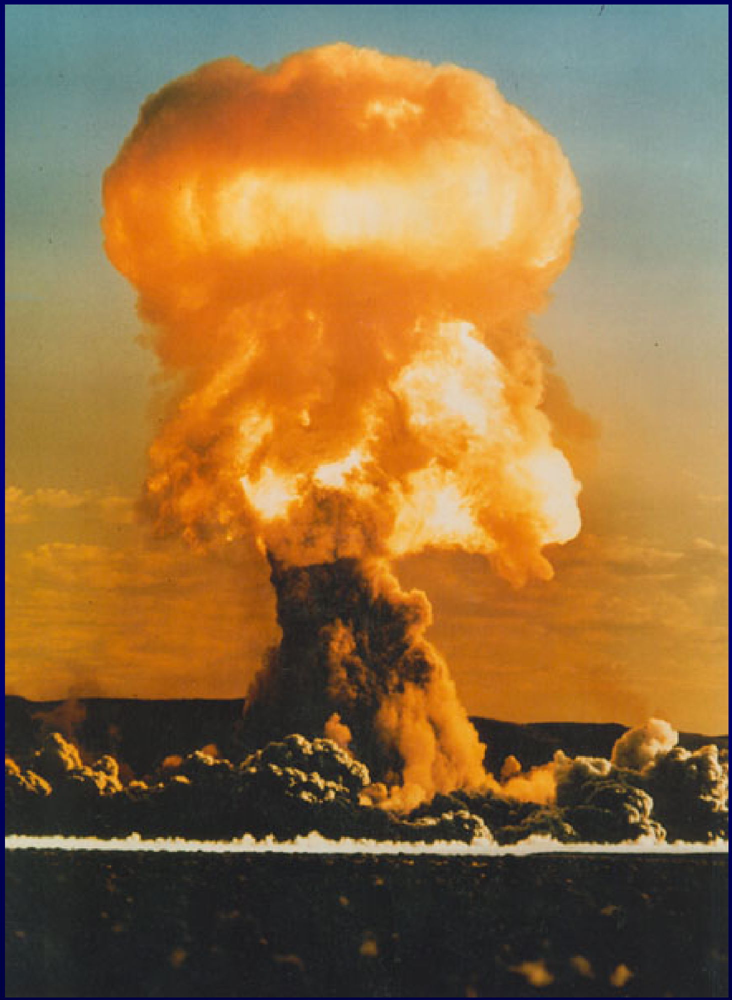
Cosmic Radiation

- 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 approximately 5,730 years, is produced in this manner

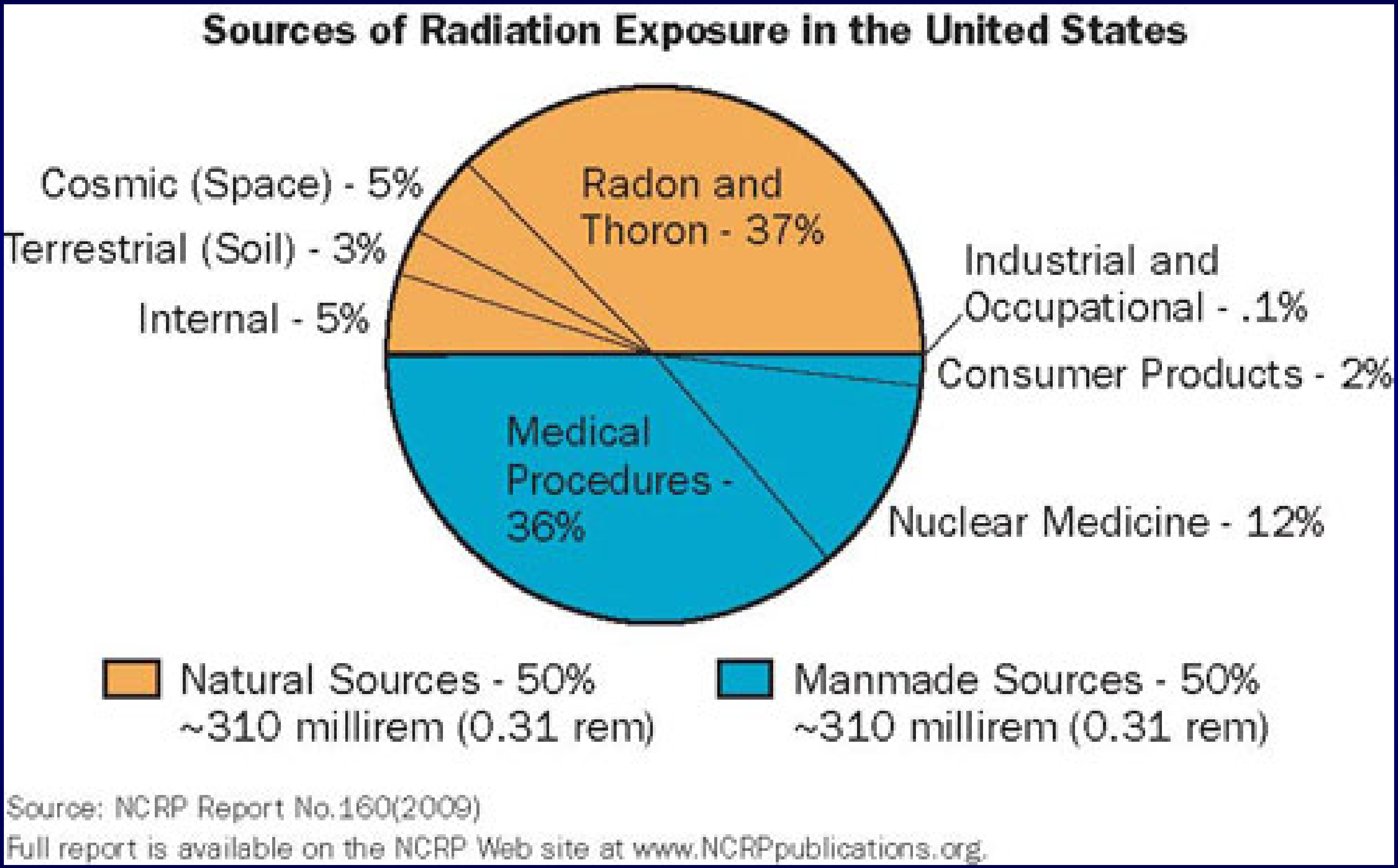
Fallout

- 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



Average Annual Dose

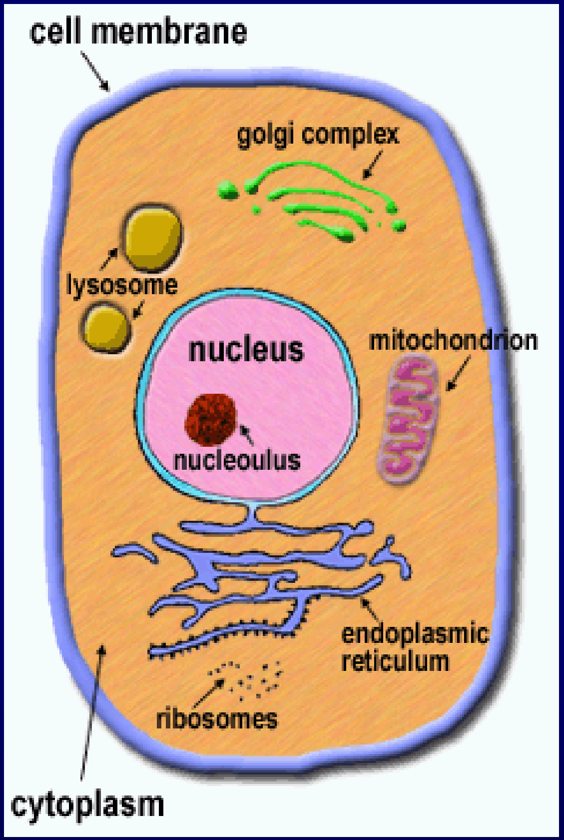


The average annual dose from all sources of radiation is about 620 mrem.

Biological Effects of Ionizing Radiation

The Human Cell

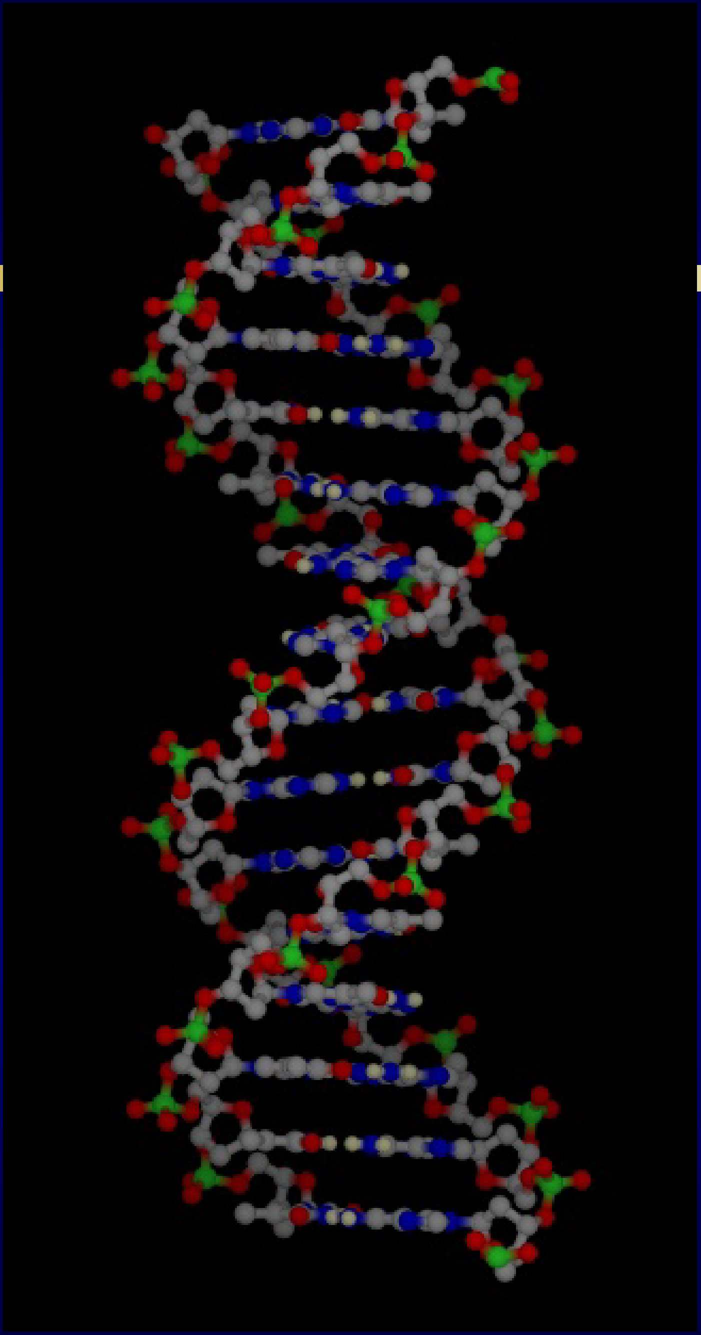
- Cell is basic building block of life
- Has basic structures that allow cell to function and reproduce
- Cell function is determined through DNA within the cell nucleus



DNA

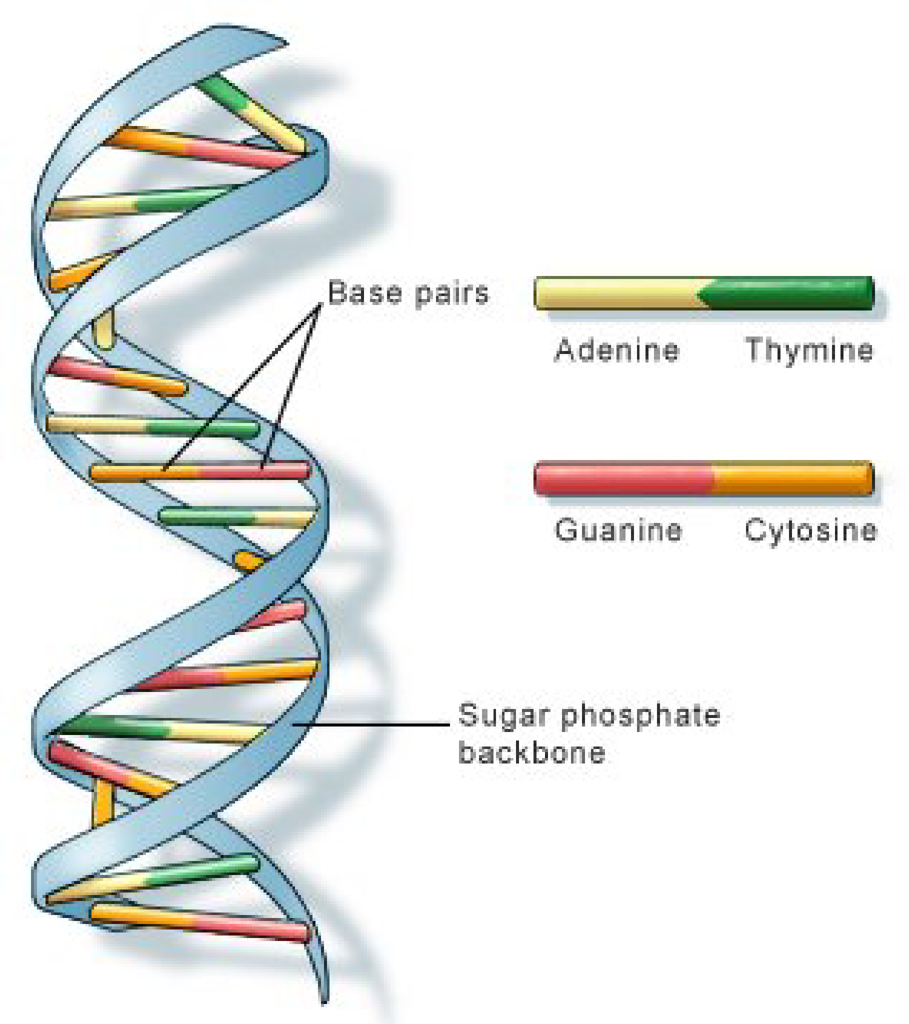
- DNA is a vast chemical database found in the nucleus of each of the body's trillions of cells. It contains the genetic instructions required for cellular development and function.

- The DNA found in every human cell is identical.



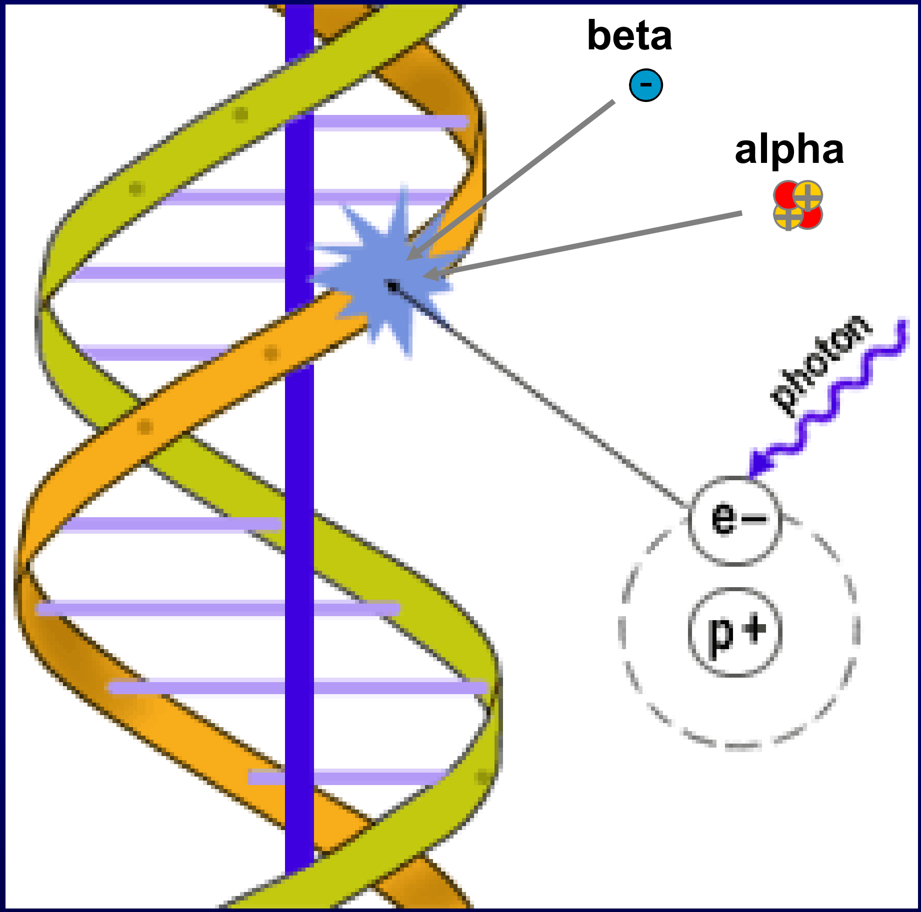
DNA Molecular Structure

- 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



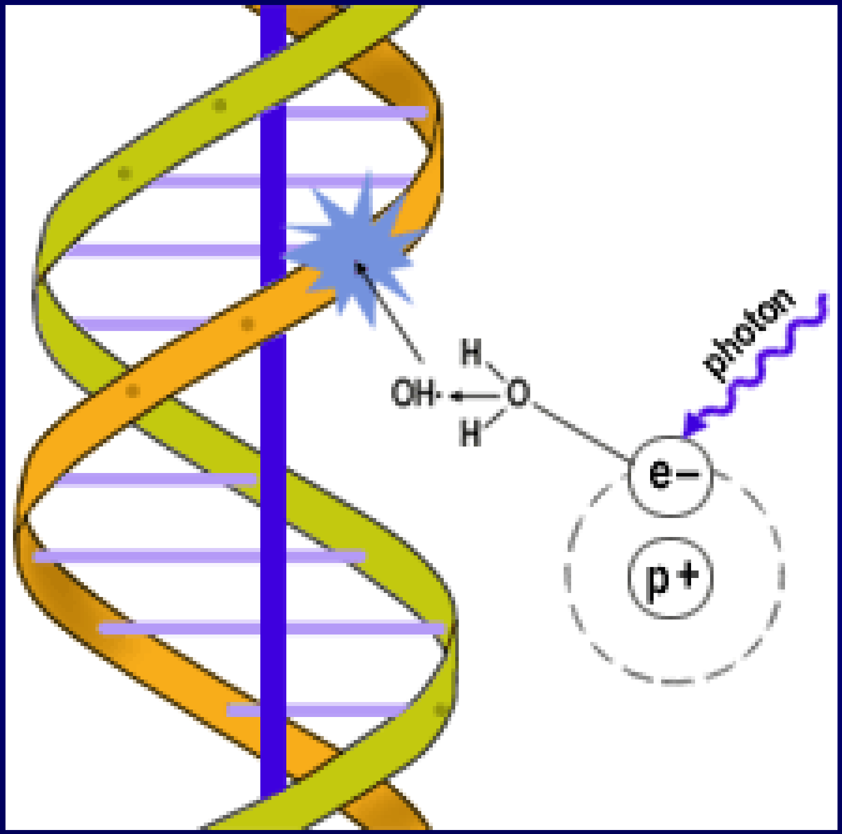
Direct Biological Effect

- When ionizing radiation or ions produced by the radiation 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 the Acute Radiation Sickness syndromes:

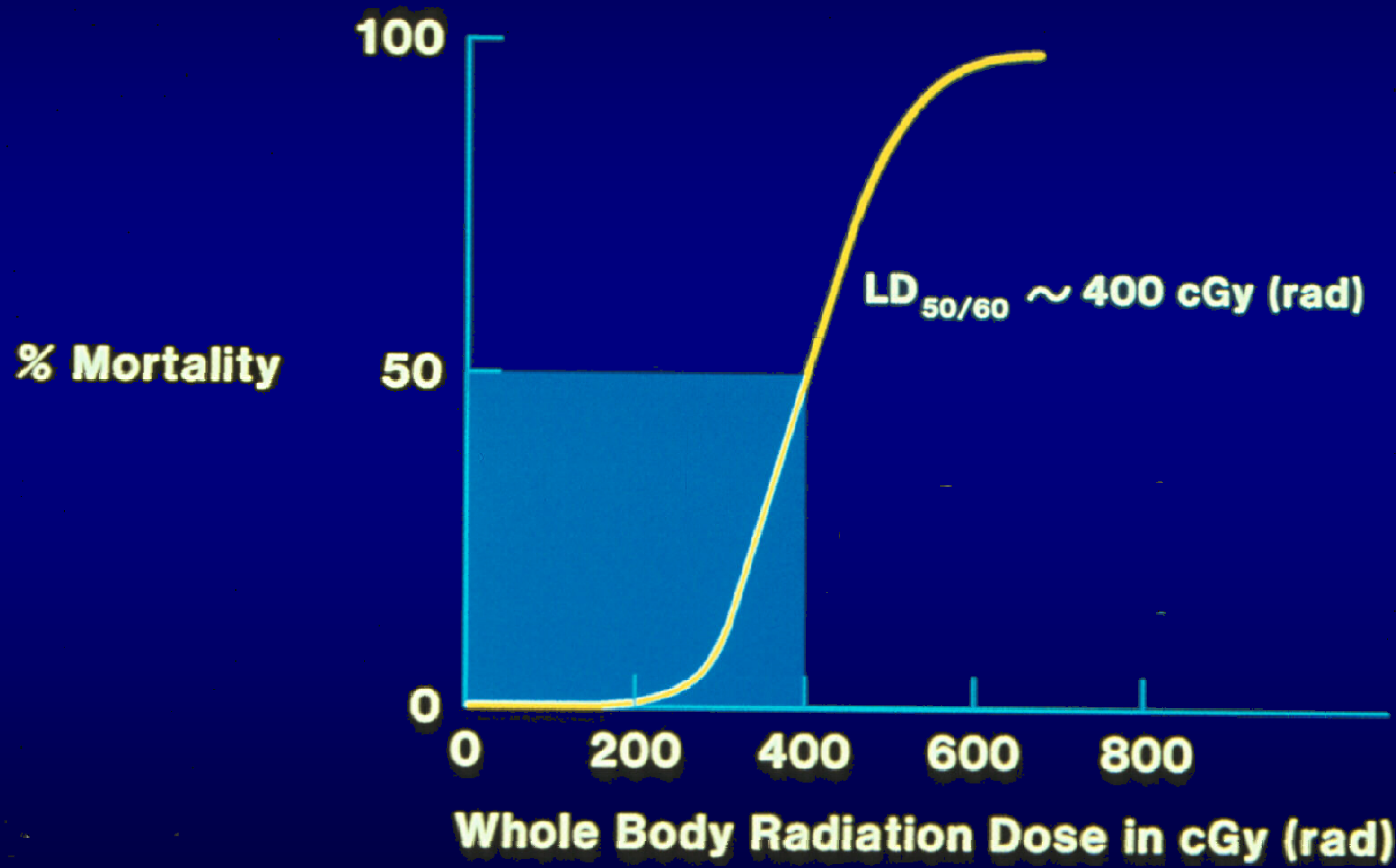
100 rad………..Hematopoietic (blood)

500 rad………..Gastrointestinal

2,000 rad……..Central Nervous System

<u>LD 50/60</u> **Lethal dose for 50% of people within 60 days; approximately 400 rad (whole body exposure - no medical intervention)**

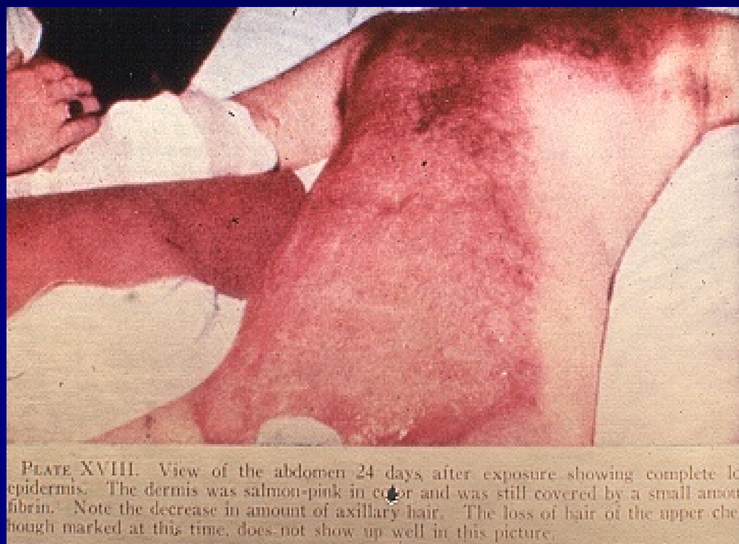
LD 50/60



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

BEWARE! **THE UPCOMING SLIDES HAVE PICTURES THAT MAY BE UNPLEASANT TO THE VIEWER…**

Biological Effects: High Doses of Radiation

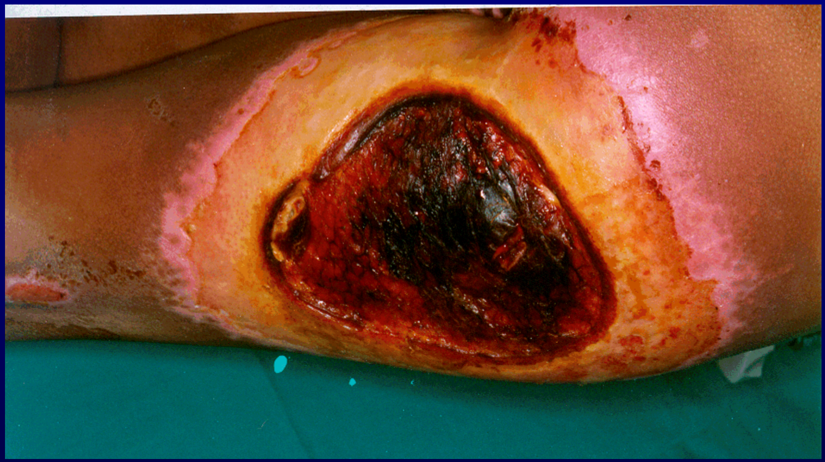


Skin Effects

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:
  - No effect
  - Cancer (not proven at doses <10 rem)
  - 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

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

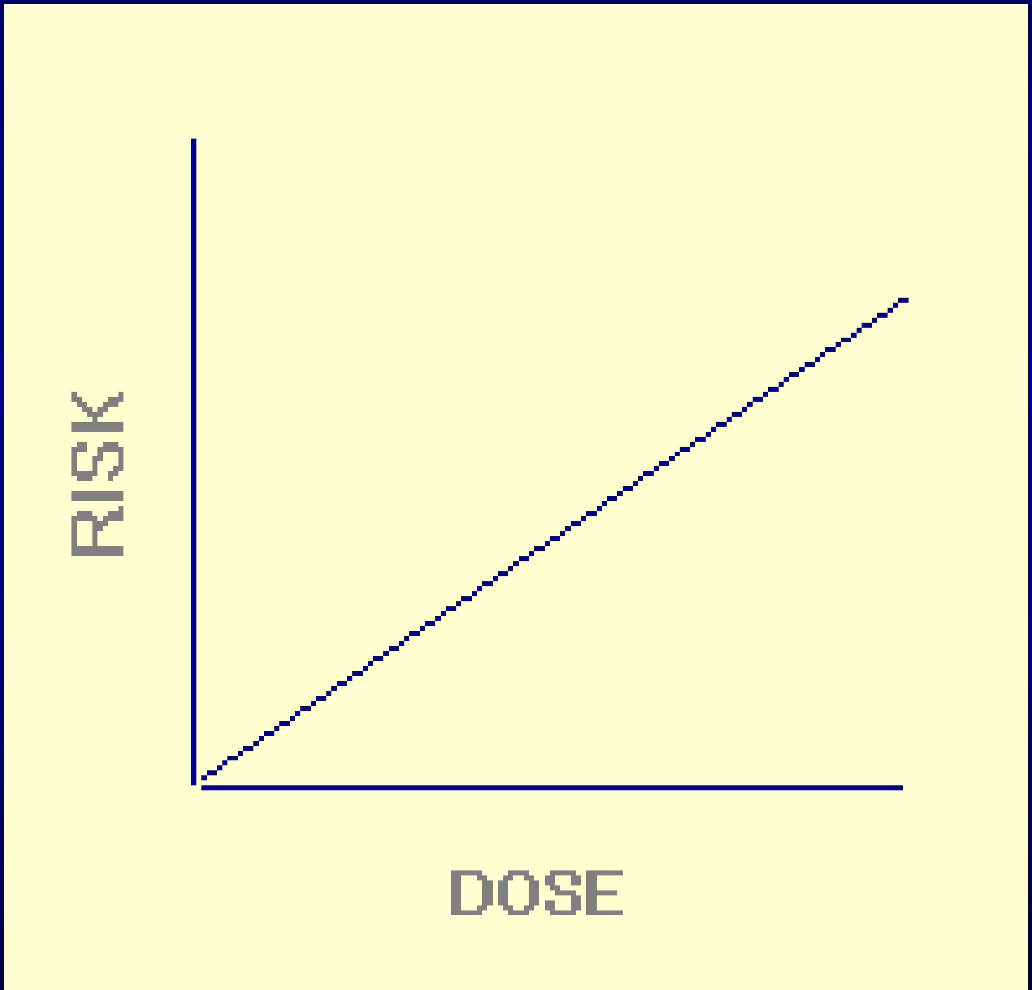
NOTE: **About 20% of the population will die from cancer in the absence of occupational radiation doses (baseline cancer mortality risk of 1 in 5)**

Biological Effects: Low Dose Radiation Risks

Since baseline cancer mortality risk is about 20%:

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

Dose-Response Relationship for a Stochastic Effect



THE END