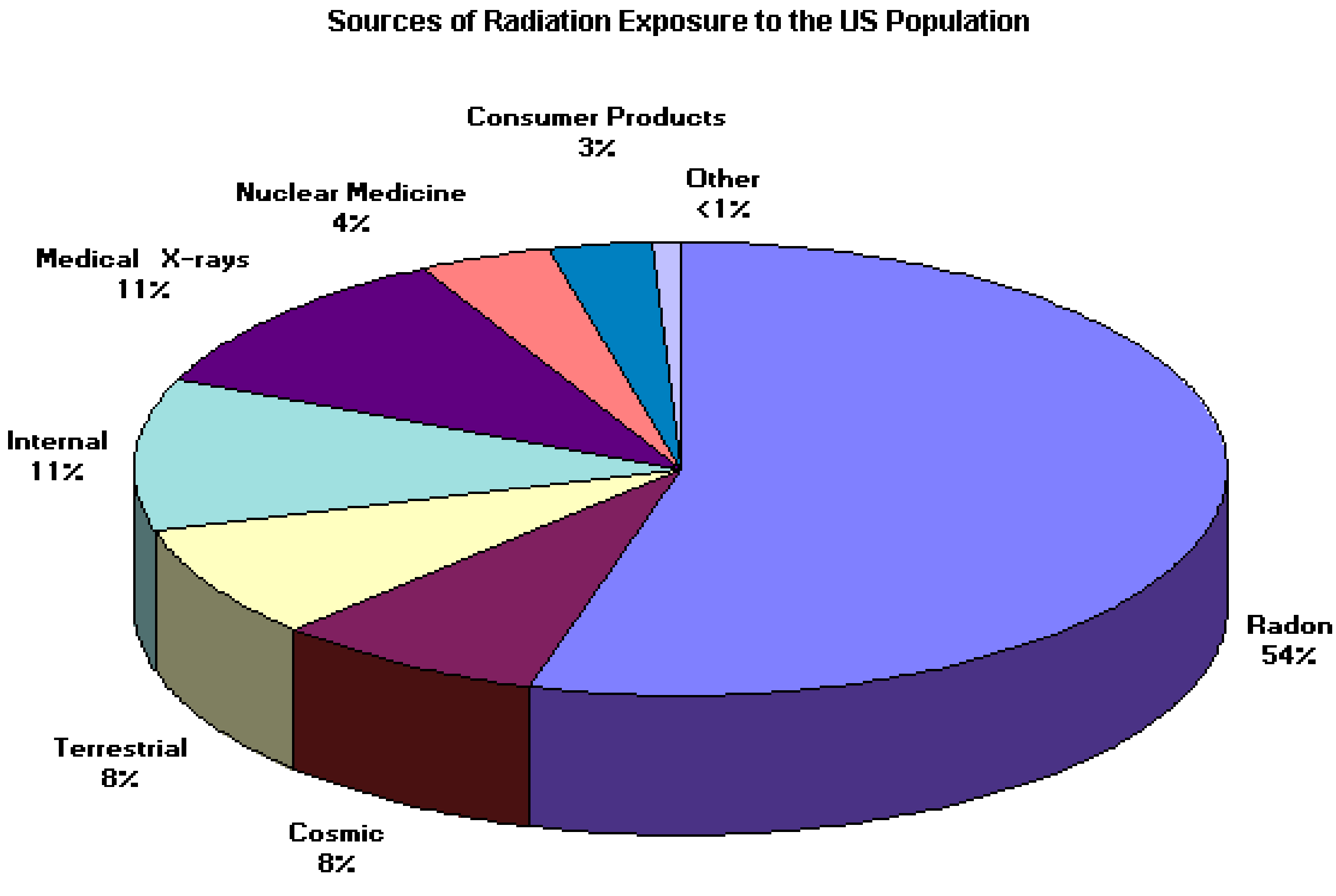
Understanding RADIATION

Where is Radiation?

- Radiation is all around us and has been since the beginning of time
- Sources of this radiation include the ground, the air, the food we eat and the solar system in general
- Everything around us contains small amounts of radioactive atoms like Potassium 40, Radium 226, and Radon 222
- These remain from the creation of the world or made by interactions with cosmic radiation like Carbon 14 and Tritium (the earth is constantly receiving cosmic radiation from outer space)
- These natural sources of radiation make up approximately 82% of the average annual dose to the US public

Where is Radiation?



Sources of radiation exposure to US population. Adapted from NCRP 93

Where is Radiation?

- YOU are Radioactive!

  These radionuclides are found in all humans:

Nuclide	Amt (nCi)
Potassium-40	120
Rubidium-87	9.2
Carbon-14	9
Tritium (Hydrogen-3)	1
Radium-226	0.1

Where is Radiation?

- Natural Radiation like Carbon 14 (C-14) and Potassium 40 (K-40) are the result of cosmic ray interactions and eventually make there way into our food
- Radon is probably the most recognizable form of natural radiation and comes from the decay of natural Uranium
- Radon levels are higher in the Northeast and Rocky Mountain regions of the U.S.
- Natural sources of radiation are present everywhere and therefore present a “Background” level of radiation
- This “background” is very low level and harmless, but varies from location (geological) and altitude (cosmic)

Where is Radiation?

- Besides Radon, radiation in our home comes from televisions, microwaves and smoke detectors
- Other low level sources of radiation we are exposed to come from sunlight, radio waves, infrared heat, cosmic rays
- Radiation in the Medical field comes from x-rays and injections of radioactive materials for diagnosis and therapy

What is Radiation?

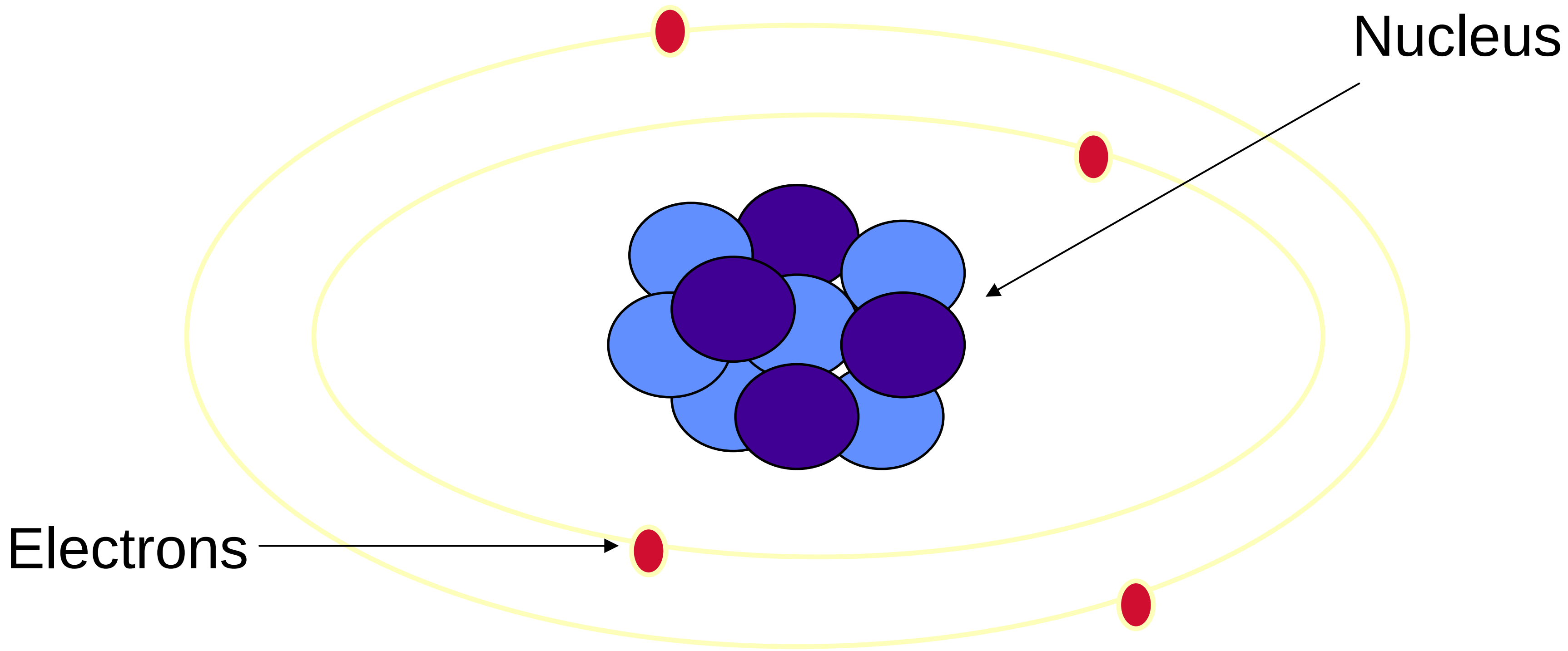
- Energy traveling through space in the form of particles or electromagnetic waves (rays)
- Can be ionizing or non-ionizing (depends on energy)
- Examples of electromagnetic wave radiation are microwaves, x-rays, radio waves, light
- Radioactivity is material emitting ionizing radiation

What is Radiation?

- Ionizing radiation is the release of unstable atoms of an element in the form of particles or waves
- This results in a lower energy atom of the same form or creates a completely different atom
- This “ionization” can remove electrons from the material they interact with, which is why ionizing radiation is harmful
- The ionization process also provides the means to detect the radiation activity

The Atom

Electrons move in orbits around a small, dense, positively charged Nucleus composed of protons and neutrons



The Atom

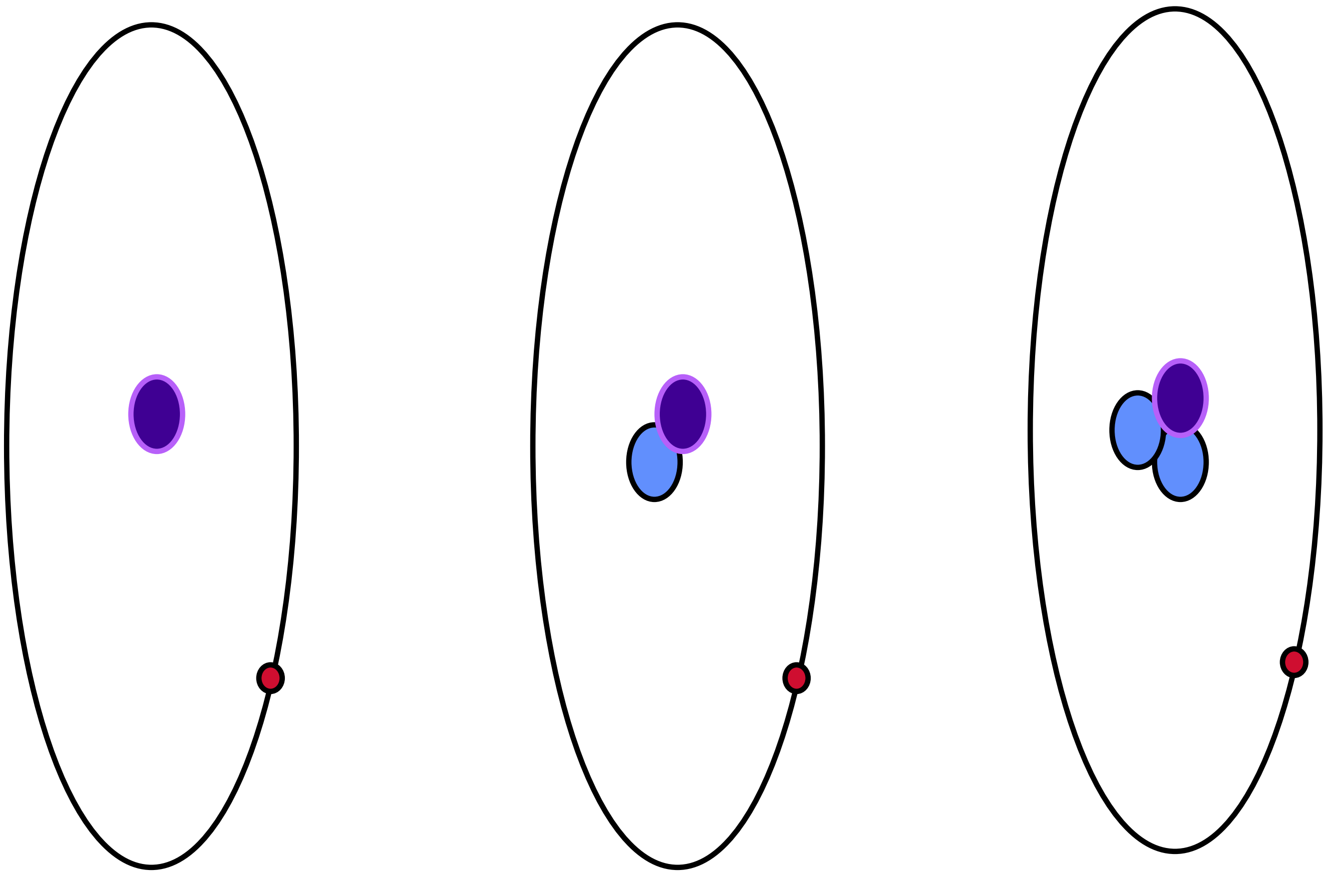
- Protons carry a positive charge
- Neutrons are electrically neutral
- Electrons carry a negative charge
- The number of protons in a nucleus determines the element of the atom, this proton number is often referred to as ‘Z’
- The elements are then arranged in the periodic table with increasing Z

The Atom

- Atoms in nature are electrically neutral, that is the number of electrons equals the number of protons in the nucleus
- Neutrons in the nucleus serve as a glue to hold the protons in place, otherwise the (+) protons would repel each other
- Elements can have nucleii with different numbers of neutrons in them, these are called isotopes
- As an example, hydrogen (H) normally only has one proton in the nucleus, adding a neutron to the nucleus forms deuterium, and adding a second neutron to the nucleus creates tritium, which is radioactive

Isotopes of Hydrogen

Protium (H-1) **Deuterium (H-2)** **Tritium (H-3)**

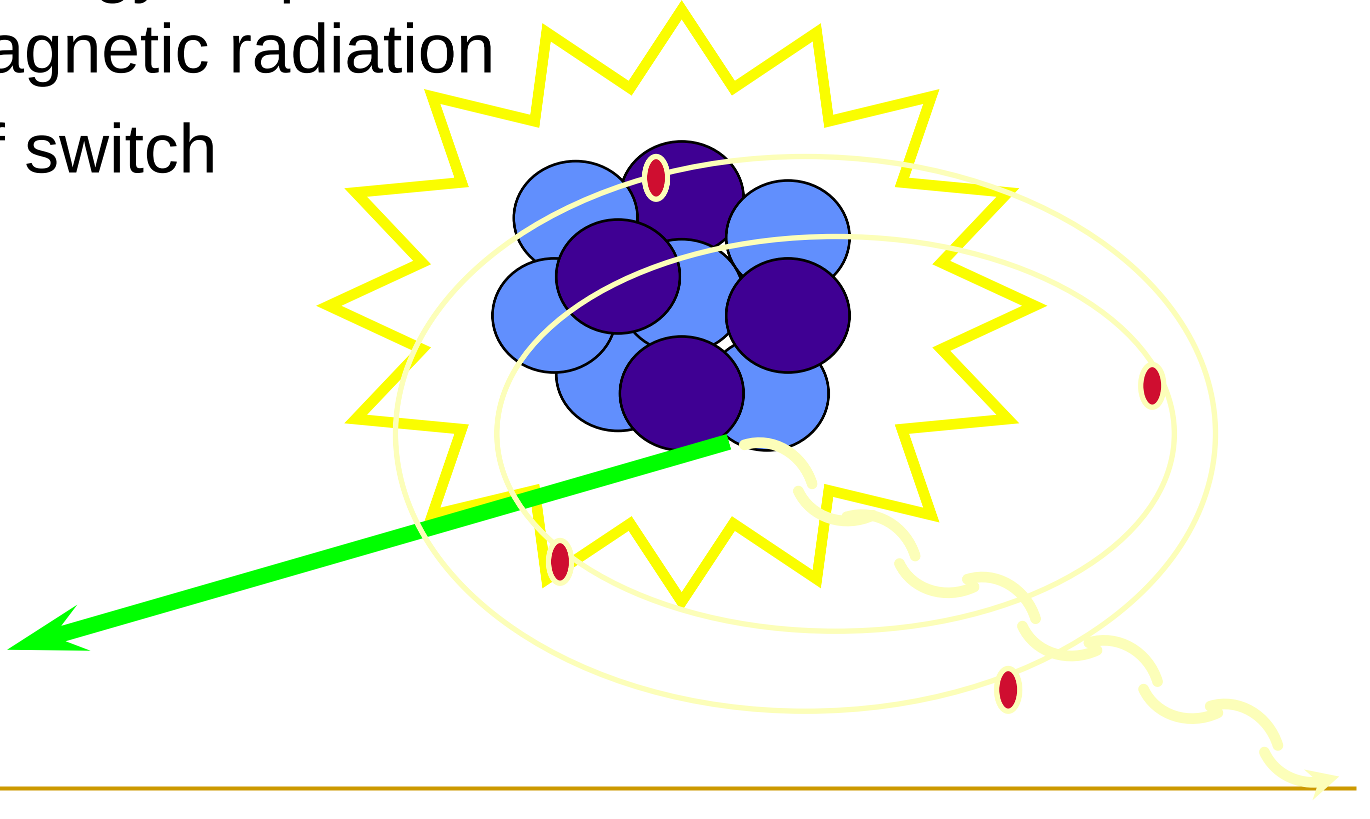


Radioactivity

- Nuclear stability depends on the combination of protons and neutrons present
- Too many or too few neutrons causes the nucleus to have excess energy
- In radioactive decay the excess energy is released and the proton:neutron ratio is adjusted toward a more stable combination

Radioactive Decay

- An unstable nucleus spontaneously emits its excess energy as particulate and/or electromagnetic radiation
- No on-off switch



Radioactive Decay

- Decay of one radioactive element may result in the formation of another radioactive element
- This new element decays into another element and the process continues until a stable element is formed
- For example, Uranium 238 (U-238) decays to Radon 222 gas and eventually to stable Lead 206, this after as many as 14 element decay transformations

Activity – Radiation Units of Measure

- The intensity or strength of the radiation source is measured in the following units:
- Traditional Unit (US): curie (Ci)
  - 1 curie = 3.7 x 10^{10} disintegrations/second
  - Rate of decay for one gram of radium
  - Named for Marie and Pierre Curie, who discovered radium in 1898
- SI Unit (Int'l.): becquerel (Bq)
  - 1 becquerel = 1 disintegration/second
  - Named for Henri Becquerel, who discovered radioactivity in 1896

Radioactive Decay - Activity

- The number of nuclear transformations, or decays per unit time
- Measure of source size or strength
- The rate of decay is expressed with two units:
  - curies (Ci)
  - becquerels (Bq)

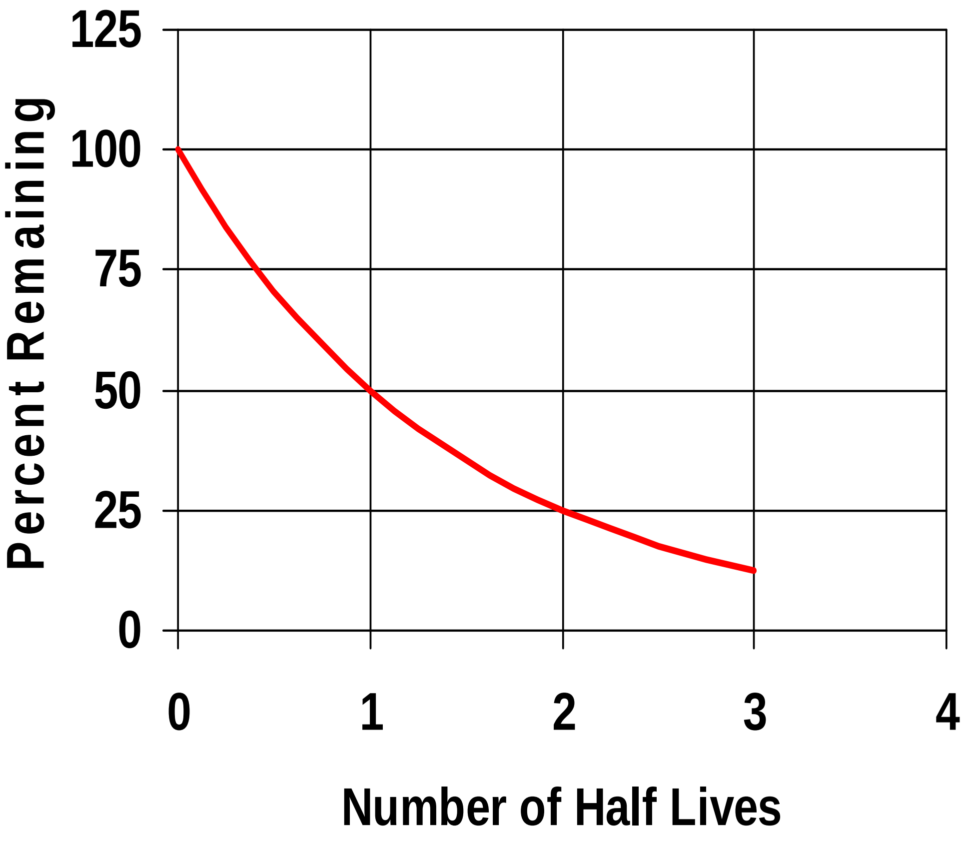
Radioactive Decay – Half Life

- Time required for a radioactive material to decay to 50% of its initial activity

OR

- Time required for 1/2 of a given number of radioactive atoms to undergo radioactive decay
- All radionuclides have a particular half-life, some are very long (millions of years) others are extremely short (minutes and even seconds)

Radioactive Decay – Half Life



Radioactive Decay – Half Life

Isotope	Half-life	Gamma Energy
Am-241	458 yr	60 keV
Cs-137	30 yr	662 keV
Co-60	5.3 yr	1.17 MeV, 1.33 MeV
Cd-109	453 d	22 keV, 88 keV
Fe-55	2.6 yr	6 keV
C-11	20 min	511 keV

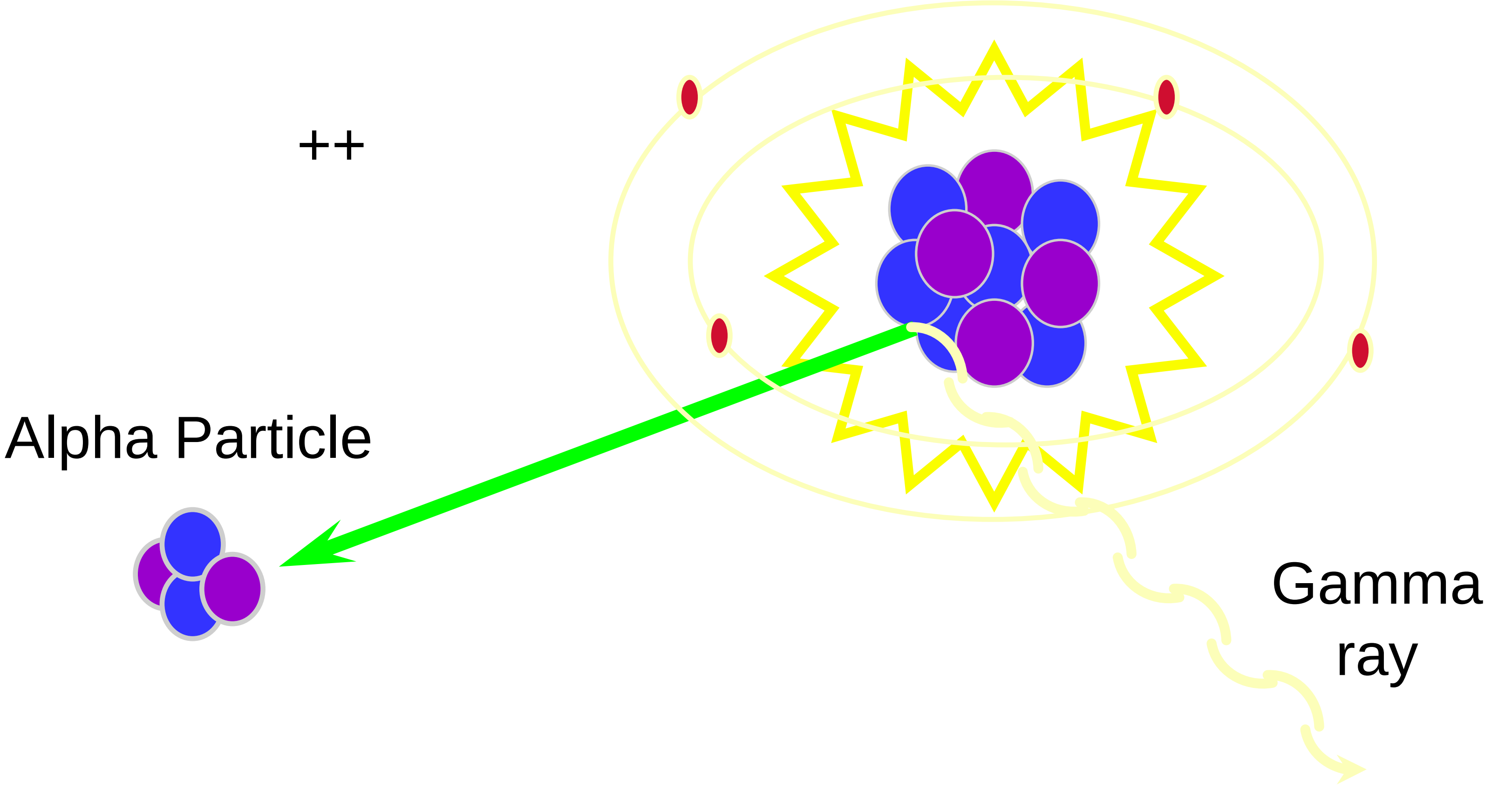
Types of Ionizing Radiation

- Particles:
  - Alpha
  - Beta
  - Neutron

- Waves (photons):
  - X-rays
  - Gamma rays

Alpha Decay

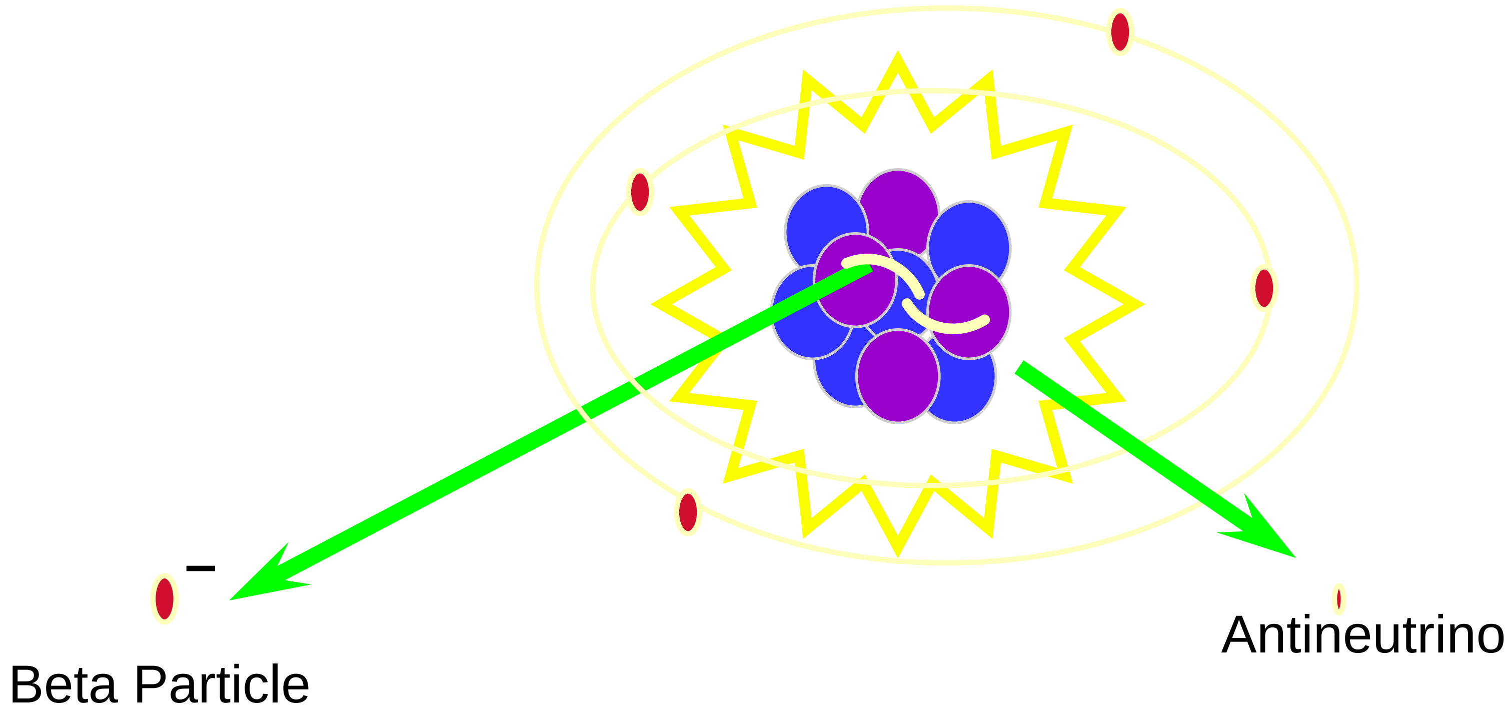
Heavy nucleus like uranium or thorium ejects 2 protons and 2 neutrons, and (usually) a gamma ray



Alpha Particles

- The double positive charge (because of the two protons) attracts adjacent electrons causing the alpha particle to slow down very quickly and will therefore will only travel a few centimeters in air
- Alpha particles are stopped by paper or the dead layer of skin on a person or air after a few centimeters
- Alpha particles pose an internal hazard only when inhaled, ingested, absorbed or injected
- No shielding is needed
- Detectors must be placed very close to the source to be able to read the radioactivity

Beta Decay



When a radioactive atom with excess neutrons ejects an electron from the nucleus (Beta particle)

Beta Particle

- Beta particles are fast electrons with a negative charge
- Antineutrinos have very little mass and no charge but carries away some energy during the decay process, this and the energy of the radioactive atom determines how far the beta particles will travel
- Beta particles can travel 12 feet/MeV in air
- They repel adjacent electrons and bounce around like billiard balls until slowed enough to begin orbiting an atom

Beta Particle

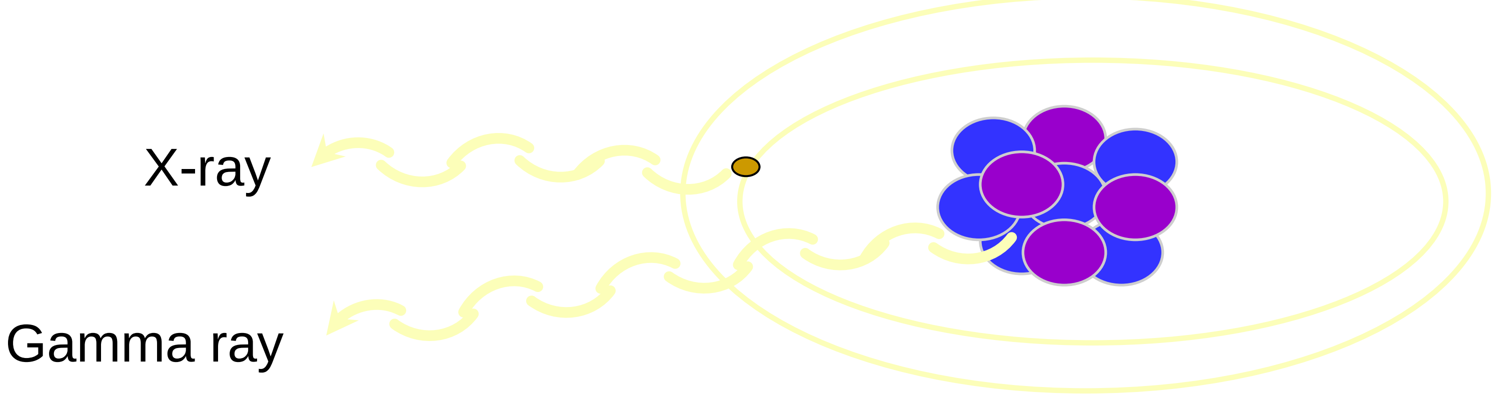
- Stops at the live layer of skin
- Presents a hazard to skin, eyes and internally if inhaled or ingested
- Plastic or aluminum is used for shielding
- Detectors must be placed close to the source to be able to read the radioactivity

Gamma Rays

- After a decay reaction of emitting an alpha or beta particle, the nucleus is left in an excited state with excess energy to burn
- Rather than producing another alpha or beta particle, this energy is lost by emitting a pulse of electromagnetic radiation called a gamma ray
- Gamma rays are similar to light or microwaves but of much higher energy
- Can travel from 1 to hundreds of meters and can easily go through people or penetrate most objects
- Important Gamma emitters are Tc-99M used in nuclear medicine and Cs-137 used to calibrate instruments

Gamma Rays and X-rays

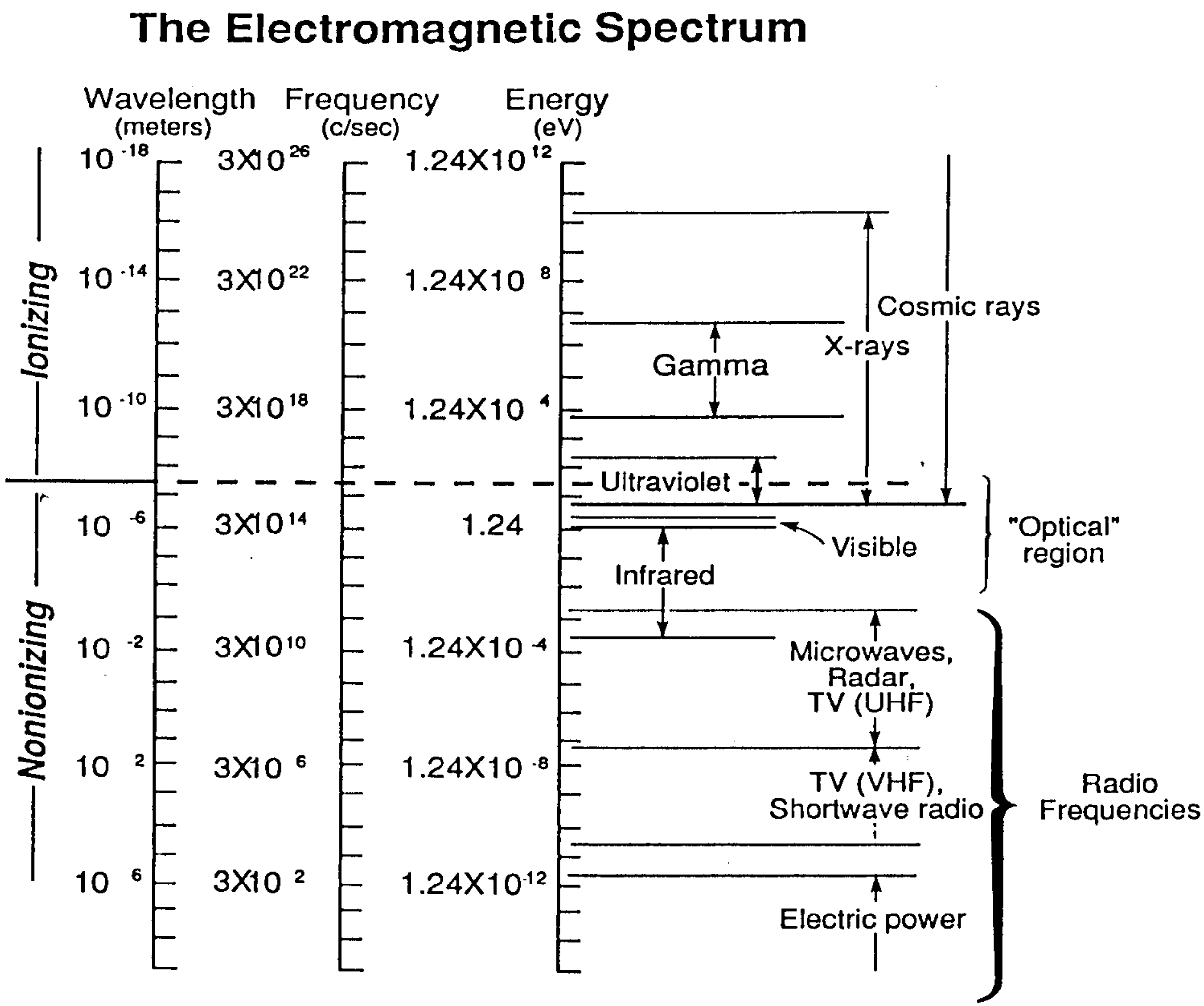
- Gamma rays (γ): Originate from nucleus
- X-rays: Originate from orbital electron rearrangements



Gamma Rays and X-rays

- Electromagnetic radiation like light
- No mass or charge, move at the speed of light
- Interact by collision with electrons in adjacent atoms therefore no finite range, only a probability of interaction per distance
- Dense materials like lead and concrete make the best shields
- X-rays are produced when electrons of high energy strike a heavy metal, some of these electrons will approach the nucleus and are deflected because of their opposite charges. This deflection causes the energy of the electron to decrease, resulting in forming an x-ray

Electromagnetic Spectrum

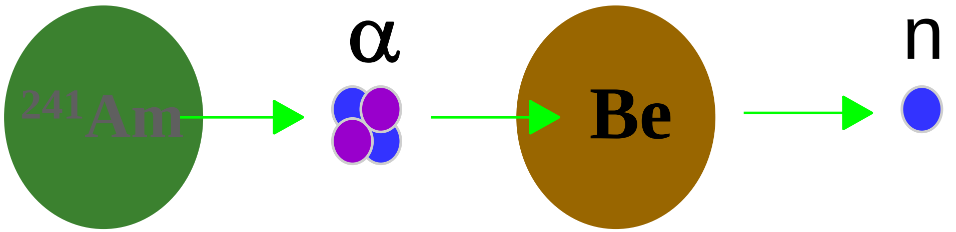


Neutrons

- Neutrons are neutral particles that are normally contained in the nucleus of all atoms and may be removed by various interactions or processes like collision and fission
- Being neutral they react weakly with material and bounce around adjacent nuclei until they slow down, thus can travel a good distance in air
- Pose an external hazard and are best shielded with lots of hydrogen atoms like water and plastic or thick layers of concrete

Neutron Sources

- Am-Be
- Po-Be
- Pu-Be



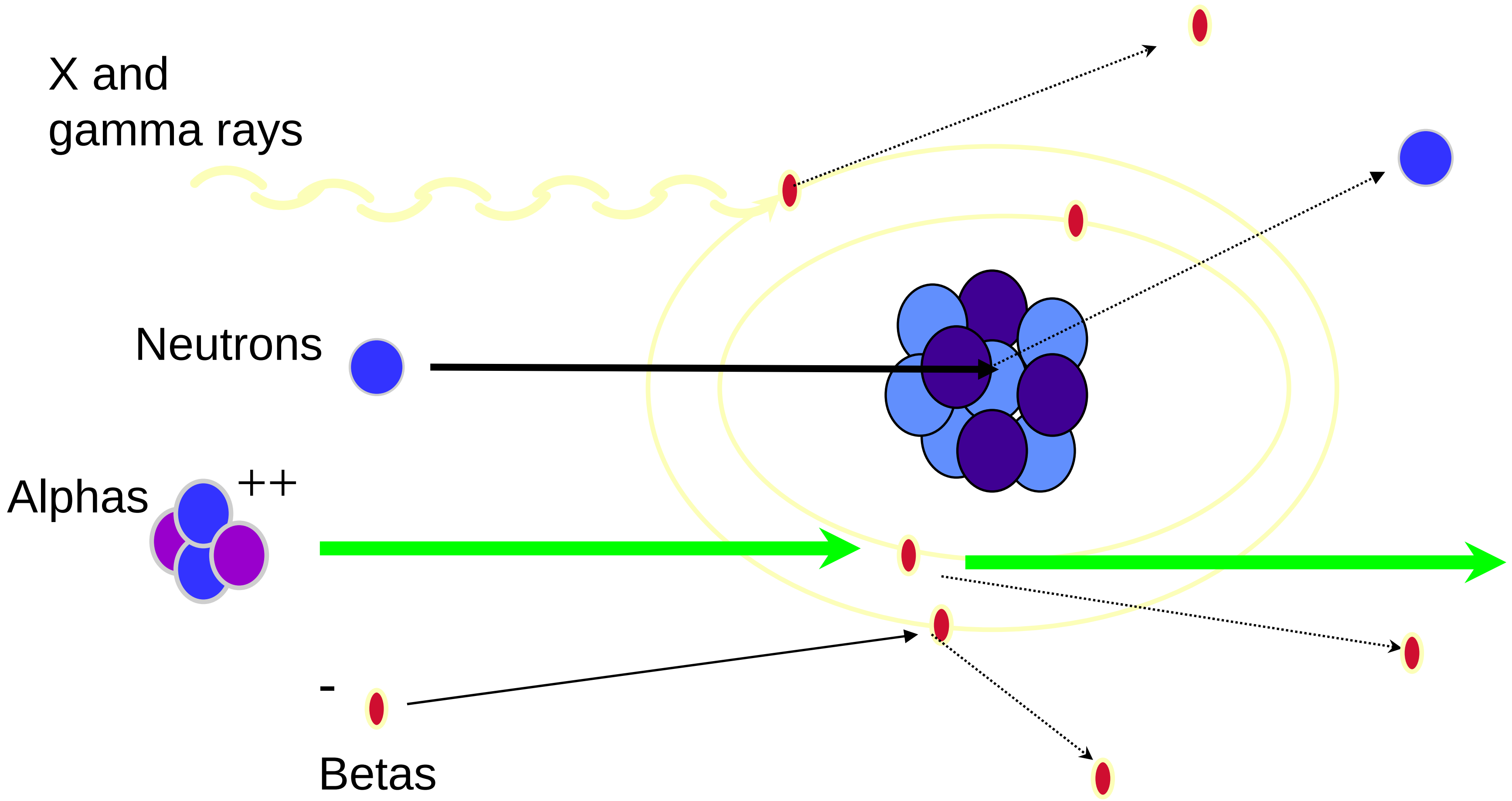
^{241}Am, ^{210}Po, and ^{239}Pu each decay by alpha emission.

$$^{9}Be + \alpha \longrightarrow {}^{12}C + n$$

Neutrons

- Not very common but pose an exposure risk because of the shielding difficulty
- Are emitted by weapons grade plutonium, that is why neutron detectors are important when checking for nuclear weapons trafficking
- Neutron emissions are usually the result of fission (or splitting) of one element into two other elements as in nuclear power
- “Thermal neutrons” by collision with other particles, have reached an energy state equal to that of its surroundings, (diffusing through air at room temp)

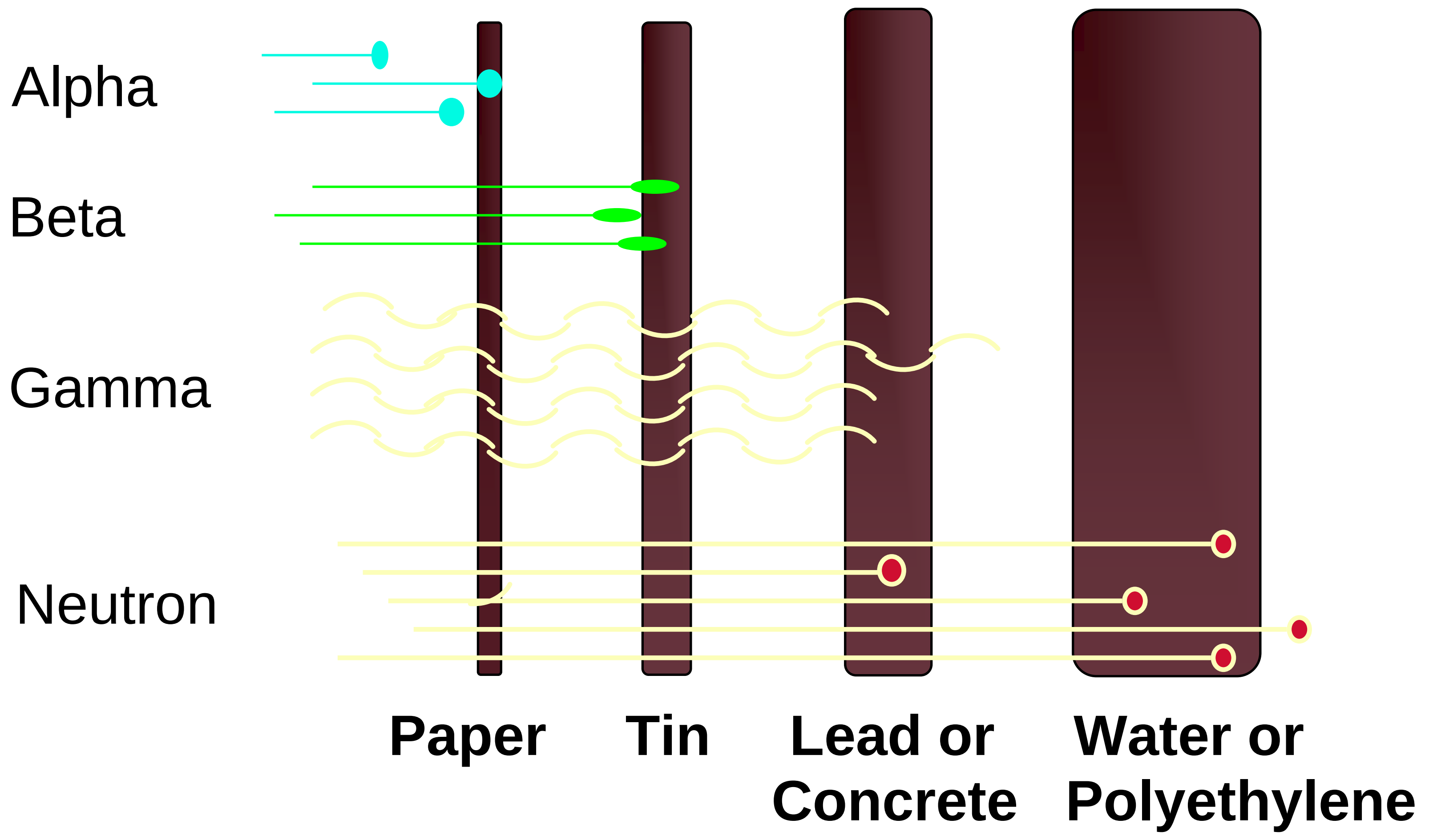
Interaction of Radiation with Matter



Induced Radioactivity

- Alphas, betas, x-rays and gamma-rays cannot make anything else radioactive
  - Because they only interact with electrons
- Only large numbers of neutrons (like in a nuclear reactor) can make other things radioactive
  - Because neutrons interact with nucluei

Shielding


Alpha
Beta
Gamma
Neutron
Paper
Tin
Lead or Concrete
Water or Polyethylene

Radioactivity Measurement

- Activity: The quantity of radioactive material based on the activity or strength rather than the mass, measured in Curies and Becquerels

  - Curie (Ci): 3.7 x 10^{10} disintegrations per second (dps)

    OR

  - Becquerel (Bq): 1 dps

Radiation Measurement

- Roentgen
  - The unit of measure for “exposure” (use is currently discouraged by the ICRU)
  - Applicable only to gamma or x-rays in air
  - International equivalent is Coulombs/kg
- Rad
  - The unit of measure for absorbed dose
  - Measure of the energy absorbed per unit mass from any type of ionizing radiation in any type of material
  - International equivalent is Grays
- Rem
  - The unit of measure for biological damage from any type of radiation, usually in the body or tissue
  - Dose (rem) = Absorbed dose (rad) x Quality factor
  - International equivalent is Seiverts

Quality Factors

Radiation Type	QF
x-ray, gamma, beta	1
neutron - thermal	2
neutron - fast, unknown	10
alpha	20

Radiation Dose Units

For X-ray and gamma radiation:

1 roentgen = 1 rad = 1 rem

- Cosmic Radiation - 30 mrem/yr

  From the sun, intensity varies with solar flares, sun spot cycles, longitude, and altitude

- Terrestrial Radiation - 30 mrem/yr

  Potassium-40, uranium & thorium

  decay series from soil and rocks

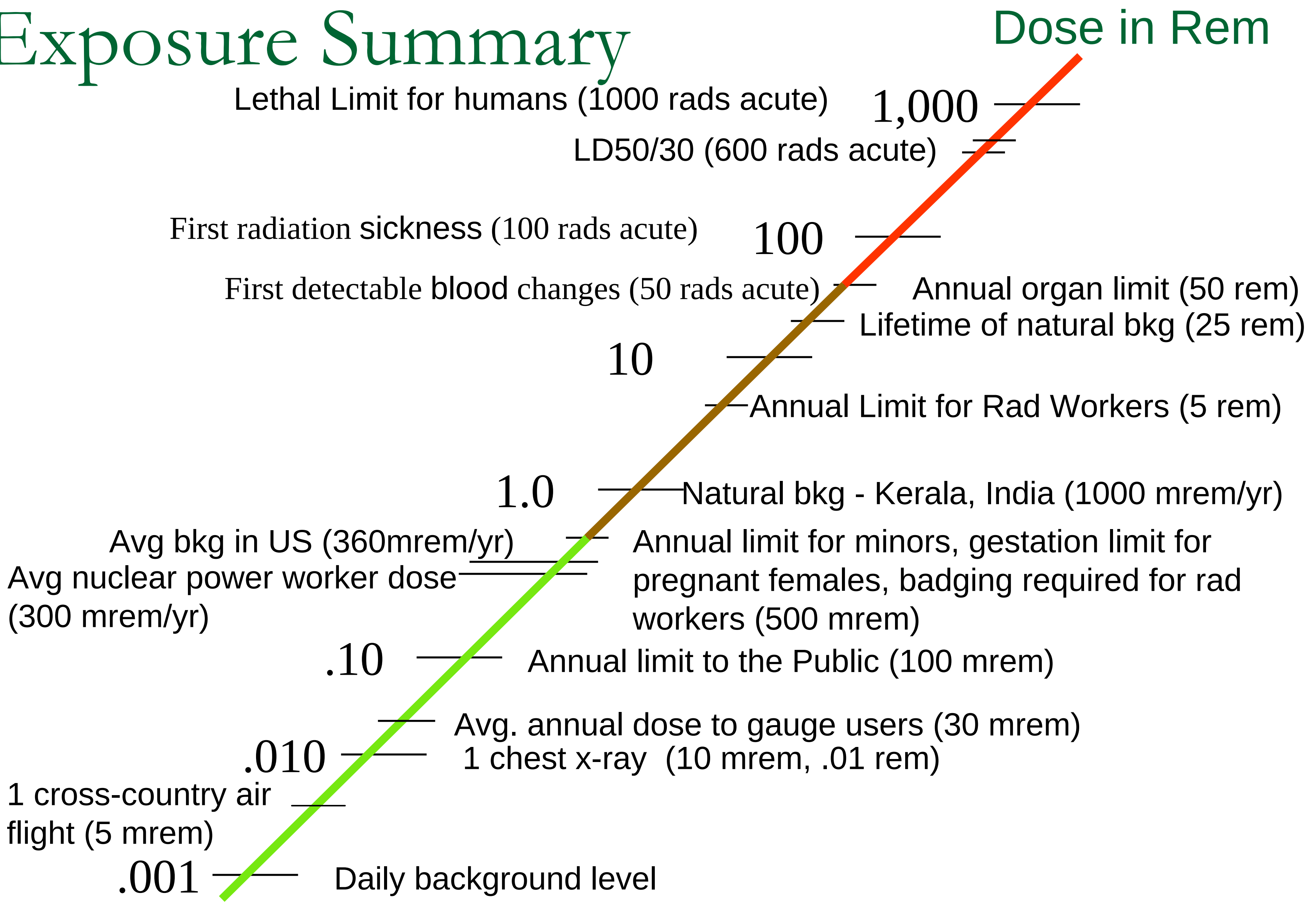
- Radon Gas - 200 mrem/yr

  From uranium decay in soil

- Ingested Radionuclides - 40 mrem/yr

Total: 300 mrem/yr

Exposure Summary



Dose in Rem

10CFR20 Requirements

- Operating and Safety Procedures
- Personnel Monitoring (if applicable)
- Quality Assurance
- Training
- Posting
- Dose Compliance Calculations
- Emergency Procedures
- Audits
- Record Keeping
- Survey Instruments
- Employee Noticing

Dose Limits

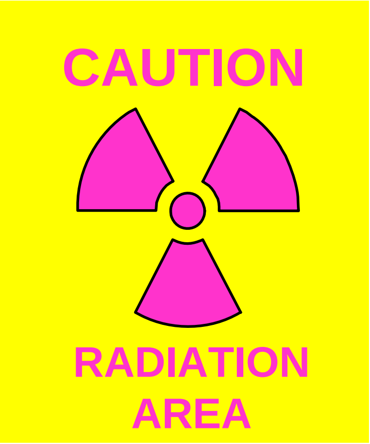
Adult

5 rem	Whole body
50 rem	Any single organ
15 rem	Lens of eye
50 rem	Skin

vs.

Annual dose limit for members of the public is 100 mrem

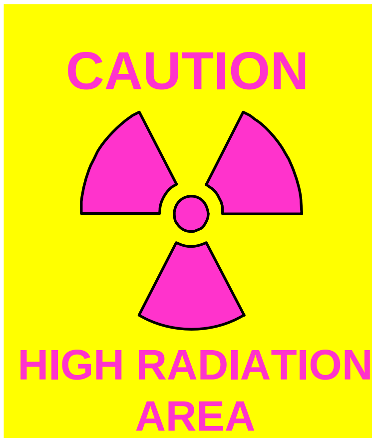
Types of Caution Postings



Caution – Radioactive material is present

Radiation Area, 5 mrem in 1 hour at 30cm

Types of Caution Postings



High Radiation Area, 100 mrem in 1 hour at 30cm

Very High Radiation Area, 500 rads in 1 hour at 1m

Radiation Surveys

- Required whenever contamination is present or suspected
- Must use calibrated survey meter
- Performer must be trained
- Survey must be documented

ALARA

- Exposure - As Low As Reasonably Achievable
- To make every reasonable effort to maintain exposures to radiation as far below the dose limits as practical, consistent with the purpose for which activities are undertaken. Consideration may be given to:
  - State of technology
  - Economics
    - Current technology
    - Benefit to public health and safety
  - Other societal and socioeconomic considerations

Exposure Rate Calculation

formula: $$D = \Gamma A$$

where:

D = Dose in mR/h at 1 foot

A = Source activity in mCi

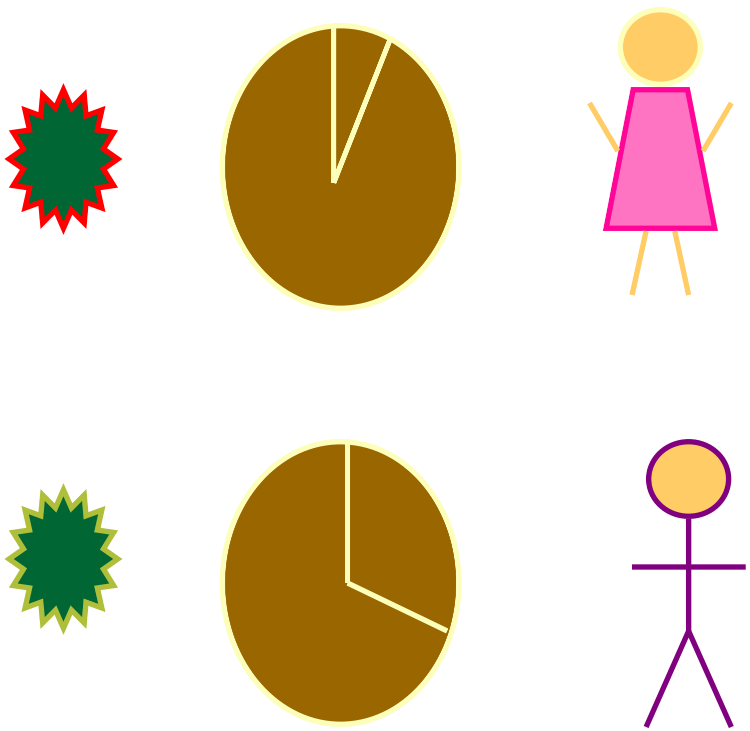
Γ = Specific Exposure Rate Constant:

Cs-137	3.4
Co-60	14.5
Ra-226	9.1

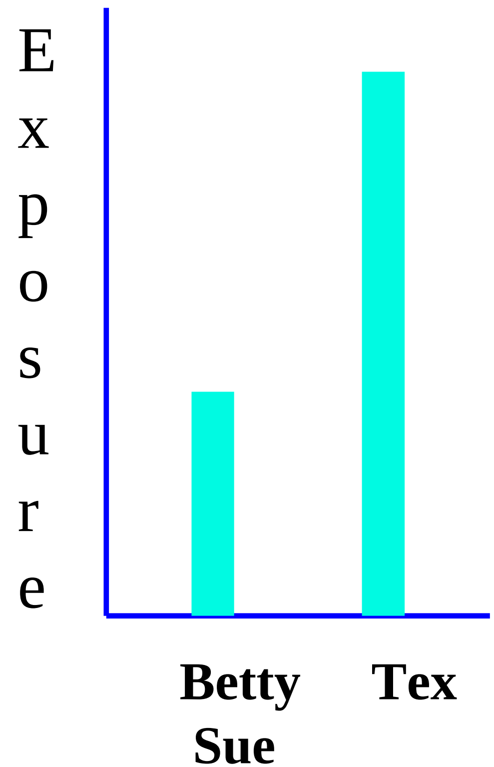
How Do We Protect Ourselves

- Minimum source size and minimize exposure
- Worker training on location and identification
- TIME
- DISTANCE
- SHIELDING

Time vs. Exposure

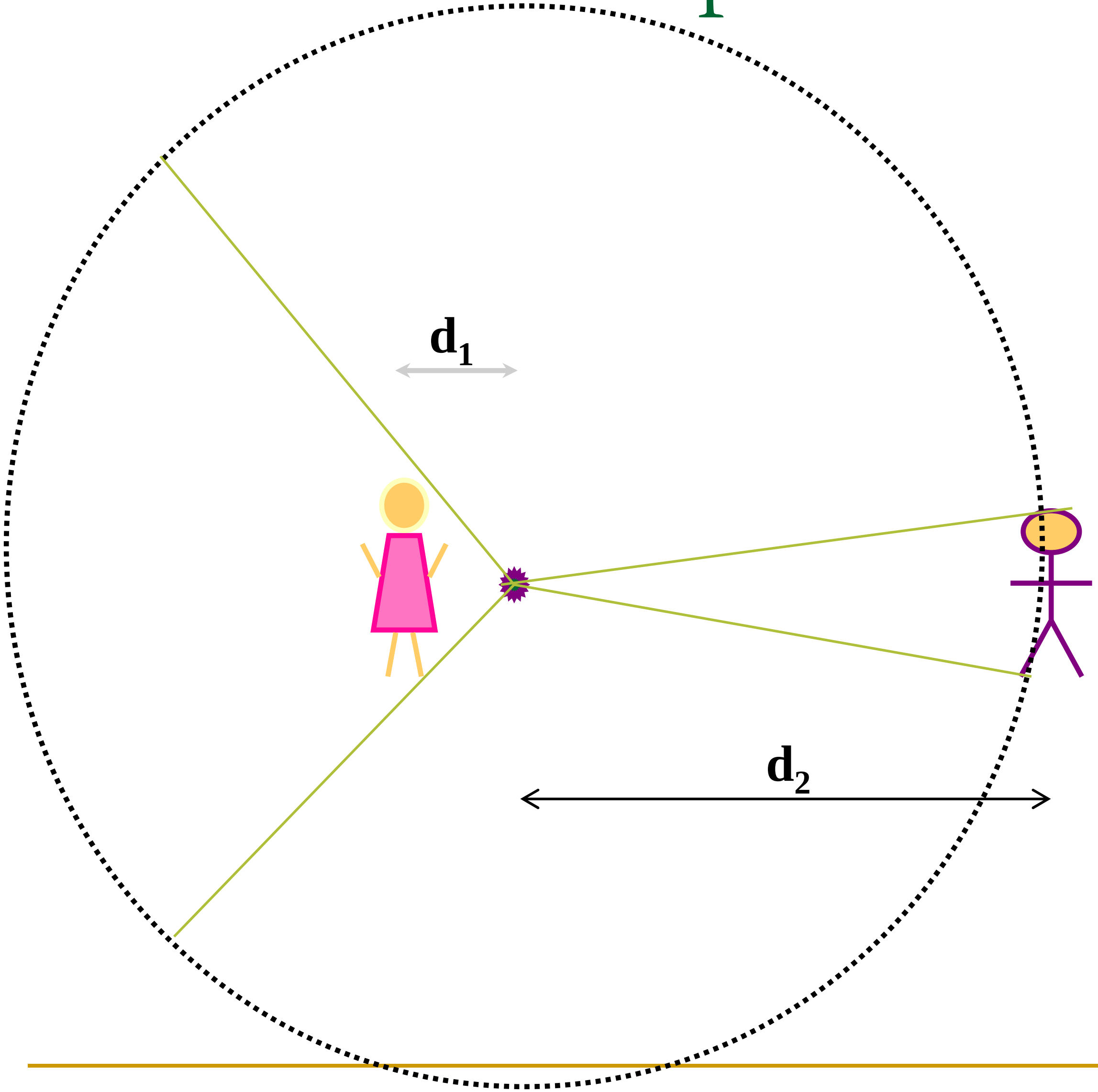


$$E = D \times T$$

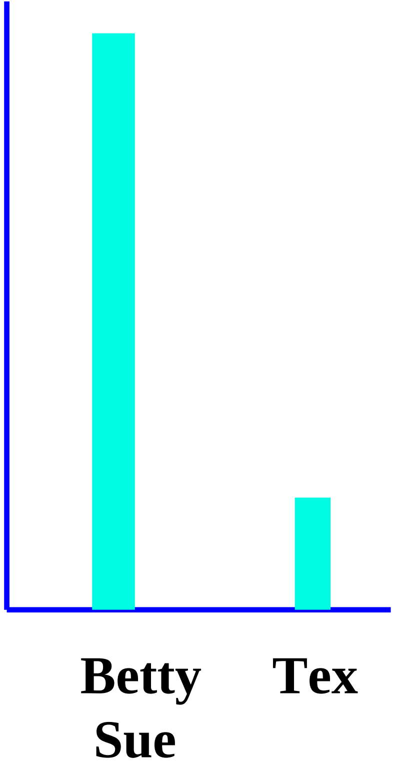


Exposure = Dose x Time

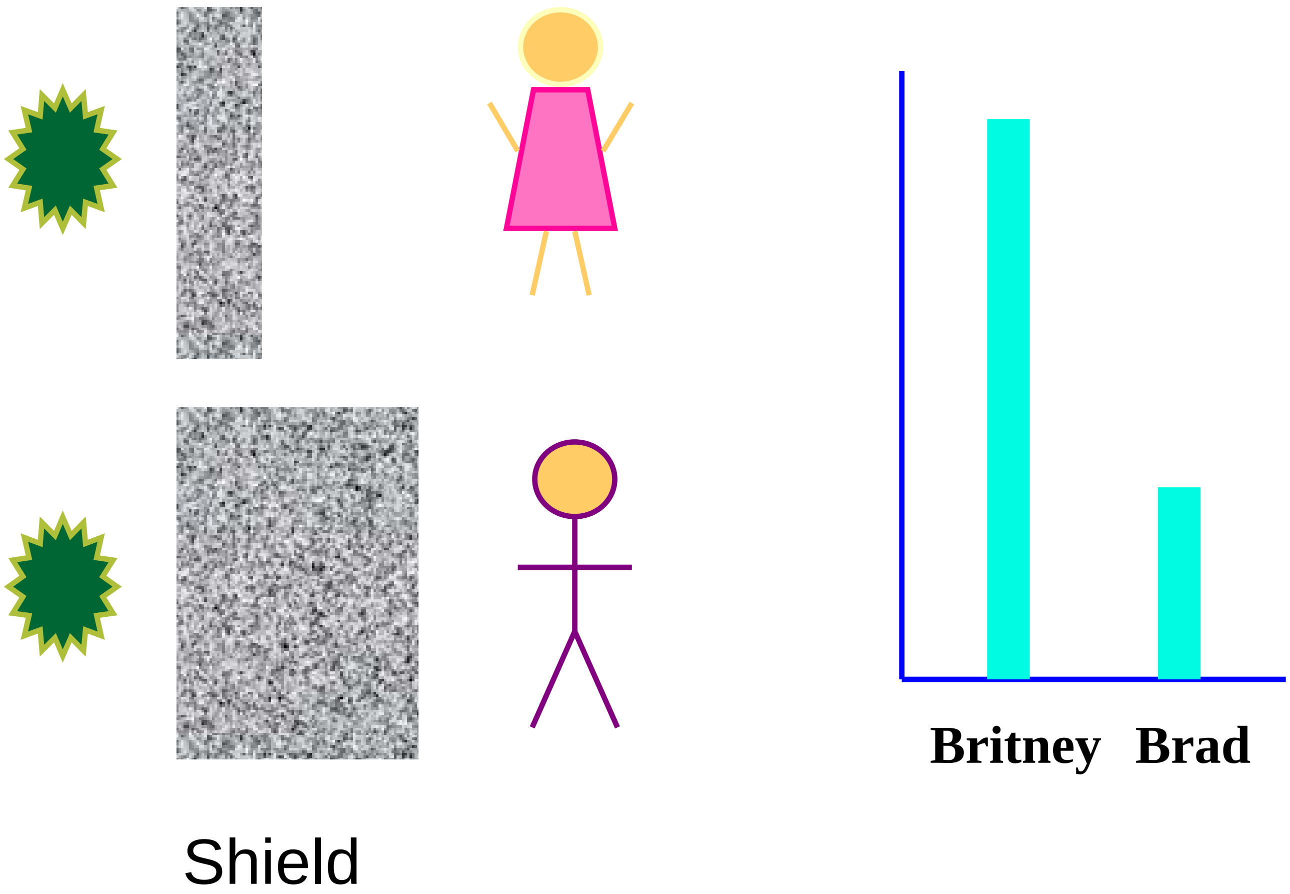
Distance vs. Exposure



$$I_2 = I_1 (d_1/d_2)^2$$



Shielding vs. Exposure

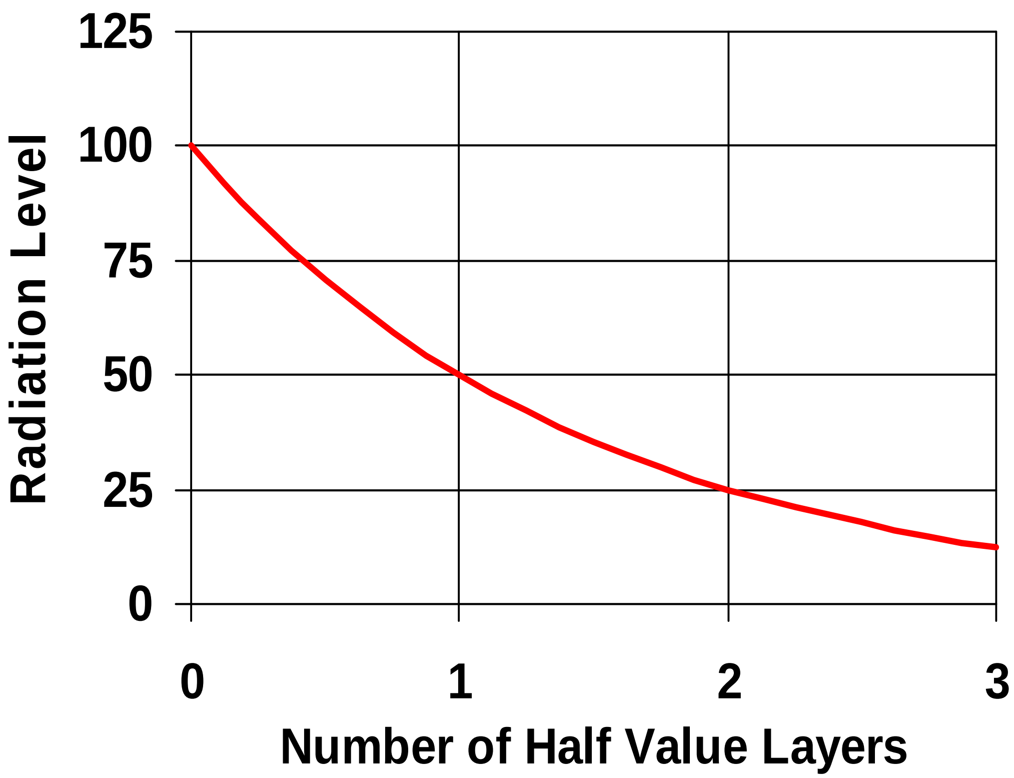


Half-Value layer

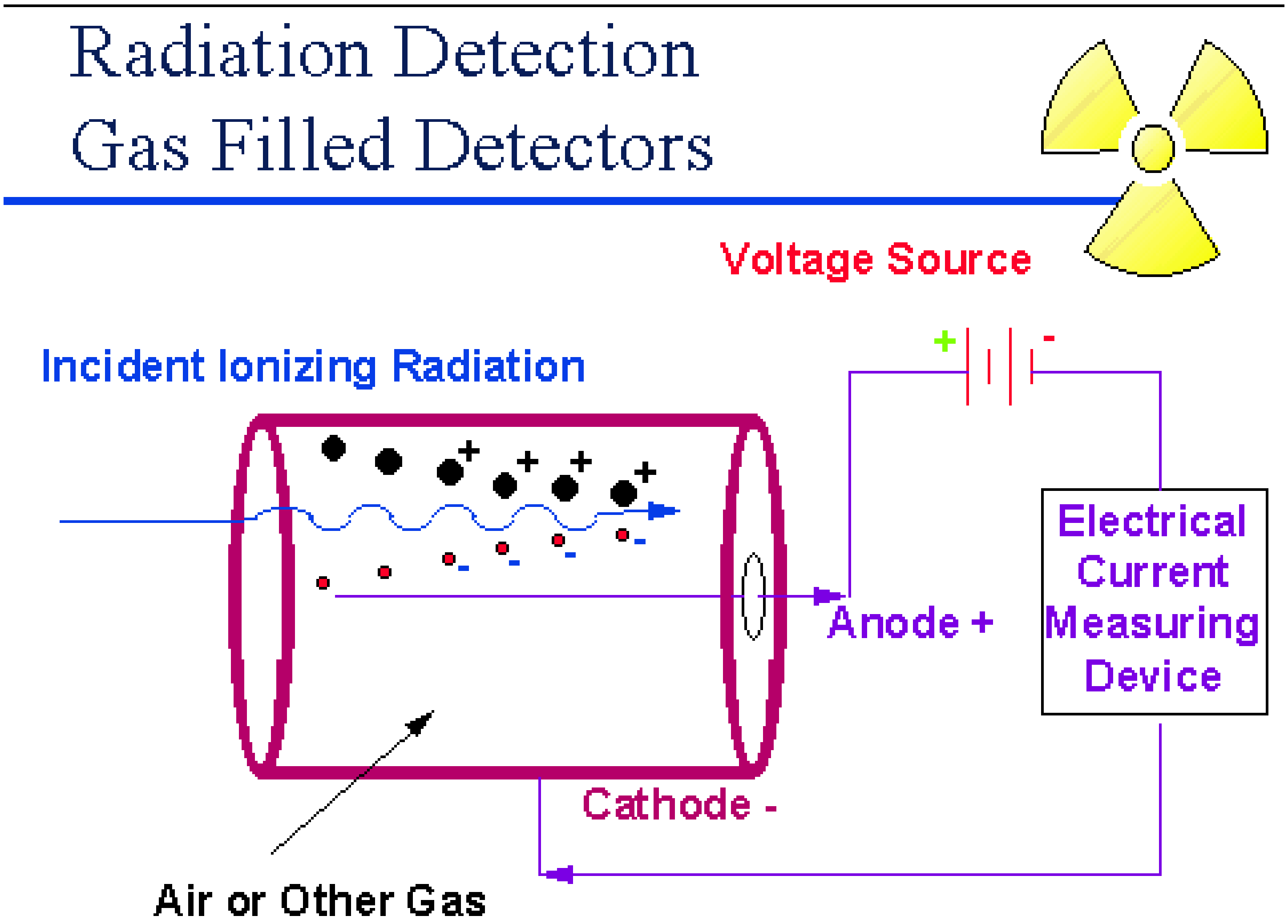
- The thickness of material required to reduce a radiation level to one-half of its initial value

  - HALF VALUE LAYER FOR Cs-137:
    - LEAD = ¼ inch
    - IRON (Steel) = 5/8 inch
    - CONCRETE = 2 inches
    - Water = 4 inches

Half Value Layers



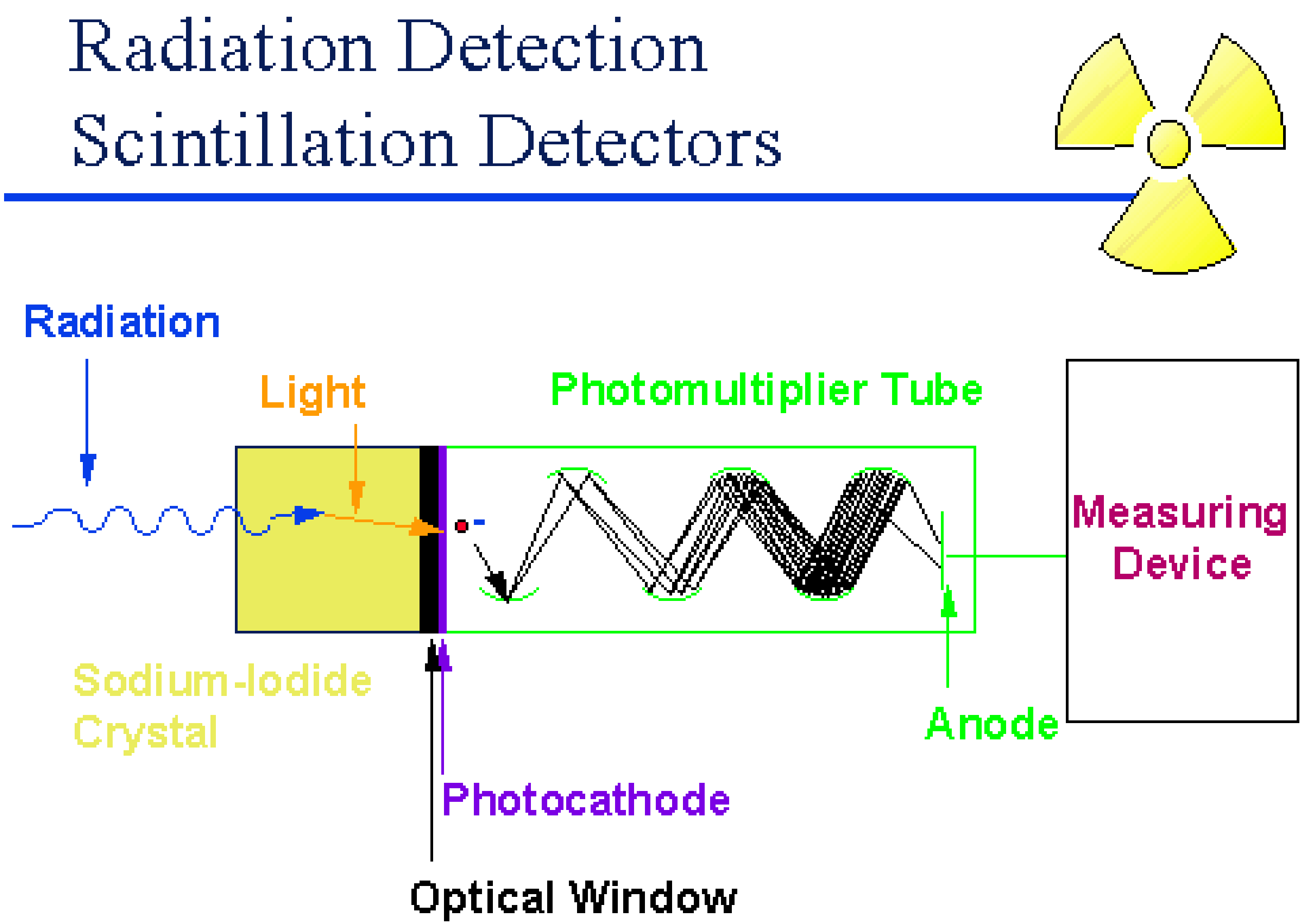
Radiation Detectors



Radiation Detectors

- We depend on instruments to indicate the presence of ionizing radiation because it can’t be seen or smelled
- Gas filled detectors like Geiger-Muller (GM) tubes are the most commonly used

Radiation Detectors



Radiation Detectors

- The second most common type of detector is the scintillator
- The sodium-iodide crystal is the most used scintillator material, that produces light when radiation interacts with it
- Very sensitive and used for special environmental surveys and in laboratories