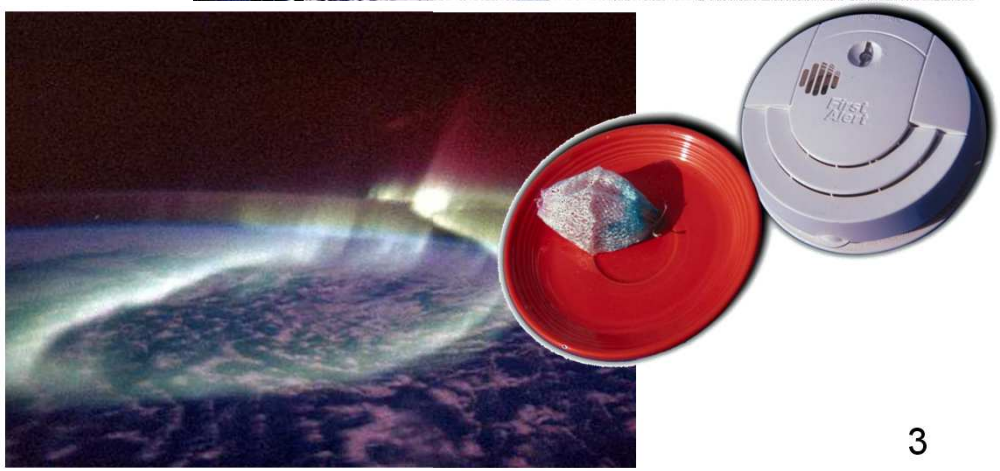
Basic Radiation Concepts
&
Radiation Protection

Objectives

- Review basic radiation concepts
- Identify common radioactive materials and sources of radiation dose
- Discuss biological effects of radiation
- Discuss methods to protect against exposure to radiation

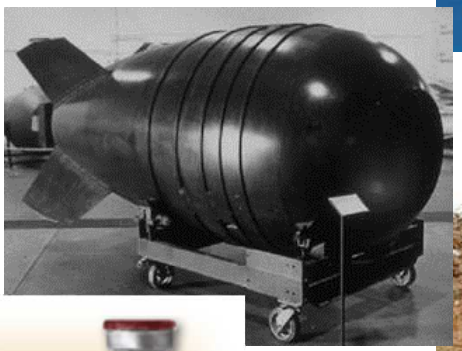
Radiation and Radioactive Material Are Part of Our Lives

- We are constantly exposed to low levels of radiation from outer space, the earth, and the healing arts
- Low levels of naturally occurring radioactive material are in our bodies and environment, (e.g., food and building materials)
- Some consumer products also contain small amounts of man-made or naturally occurring radioactive material



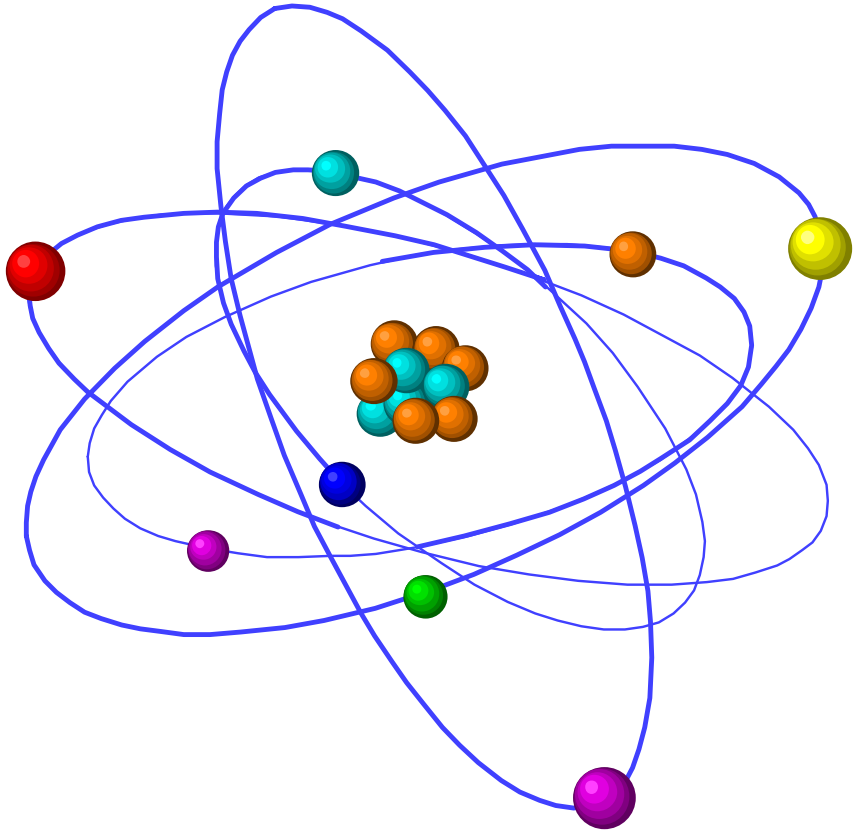
Radioactive Material Use In Industry

- We may also encounter radioactive materials used in various industrial settings, including:
  - Nuclear Power
  - Nuclear Weapons Complex
  - Radiography
  - Soil Moisture/Density Gages
  - Well Logging
  - Nuclear Medicine



The Atom

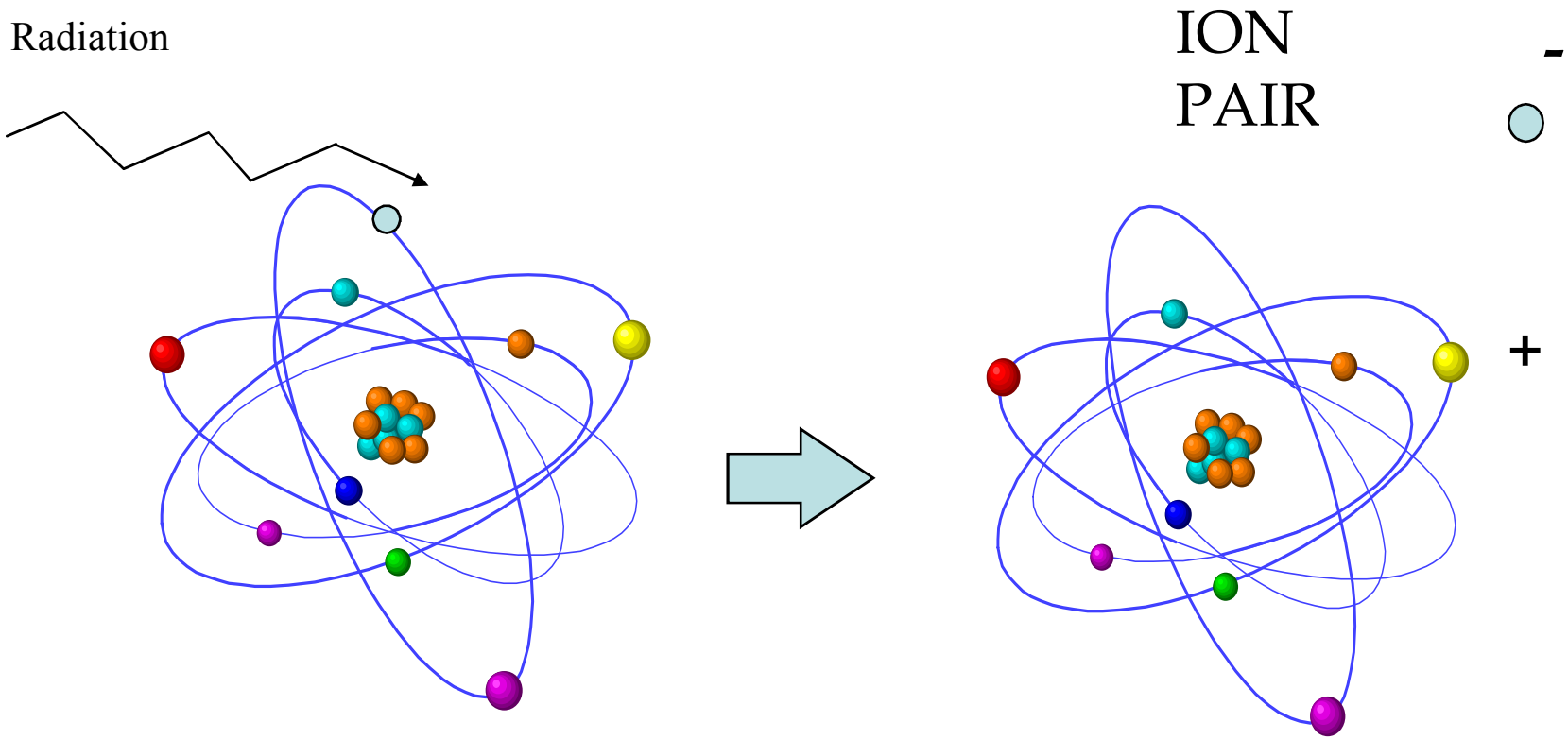
- PROTONS (positively charged) and NEUTRONS (neutral charge) in the nucleus.
- ELECTRONS orbit the nucleus.
  - Mass of electron is ~1/1800 the mass of a proton or neuron
- In a neutral atom, the number of protons and electrons are equal



Ionization and Excitation

- IONIZATION is the process by which incoming radiation transfers sufficient energy to an orbital electron to remove it from the orbit of an atom.
  - An ionization event results in an ION PAIR (a free electron and a positive ion).
- EXCITATION occurs when the energy transferred is insufficient to remove the electron – no ion pair produced.
  - The electron is raised to a higher energy state, and the atom is in an excited state. The electron may return to its ground state, resulting in emission of an X-ray

Ionization



C ionization C+ + e-

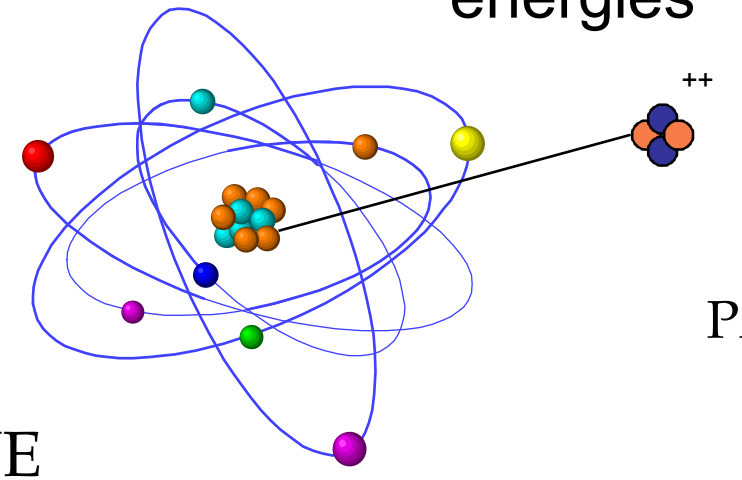
Types of Ionizing Radiation

- Four basic types of ionizing radiation of interest in radiation safety

- Directly Ionizing
  - Alpha (α)
  - Beta (β)
- Indirectly Ionizing
  - Photons
    - Gamma (γ)
    - X-ray (X)
  - Neutron (η)

Alpha Particles

- Two protons and two neutrons
- Electrical charge of plus two
- Recoil atom has two less protons and neutrons
- Emitted at characteristic energies

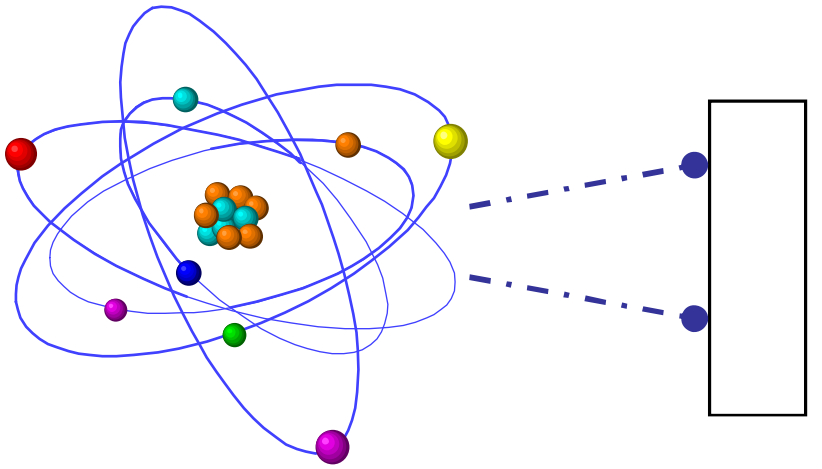


ALPHA PARTICLE

RADIOACTIVE ATOM

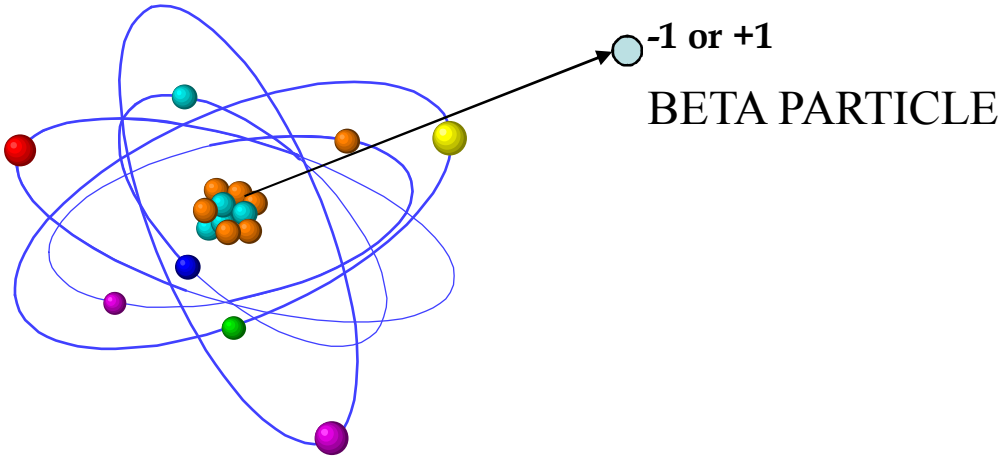
Alpha Particles

- Alpha particles only travel 2 – 5 cm in air
- Cannot penetrate the dead layer of the skin
- Easily shielded (sheet of paper, dead layer of skin)
- Greatest danger is from inhalation or ingestion of alpha emitter



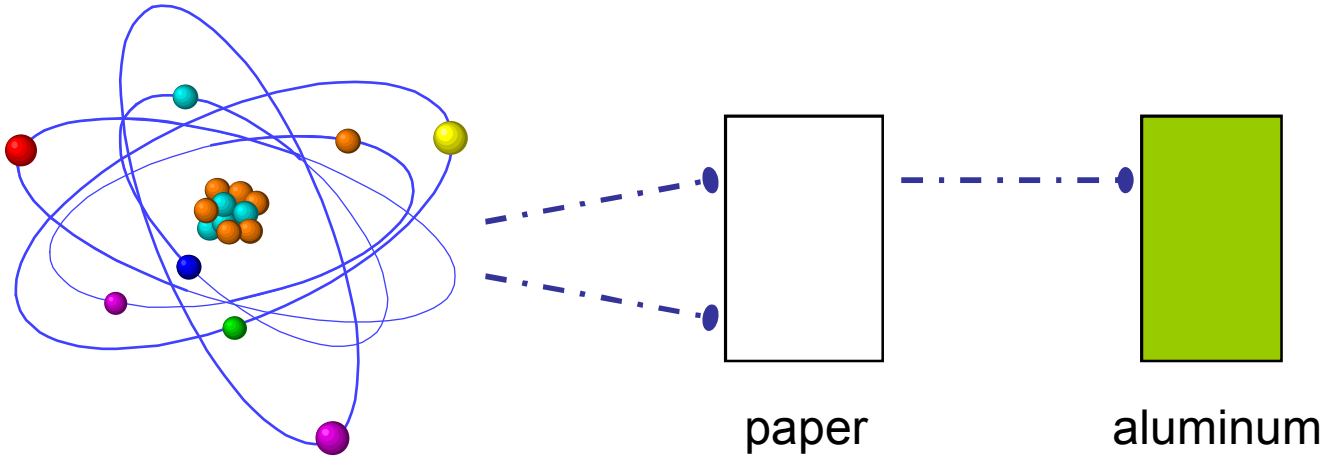
Beta Particles

- Electrons emitted from nucleus of unstable atom
- Electrical charge of plus or minus one
- Beta particles have range of energies
- Typically travel <3 meters in air depending on energy
- β^- emission: recoil atom has one additional proton and one less neutron (opposite for positron emission)



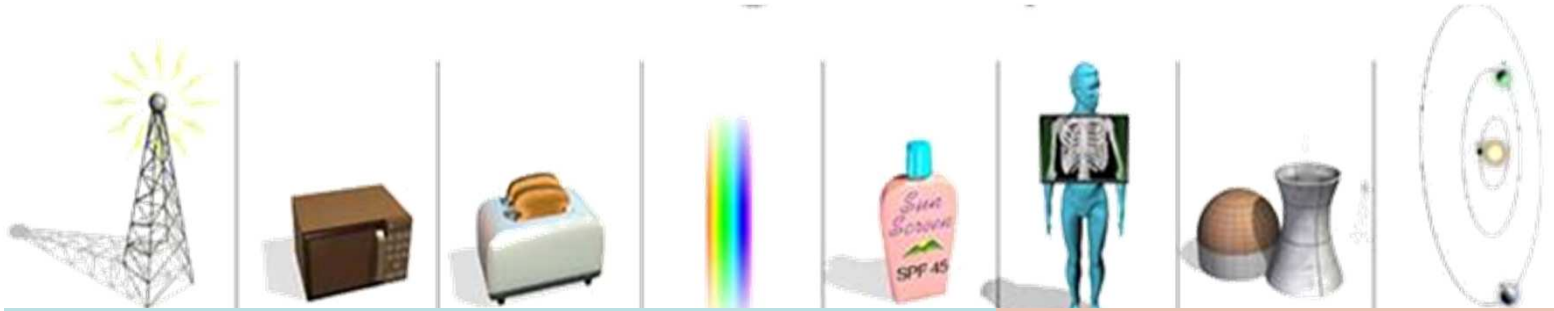
Beta Particles

- Behaves like free electrons
- May penetrate skin but not vital organs
- Shielded by thick clothing or aluminum
- Greatest danger is through inhalation or absorption of beta emitters



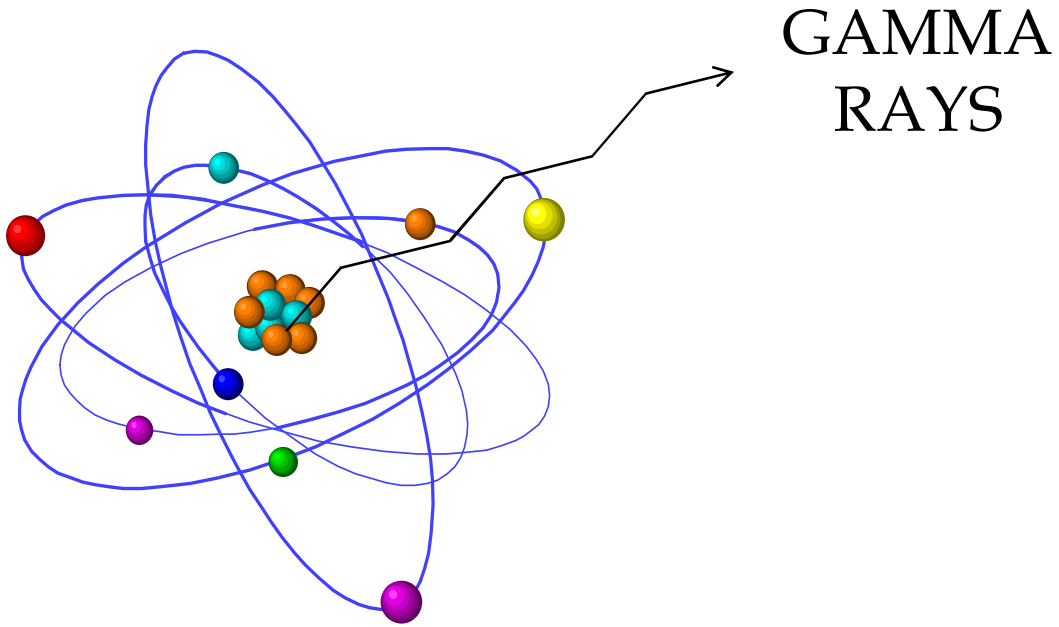
Photons (Gamma/X-rays)

The Electromagnetic Spectrum



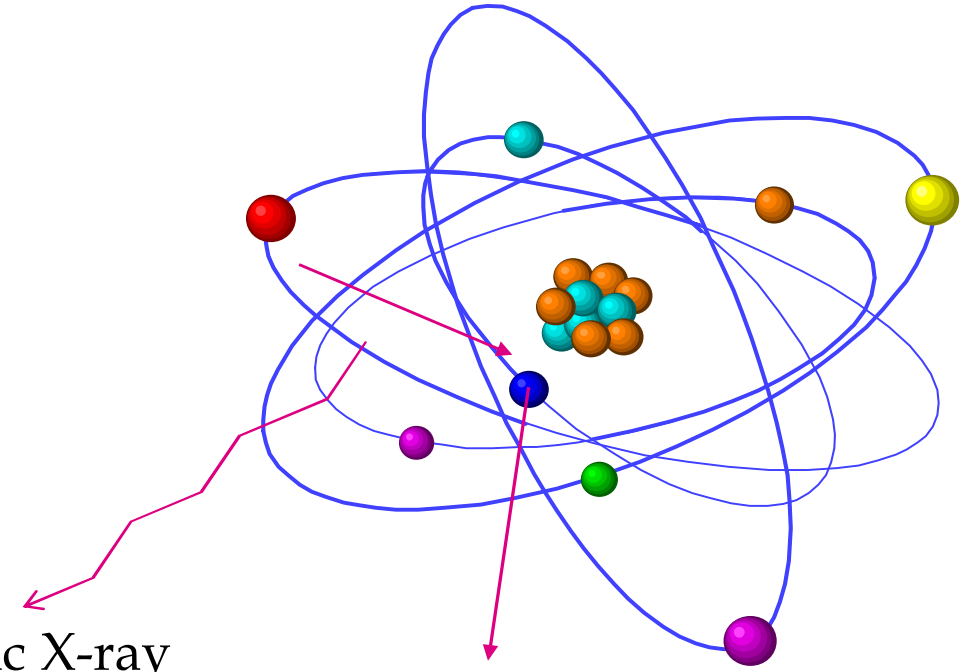
Gamma Rays

- Massless, chargeless packets of electromagnetic energy emitted in nuclear transformation
- Usually associated with alpha or beta decay
- Emitted at characteristic energies



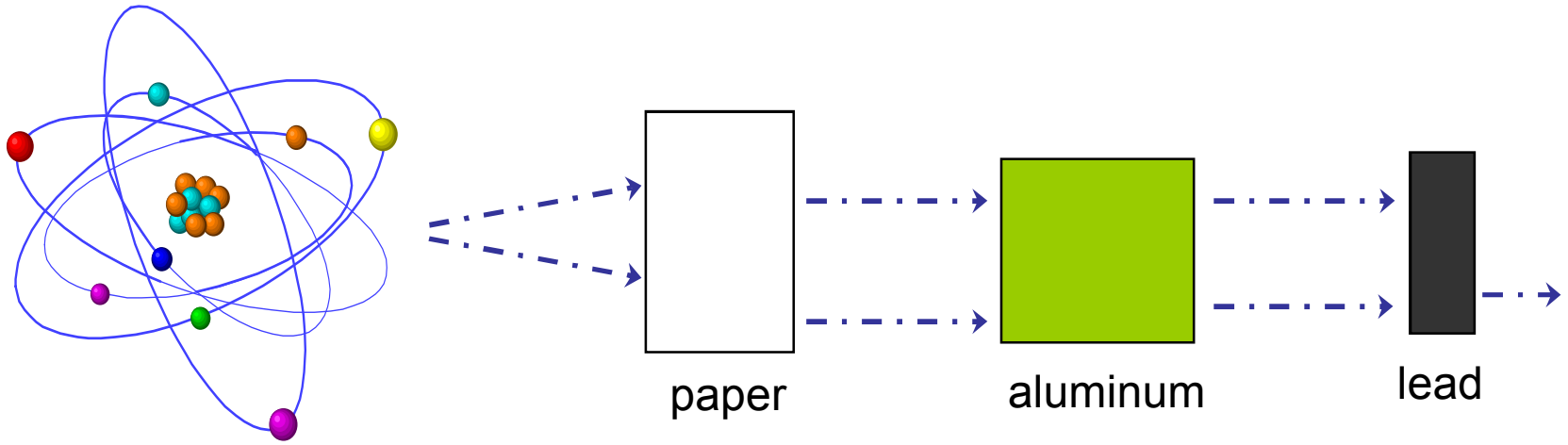
X-Rays

- Massless, chargeless packets of electromagnetic energy emitted in *atomic* interactions
- Characteristic X-rays from collisions
- Radiative process also (Bremsstrahlung)



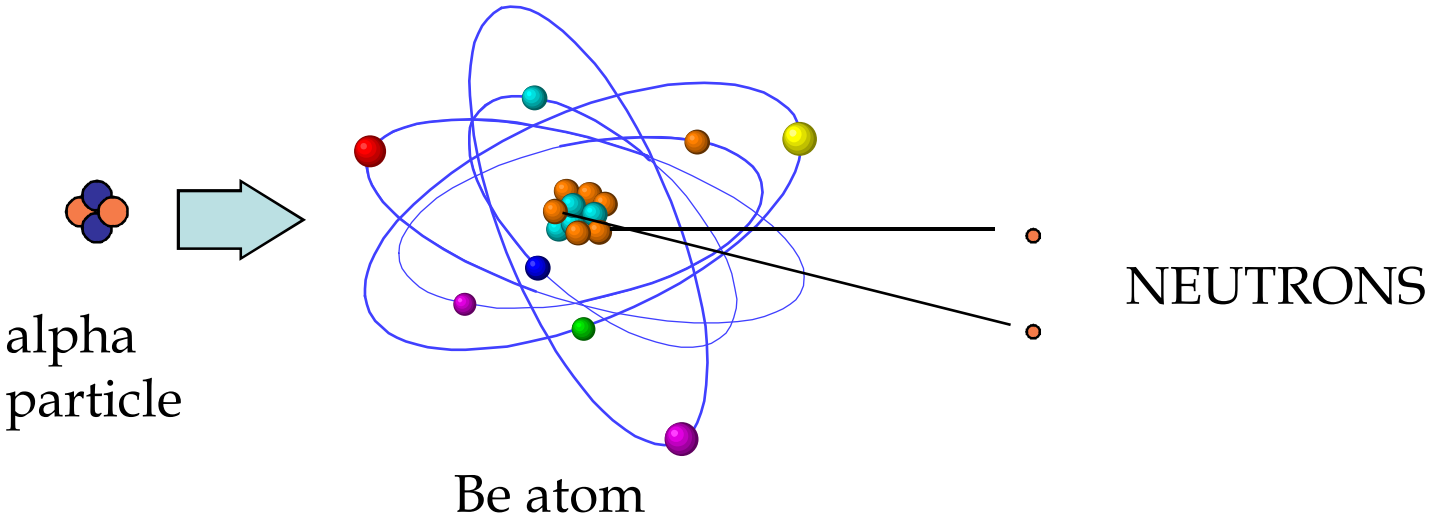
Photons (Gamma / X rays)

- High energy electromagnetic radiation (rays)
- Produced from radioactive decay or by machines
- Very penetrating; require dense shielding
- Primarily an external radiation hazard



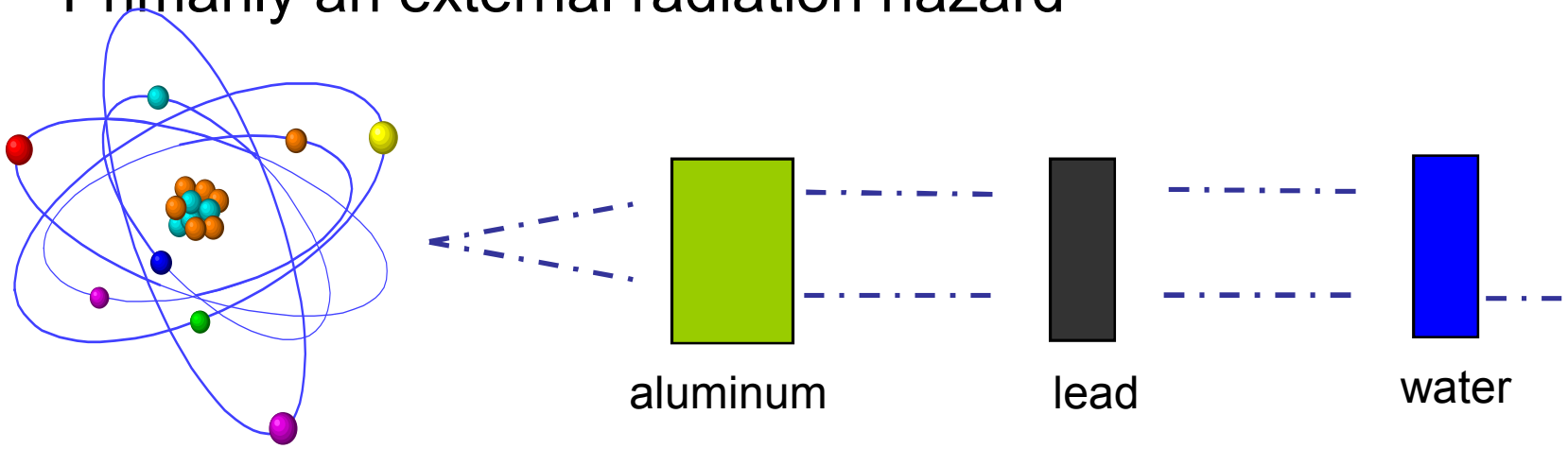
Neutrons

- approximately same mass as proton
- no electrical charge
- created during nuclear interactions



Neutrons

- Originate from a fission or fusion reactions, special nuclear material (spontaneous fission), alpha/neutron reactions.
- Can make material they strike radioactive
- Highly penetrating; requires materials with high hydrogen content such as water, oil, paraffin to shield
- Primarily an external radiation hazard



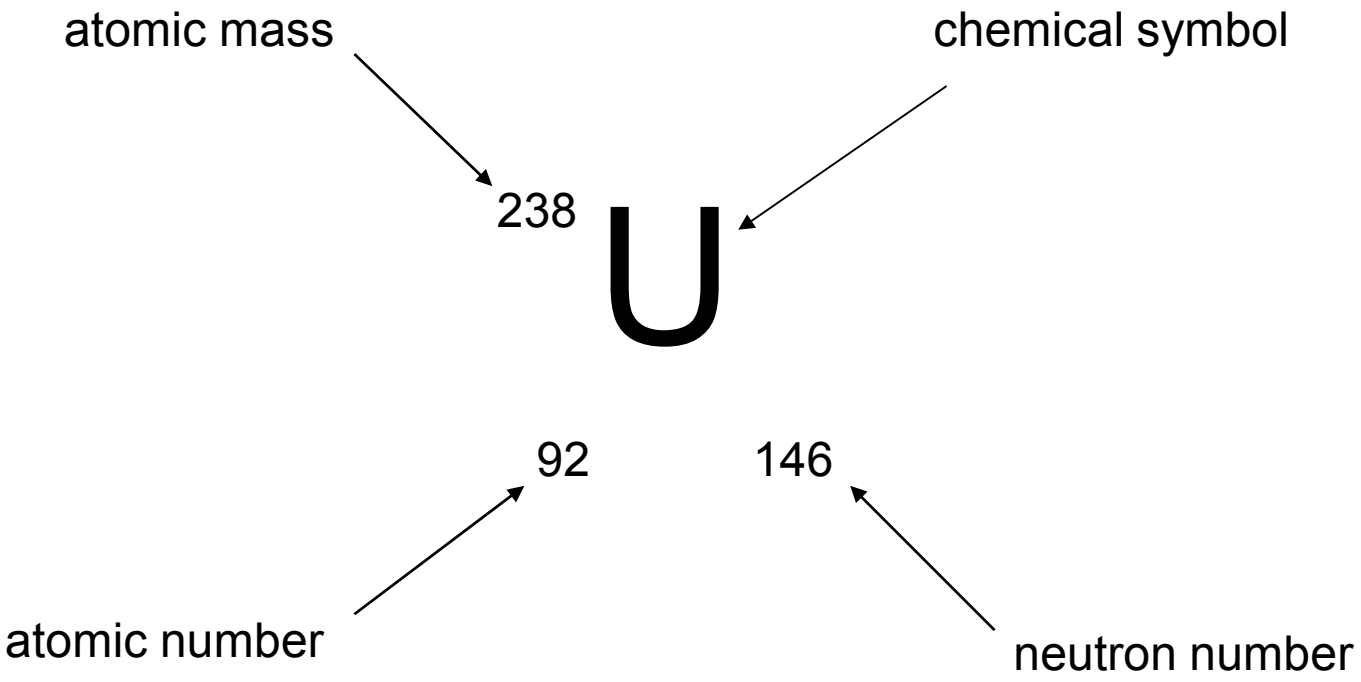
Terminology

- Isotope: species of particular element identified by the number of neutrons in nucleus.

- Radionuclide or Radioisotope: generic terms for the radioactive isotope of element.

- Radioactive Decay: the process by which unstable atoms release energy, in the form of particles and rays, to become stable (non-radioactive)

Nomenclature

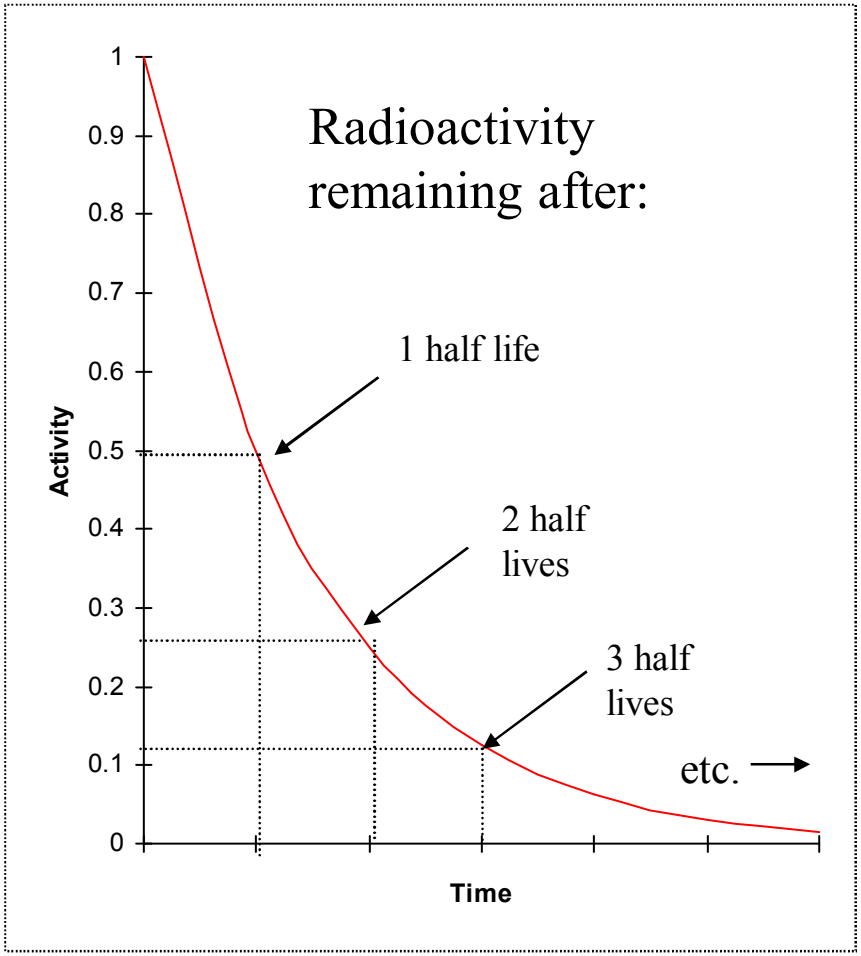


Commonly identified as U-238, U^{238}, or ^{238}U

Radioactive Half-Life

- Time required for a radioactive substance to lose half of its radioactivity
- Examples:

Tc-99m	6 hrs
I-131	8 days
Co-60	5.3 yrs
Sr-90	28 yrs
Pu-239	24,400 yrs
U-238	4,500,000,000 yrs



Radioactivity Units

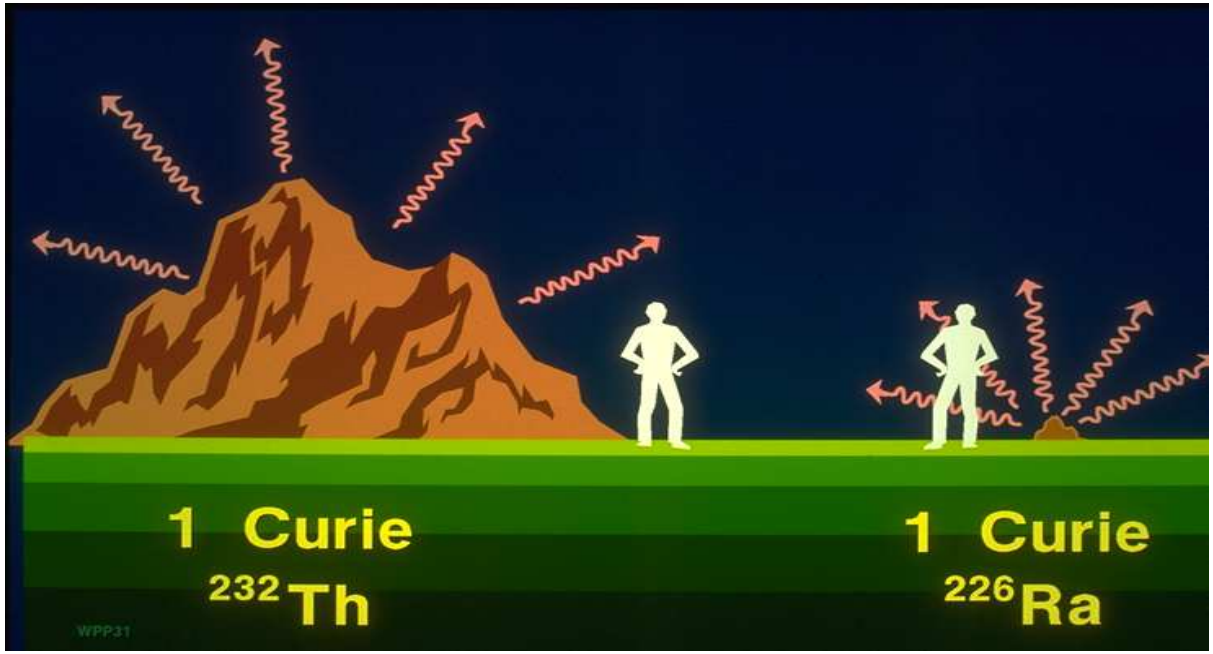
- Becquerel (Bq) - a unit of radioactivity equal to 1 disintegration (or transformation) per second
- Curie (Ci) – unit of radioactivity equal to 3.7×10^{10} disintegrations per second
- Specific Activity – the amount of radioactivity (Bq or Ci) per unit mass (usually grams) of a radionuclide

Prefixes

Prefix	Definition	Symbol
tera	trillion (x 10^{12})	T
giga	billion (x 10^{9})	G
mega	million (x 10^{6})	M
kilo	thousand (x 10^{3})	K
centi	hundredth (x 10^{-2})	c
milli	thousandth (x 10^{-3})	m
micro	millionth (x 10^{-6})	μ
nano	billionth (x 10^{-9})	n
pico	trillionth (x 10^{-12})	p

Specific Activity

- The amount of radioactivity is not related to the physical size of the source
- Specific activity is the amount of radioactivity found in a gram of material.
- Radioactive material with long half-lives have low specific activity.



Specific Activity Examples

Radionuclide	Half-Life	Specific Activity (Bq/gram)
U-238	4.5 billion years	1.2×10^{4}
Natural Uranium	NA	2.5×10^{4}
Pu-239	24,000 years	2.3×10^{9}
Cs-137	30 years	3.2×10^{12}
Co-60	5.3 years	4.2×10^{13}
H-3	12.3 years	3.6×10^{14}
Tc-99m	6.02 hours	2×10^{17}

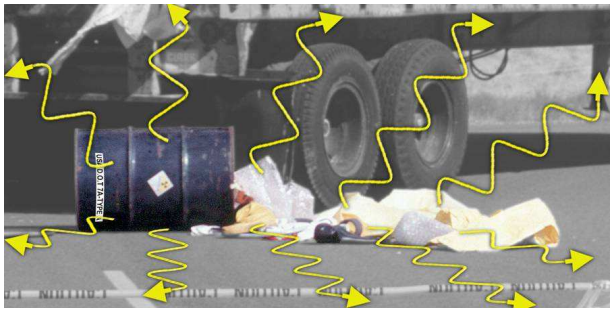
Terminology

- Radioactive material: material that emits ionizing radiation.

- Contamination: radioactive material where you don’t want it.

Radiation or Contamination?

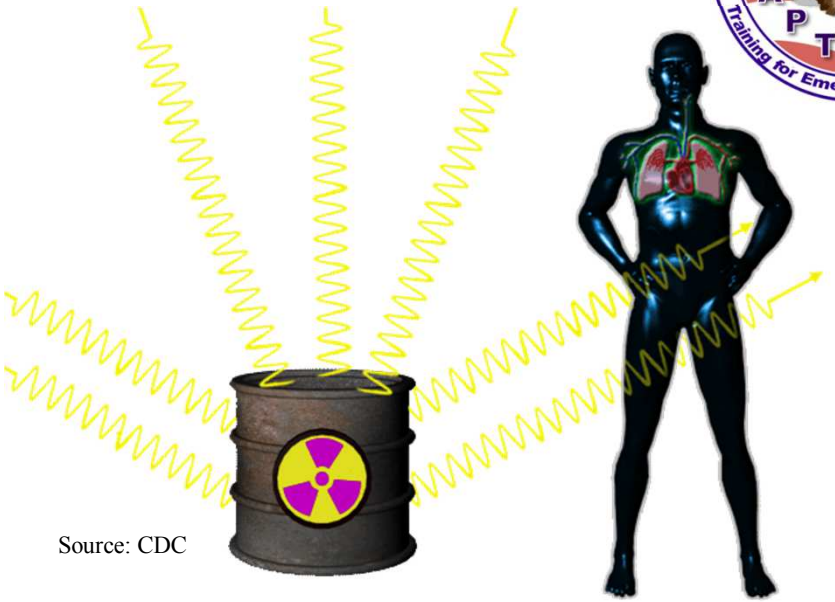
- *Contamination* is radioactive material where you don't want it
- *Radiation* is energy in the form of particles or electromagnetic waves
- Exposure to radiation will not contaminate you or make you radioactive
- Contact with radioactive material can contaminate you
- Radioactive contamination emits radiation



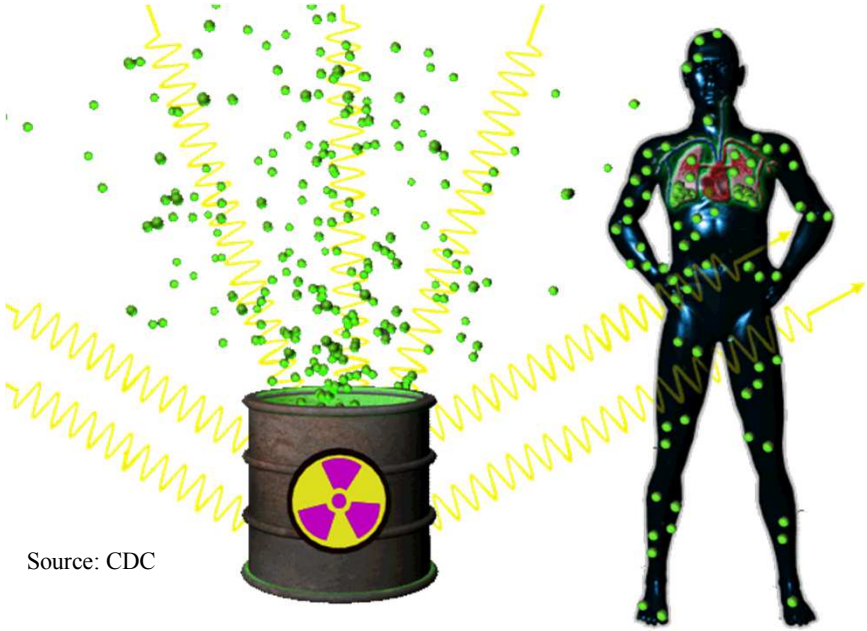
Exposure vs. Contamination

Exposure:

- Irradiation of the body resulting in an absorbed dose.



Source: CDC



Source: CDC

Contamination:

- Radioactive material on patient (external contamination) or within patient (internal contamination).
- Can come in any form – liquid, powder, etc
- Particles are exposing you to radiation.

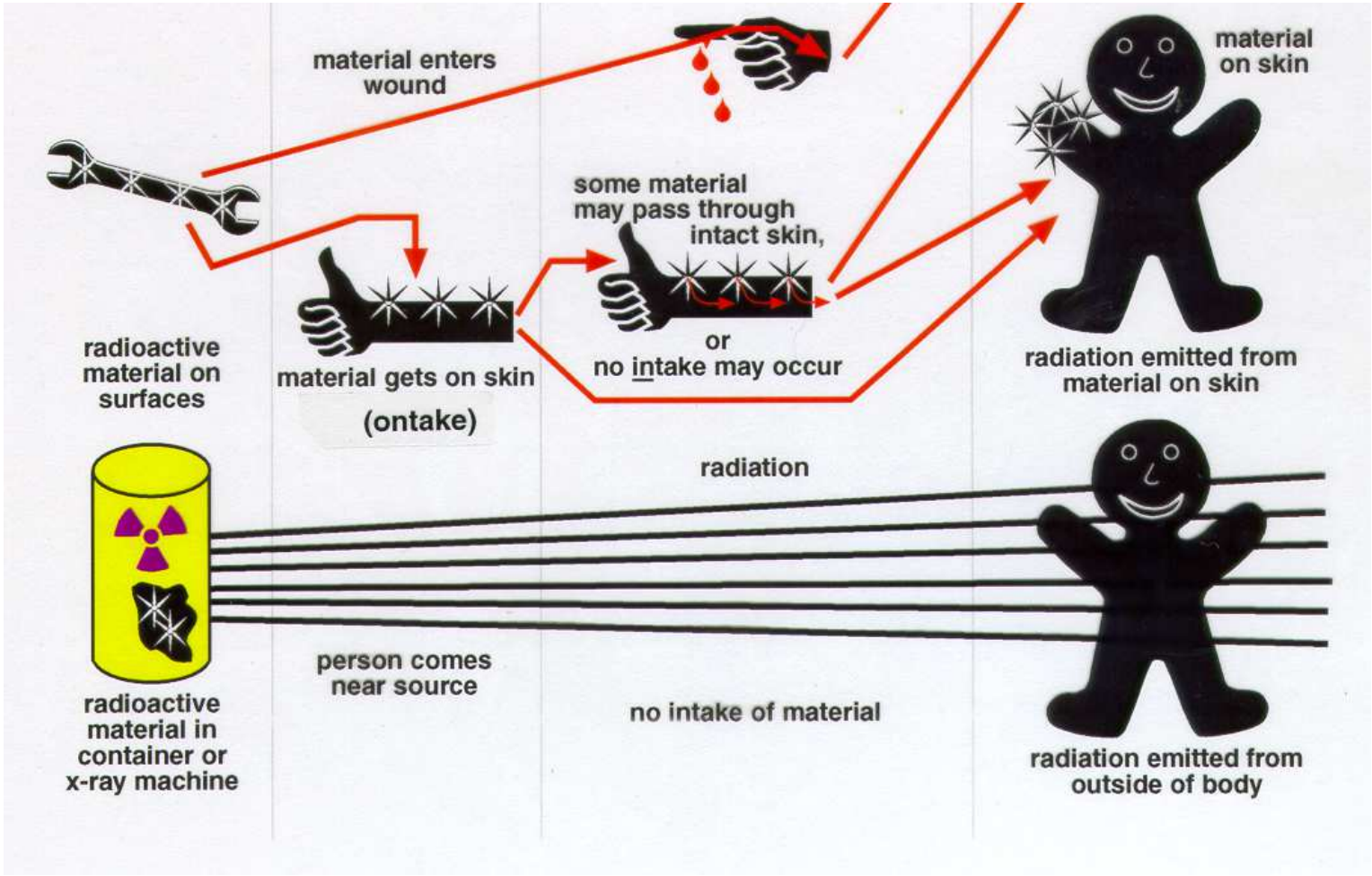
External and Internal Contamination

External Contamination
Can usually be washed off

Internal Contamination
Often through inhalation

Source: CDC

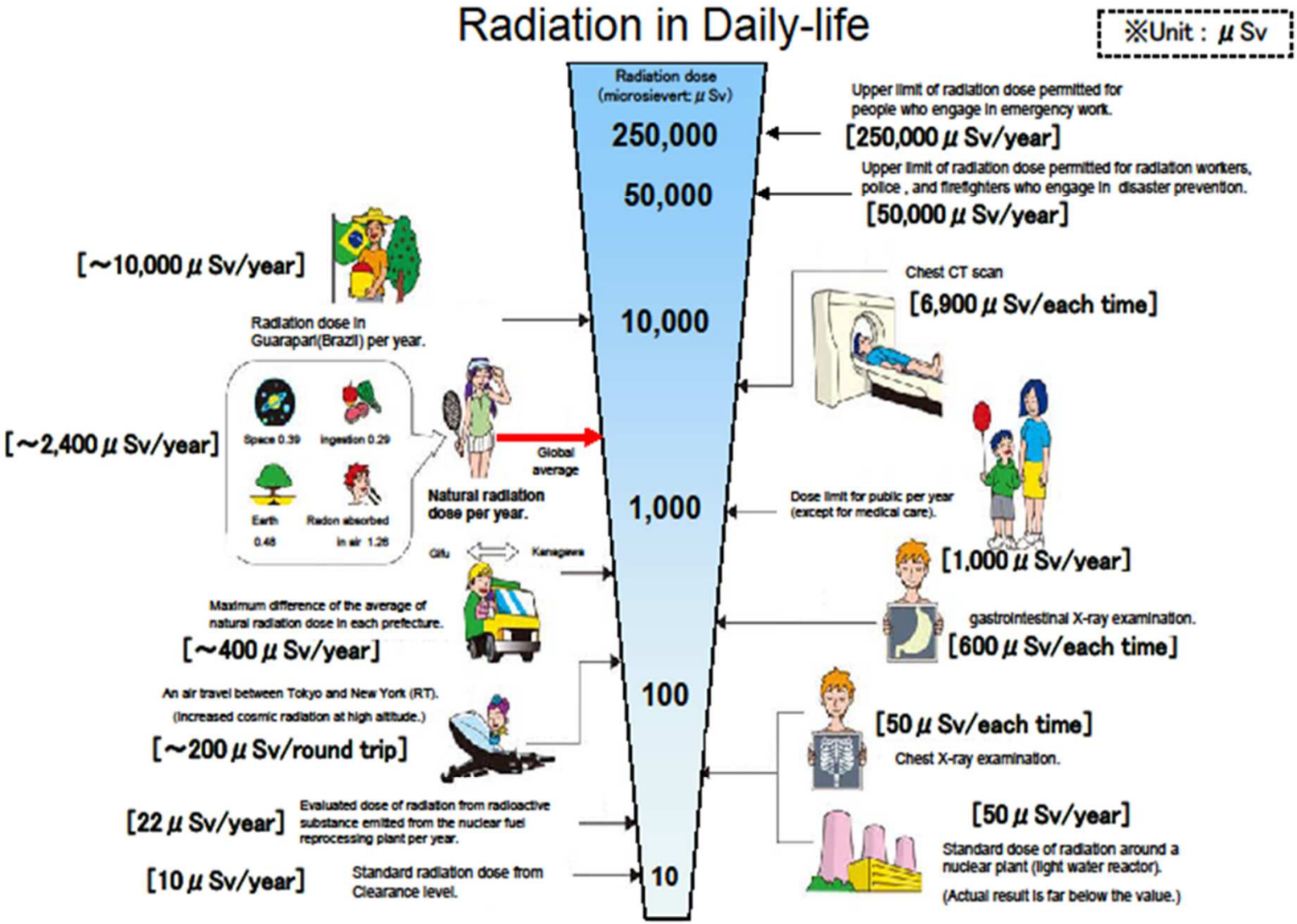
Source Cont /Exp Intake Irradiation



Radiation Doses in Perspective

Natural background radiation	2.4 mSv/year
Diagnostic chest x-ray	100 uSv
Airplane flight	5 uSv/hour
Barium enema	8 mSv
Smoking 1.5 pack/per day (lung)	16 mSv/year
Heart catheterization	450 mSv
Mild acute radiation sickness	1 Sv
LD_{50} for irradiation	4.5 Sv

LD_{50} is the dose of radiation that causes a mortality rate of 50% of the group exposed within a specified time


Radiation in Daily-life
※Unit : μ Sv
Radiation dose
(microsievert: μ Sv)
250,000
50,000
10,000
1,000
100
10
Upper limit of radiation dose permitted for people who engage in emergency work.
[250,000 μ Sv/year]
Upper limit of radiation dose permitted for radiation workers, police , and firefighters who engage in disaster prevention.
[50,000 μ Sv/year]
[~10,000 μ Sv/year]
Radiation dose in Guarapari(Brazil) per year.
Chest CT scan
[6,900 μ Sv/each time]
[~2,400 μ Sv/year]
Space 0.39
Ingestion 0.29
Earth 0.48
Radon absorbed in air 1.26
Natural radiation dose per year.
Global average
Dose limit for public per year (except for medical care).
[1,000 μ Sv/year]
Gifu
Kanagawa
Maximum difference of the average of natural radiation dose in each prefecture.
[~400 μ Sv/year]
gastrointestinal X-ray examination.
[600 μ Sv/each time]
An air travel between Tokyo and New York (RT).
(Increased cosmic radiation at high altitude.)
[~200 μ Sv/round trip]
[50 μ Sv/each time]
Chest X-ray examination.
[22 μ Sv/year]
Evaluated dose of radiation from radioactive substance emitted from the nuclear fuel reprocessing plant per year.
[50 μ Sv/year]
Standard dose of radiation around a nuclear plant (light water reactor).
(Actual result is far below the value.)
[10 μ Sv/year]
Standard radiation dose from Clearance level.

Medical Countermeasures

- Consult with specialists
  - Radiation Emergency Assistance Center/Training Site (REAC/TS)
- External Exposure:
  - Prevention and management of infection is the primary therapy
  - Extreme cases, blood transfusion/bone marrow transplant

Dose Limits

Dose Limits	ICRP-60 (mSv/yr)
Occupational - Equivalent (Whole Body) Dose	20
Lens of Eye	150
Skin or Extremities	500
Any organ	NA
Public	1

IAEA Emergency Dose Limits

Tasks	Dose* (mSv)
Life Saving Actions	1000
Actions to prevent severe health effects or injuries Actions to prevent development of catastrophic conditions	500
Actions to avert a large collective dose to the public	50

* Do not exceed without Incident Commander approval

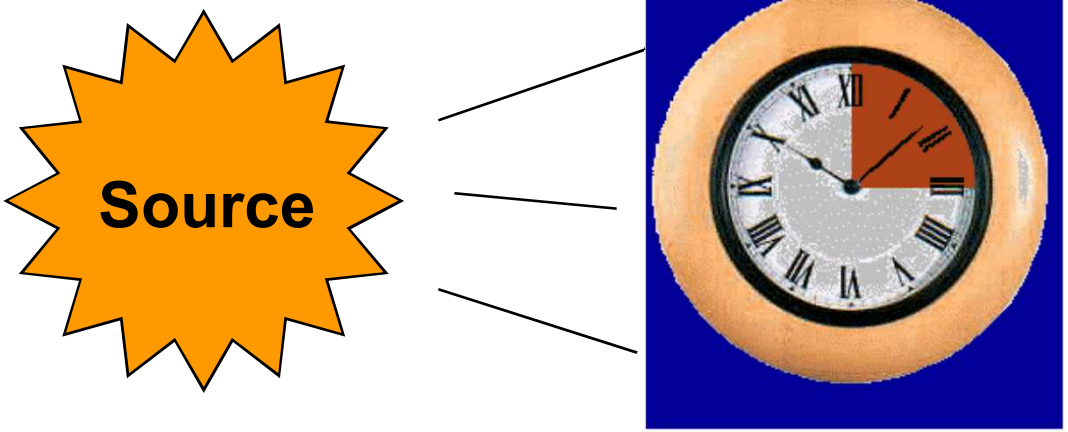
Ref: IAEA Manual for First Responders to a Radiological Emergency, 2006

Radiation Protection

External Hazard Protection

- Three basic principles to minimize dose from external radiation:
  - Time
  - Distance
  - Shielding

Time



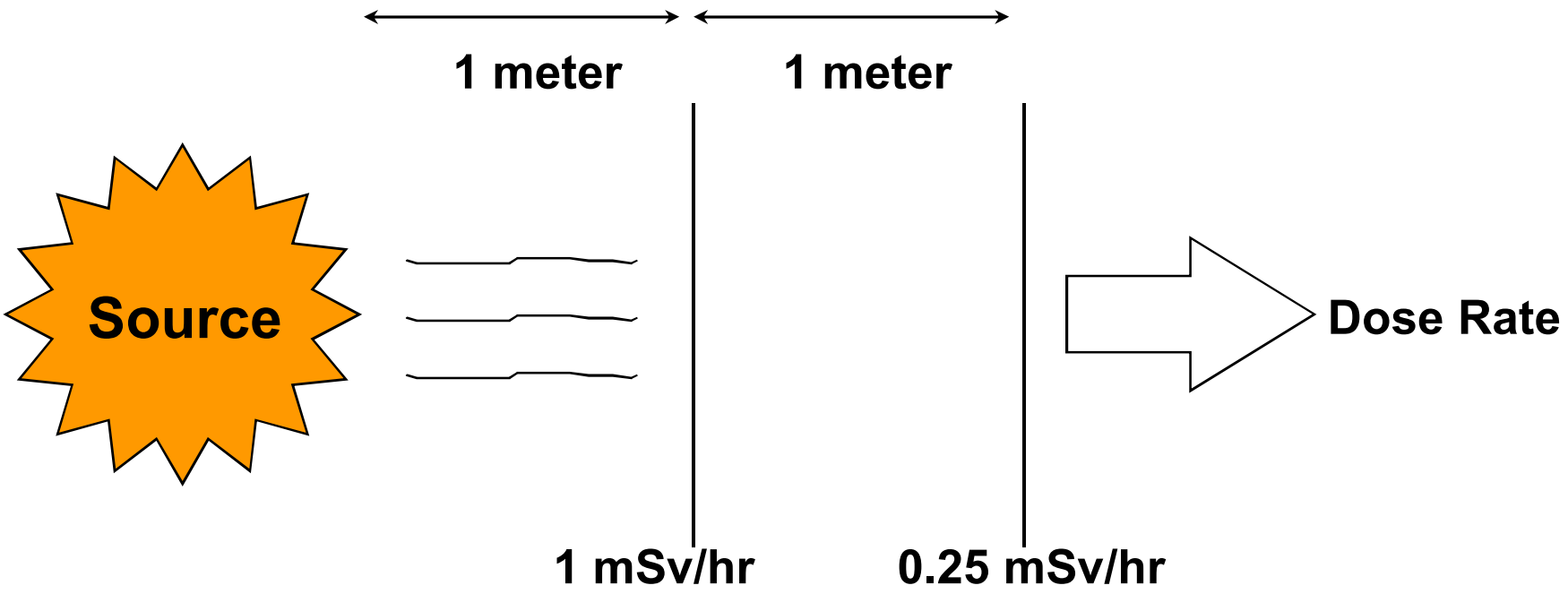
Result

Dose Rate
1 mSv/hr

Dose
0.25 mSv

1 mSv per hour x 15 minutes (.25 hour) = 0.25 mSv

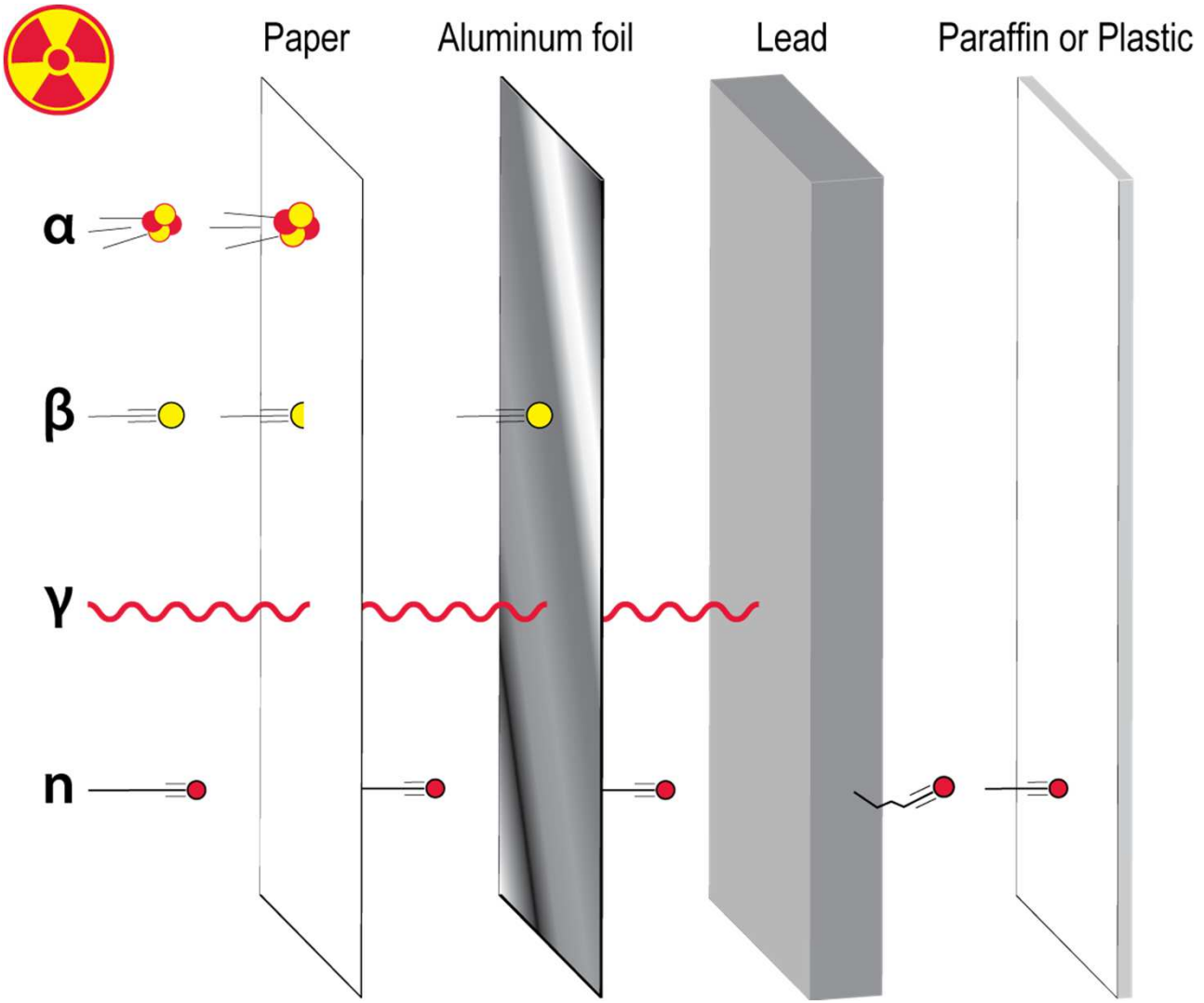
Distance



Dose rate falls off as the square of the distance

Doubling the distance reduces the dose rate by a factor of four

Shielding



Radiation Protection

Controlling internal exposure:

- Avoid inhalation of particulate radiation.
- Avoid ingestion of radioactive material.
- Prevent absorption of radioactive material through the skin by cleaning contaminated areas as soon as possible.
- Clean wounds and punctures of radioactive material and close them to prevent internalizing the contamination.

IAEA First Responder Recommendations

SITUATION	INITIAL INNER CORDONE AREA (Safety Perimeter)
OUTDOOR EVENT	
Unshielded or Damaged Potentially Dangerous Sources	30 meter radius
Major Spill from Potentially Dangerous Source	100 meter radius
Fire, explosion,fumes involving potentially dangerous source	300 meter radius
Suspsected bomb (RDD) exploded or unexploded	400 meter radius or more for frag

IAEA First Responder Recommendations

SITUATION	INITIAL INNER CORDONE AREA (Safety Perimeter)
INDOOR EVENT	
Damage, loss of shielding or spill - potentially dangerous source	Affected and adjacent areas, including floors above and below
Fire or other event that can spread material through building (e.g., thru ventilation system)	Entire building and outside area as described above
EXPANSION OF AREA BASED ON RADIOLOGICAL MONITORING	
Ambient Dose Rate at 1m above ground	Areas greater than 100 uSv/hour

IAEA First Responder Recommendations

- Additional Guidance
  - Areas greater than 100 mSv/hour should only be entered for life-saving or other time critical actions – limit stay-time to 30 minutes
  - Areas greater than 1000 mSv/hr (1 Sv/hour) – do not enter unless directed by radiological assessor

Summary

- **Radiation is energy**
  - Electromagnetic radiation – photons
  - Particulate Radiation – alphas, betas and neutrons
- **Radiation interacts with orbital electrons or with the nucleus**
- **Dosimetric quantities**
  - Activity
  - Exposure
  - Absorbed dose and equivalent dose
- **Radiation protection**
  - Time, distance and shielding
  - Avoid internalizing particulate radiation

QUESTIONS??