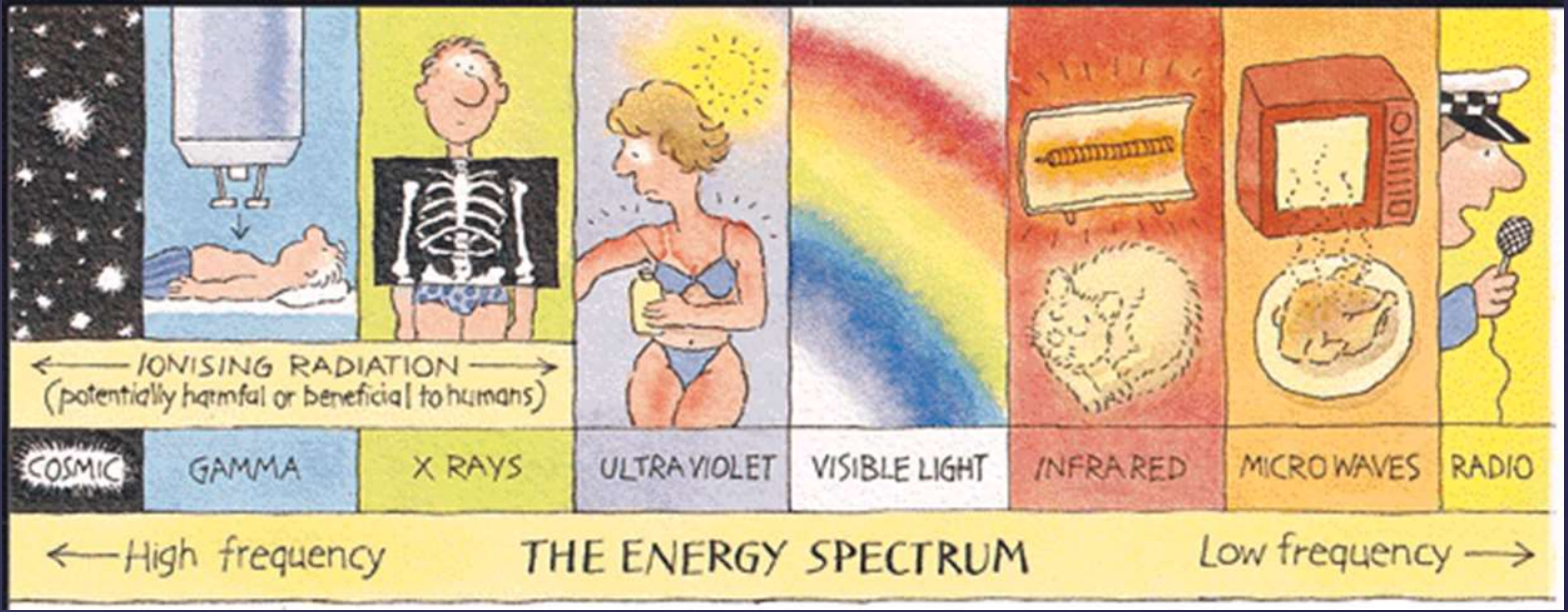
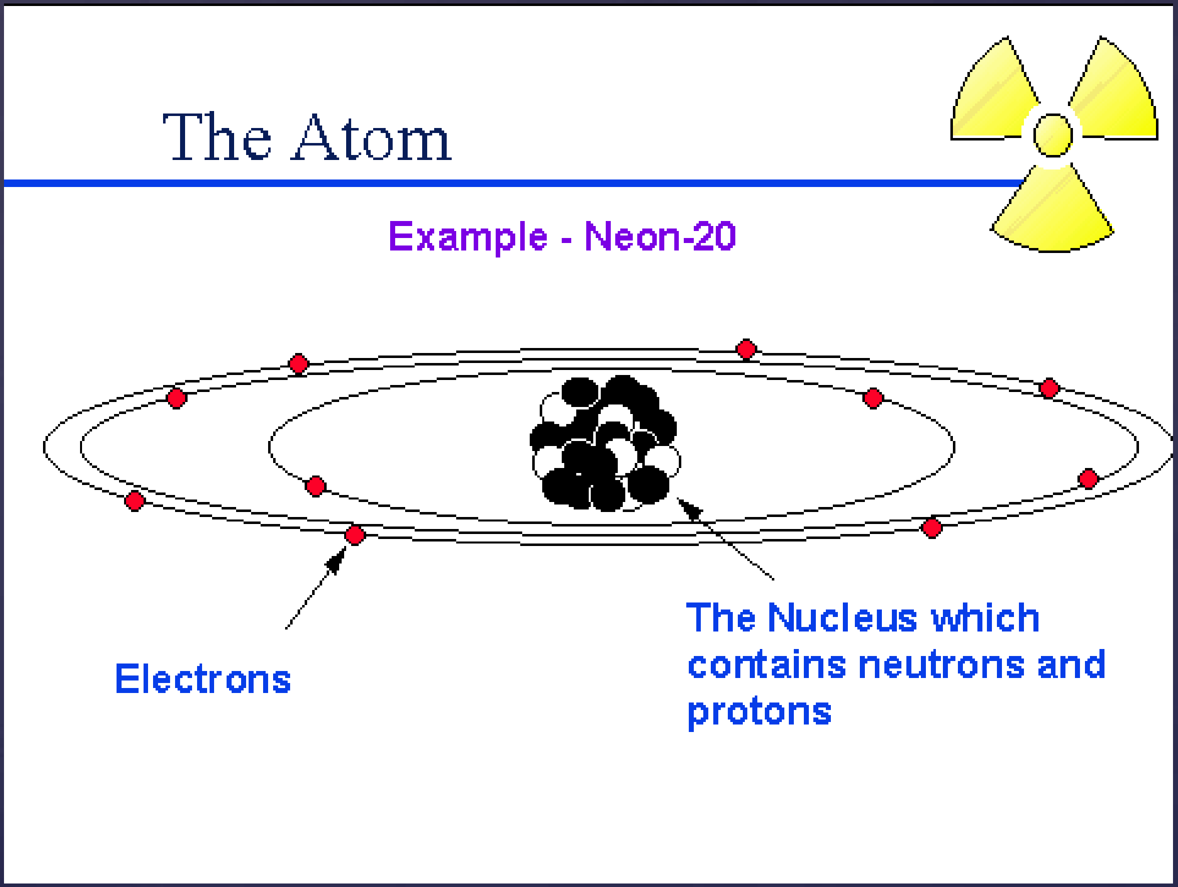
Fundamentals of Radiation

Electromagnetic Spectrum



The electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation. Ionizing radiation is found in the high frequency portion of the electromagnetic spectrum. These are radiations that can transfer enough energy to remove electrons from their atoms.

The Atom



The Atom

Example - Neon-20

Electrons

The Nucleus which contains neutrons and protons

Protons

- Positive Charge
- 1 AMU
- determines element

Neutron

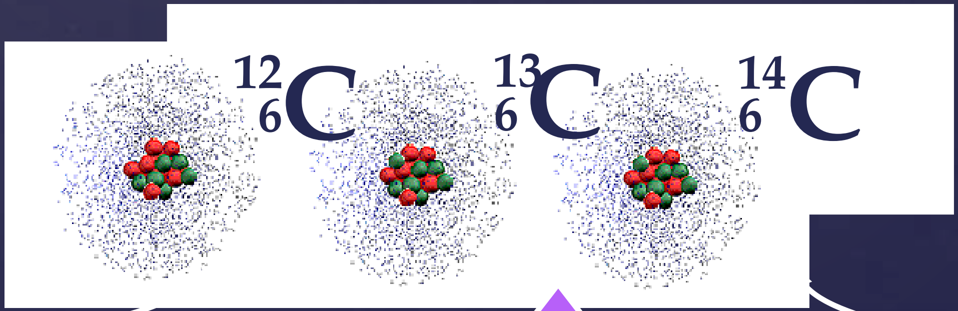
- Neutral Charge
- “Nuclear Glue” to hold nucleus together
- 1 AMU

Electron

- Negative Charge
- Orbits nucleus
- determines atoms reactivity

Radioisotopes

Not all atomic nuclei are radioactive. Some nuclei are stable while others are radioactive; those that are radioactive are sometimes referred to as ***RADIOISOTOPES.***



Stable

Stable

Radioactive

Nuclear Arithmetic

Protons and neutrons are collectively called nucleons

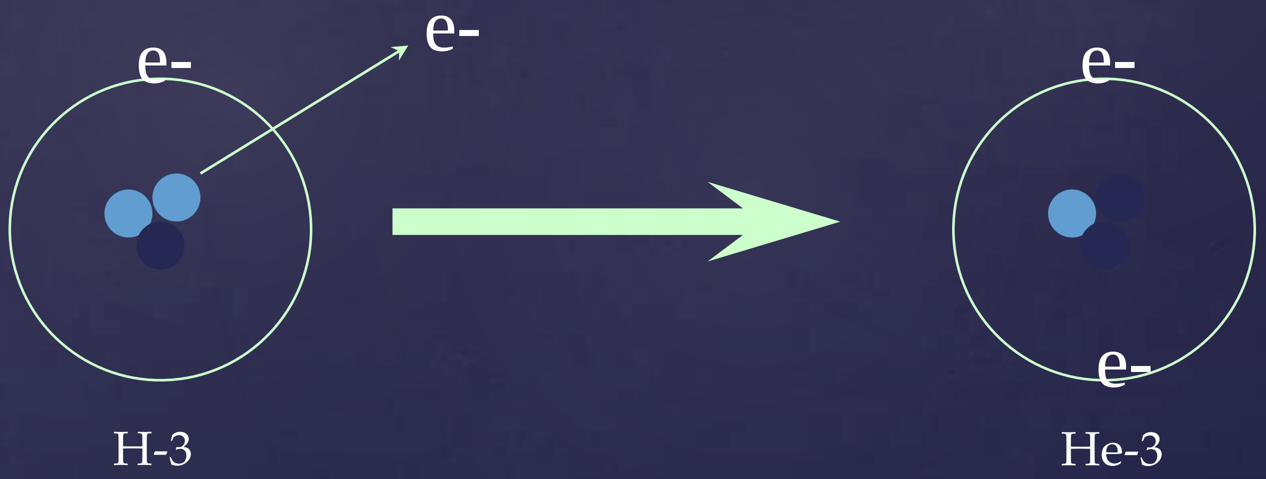
Where $^{A}_{Z}X$

X = *chemical symbol*
A = *nucleon number (sum of p and n)*
Z = *atomic number (# of p)*

1. Number of neutrons = A-Z
2. The nucleon number of an isotope is written as a suffix to the name ex. Hydrogen - 2

Where Does Radiation Come From?

Radiation results from an unstable nucleus. An atom with an unstable nucleus will "decay" until it becomes a stable atom, emitting radiation as it decays.



This is an example of H-3, tritium, it contains 1 proton and 2 neutrons. A neutron in the atom nucleus emits an electron. In so doing, the neutron becomes a proton. The conversion results in the atom becoming a Helium – 3 atom (2 protons, 1 neutron)

Radioactive Decay

- Radiation is the result of *radioactive decay*. An atom with an unstable nucleus will “decay” until it becomes a stable atom, emitting radiation as it decays.

- Radioactivity comes from the atomic nucleus

- Radioactivity cannot be seen, felt, smelled, tasted, or detected by human beings. For this reason, it went undiscovered until this century.

Radiation in Research

- Radiation and radioactive materials can be valuable tools in research.
- Radioactive materials are used in a variety of STEM disciplines, ranging from the biological sciences to physics and materials science.
- There are several labs approved to use radioactive isotopes at UAH.

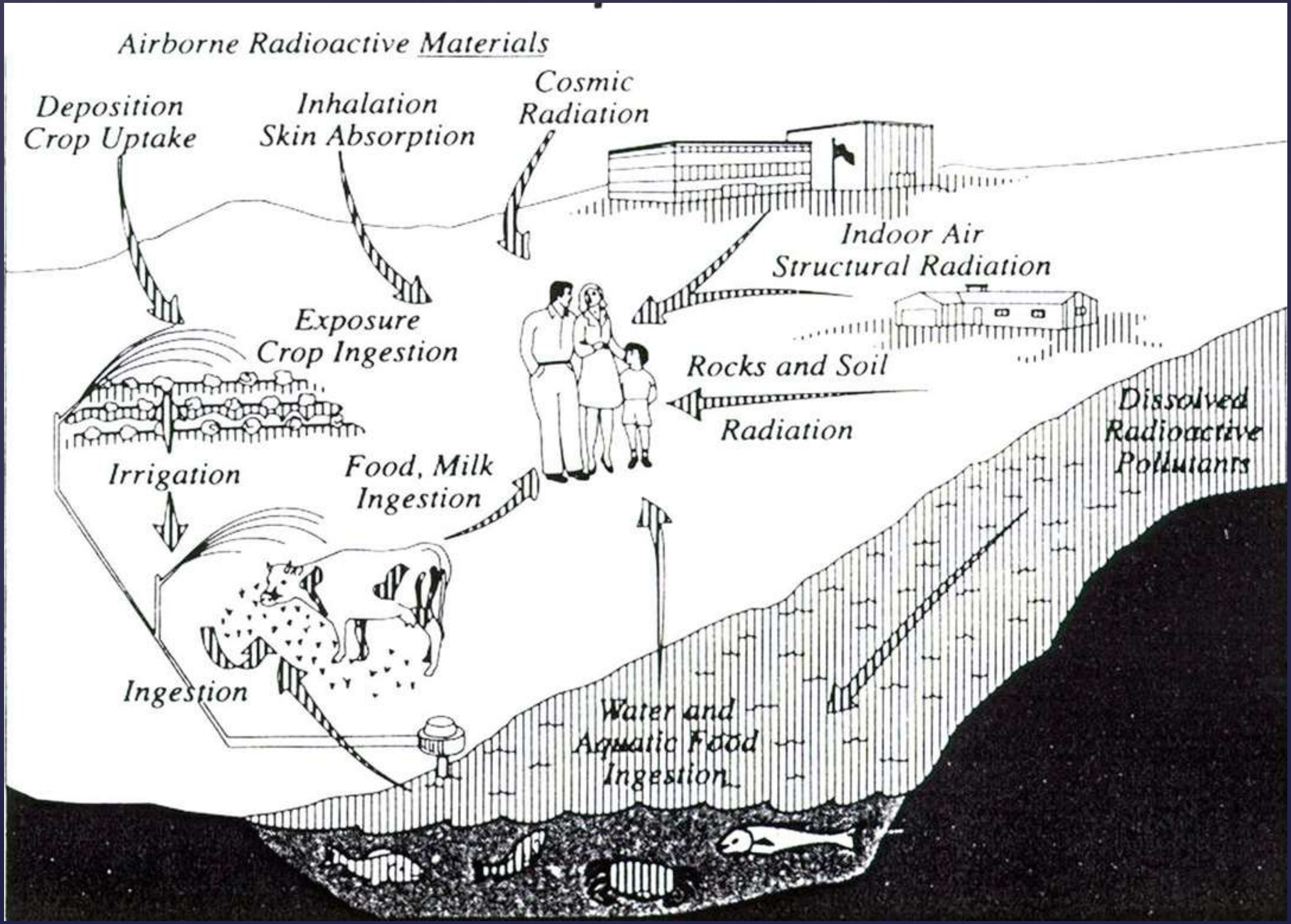
Radiation and You

- Radiation and radioactive materials are safe if used properly

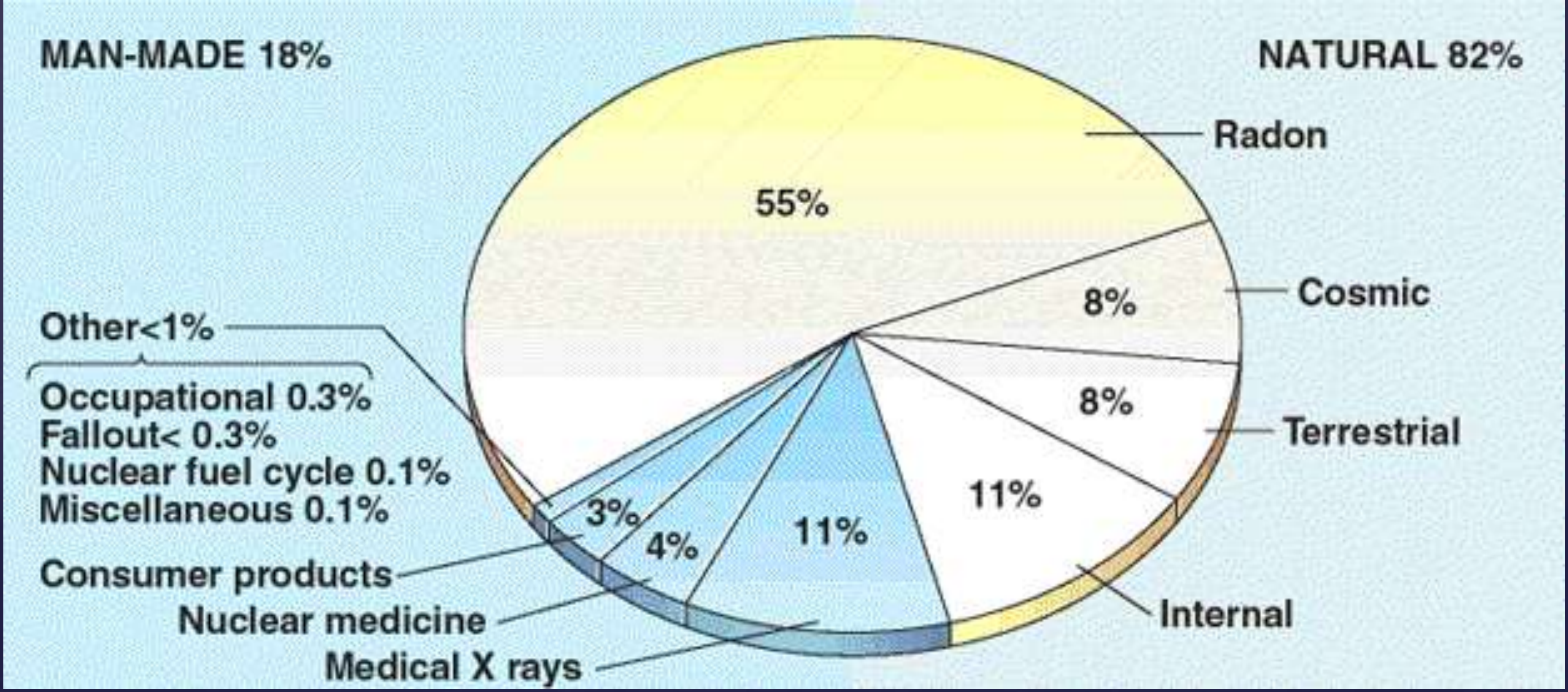
- ***Background radiation*** is the ionizing radiation emitted from a variety of natural and artificial radiation sources

Your exposure can never be zero, because natural and manmade background radiation is always present

Background Sources of Radiation



Average background radiation dose for a U.S. citizen to receive per year is 360 millirem. This dose varies depending upon where the person lives.



Measuring Radioactivity

- The number of decays per time is called the activity of the material .
- The units of decay are Becquerels (bq)
  - 1 Bq = 1 disintegration / second
  - 1 Curie (Ci) = 3.7×10^{10} disintegration / second
- Activity changes over time
- Activity decays exponentially

Half Life

- A property often used to describe a radioactive substance is known as the *half-life*.

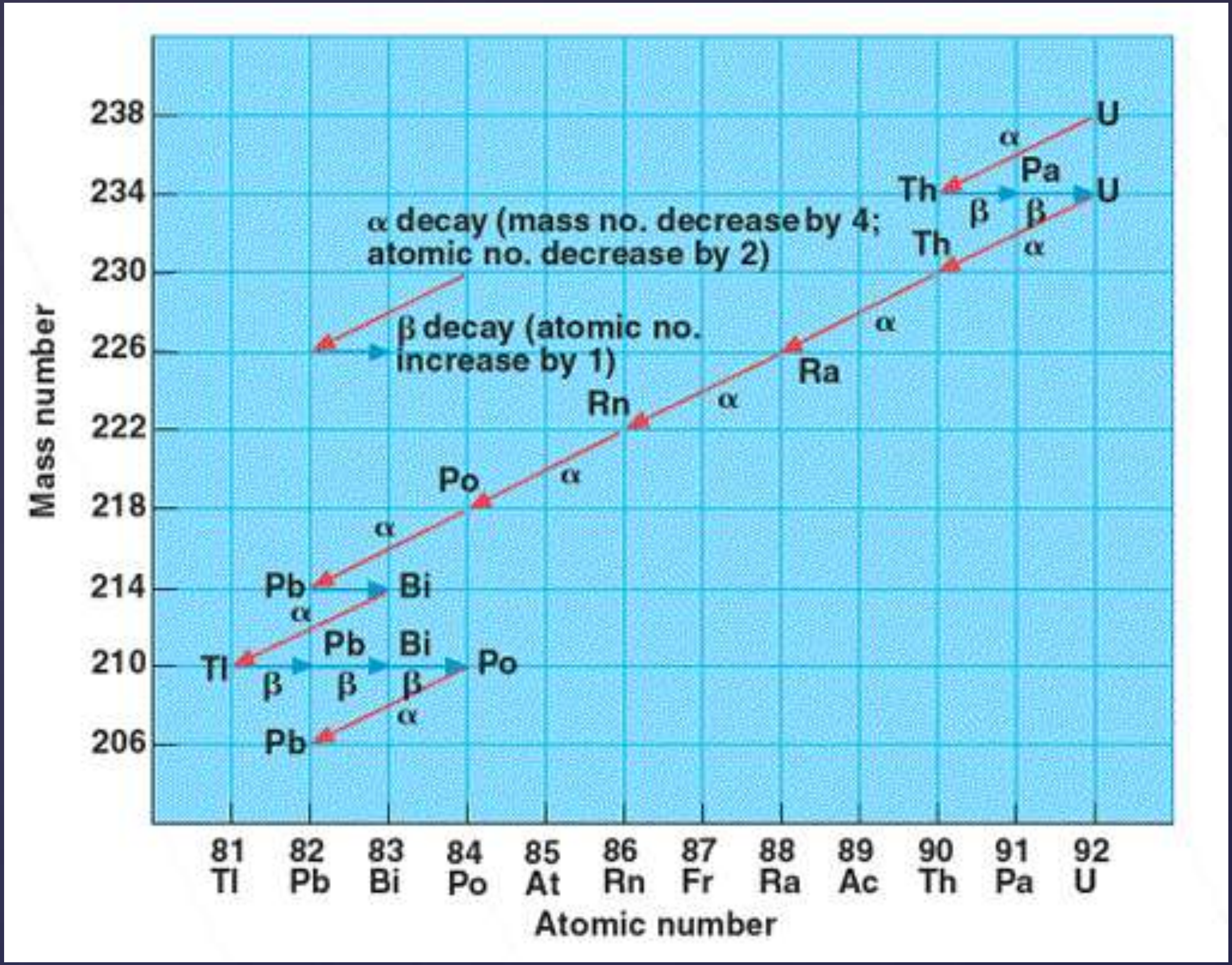
- The half life is the time it takes for half of the unstable nuclei in the radioactive substance to undergo radioactive decay.

There is a wide range of half-lives for isotopes; The half-life of P-32 is only 14.3 days whereas the half-life of C-14 is 5730 <ins>years</ins>

Half Life

Radioactive decay occurs randomly, that is, it is not known when individual atoms will undergo decay.

Although the decay of individual atoms is random a radioactive substance with many atoms will decay according to a known pattern.

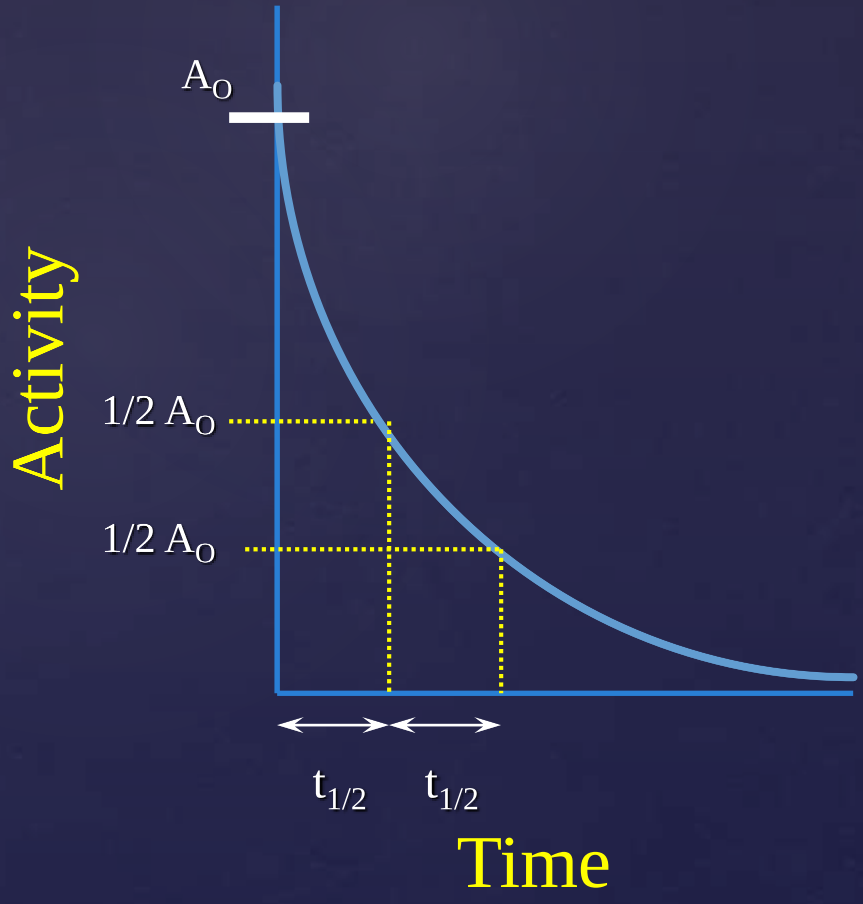


A substance often progresses through several radioactive decays until it reaches a stable state. This shows the radioactive decay progression of uranium to lead.

Half-life & the Decay Constant

Half-life ($t_{1/2}$) is related to the constant according to this equation:
$t_{1/2}= (\ln 2)/\lambda$

λ is the decay constant



Activity / Decay Equation

This equation is used to determine the activity level after a period of time.

$A = A_1e^{-0.693\ t\ /\ T1/2}$

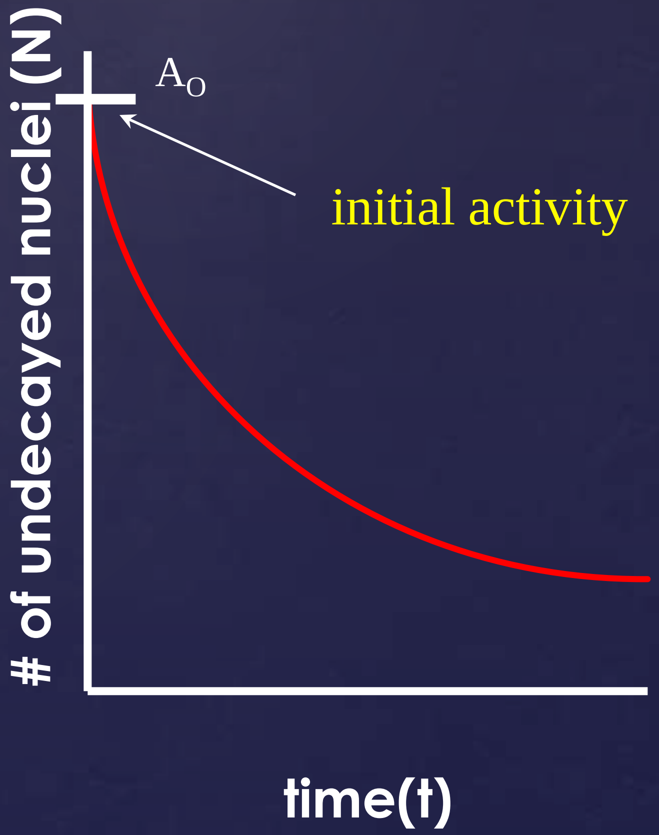
A = Activity after time t

A_1= Initial activity level

t = time since initial activity

$T_{1/2}$= Half life

-0.693 is a constant



Half Life Example

- The half-life of P-32 is 14.3 days. If you start with 100 microcuries(the unit of the microcurie will be explained later) of P-32 , after 14.3 days there would be 50 microcuries left.

- After another 14.3 days there would be 25 microcuries left.

- After 10 half-lives, only about 1/1000th (actually 1/210, which is 1/1024) of the original will be left.

Equation $N_t = N_o \text{ x } (0.5)^{\text{number of half lives}}$

N_t = amount of radioisotope remaining
N_o= original amount of radioisotope
Number of half lives = time / half-life

Radioactive Decay Emissions

- Alpha particles
- Beta particles
- Gamma Rays

Radioactive Emissions

Alpha particles contain two protons and two neutrons (a helium nucleus). They have an atomic number of 2.

Alpha Properties

- Heavy particles and carry charge, they cannot travel very far; they typically travel up to a few centimeters in air, depending on their energy.
- Not generally considered to be an external radiation hazard, as they cannot penetrate the outer protective layer of your skin.
- Alpha's can be inhaled and through further decay, irradiate lung tissue, as in the case of radon and its daughter's.

Radioactive Emissions

Beta particles are simply electrons. Beta radiation is a stream of electrons from the nucleus of the atom.

Properties - Beta Particles

Beta particles:

β+

- are either an electron (-1 charge) or positron (+1 charge)

β–

- travel about 12 feet per MeV in air
- higher energy betas should be shielded with low Z materials such as Plexiglas/Lucite or wood (a low Z means refers to the electrostatic interaction between negatively charged electrons and positively charged protons in the atom)

Typical beta isotopes

Several ß emitters are used at UAH. These can be classified as low or high energy particles

Isotope	**Energy MeV**	**1/2 Life**
^{3}H	0.018	12.3 years
^{14}C	0.155	5570 years
^{32}P	1.71	14.2 days
^{33}P	0.215	25 Days
^{35}S	0.167	87.1 days

Radioactive Emissions

Gamma rays are a high energy form of electromagnetic radiation. They are similar to light waves but have shorter wavelengths and are more energetic.

Properties - Gamma Rays

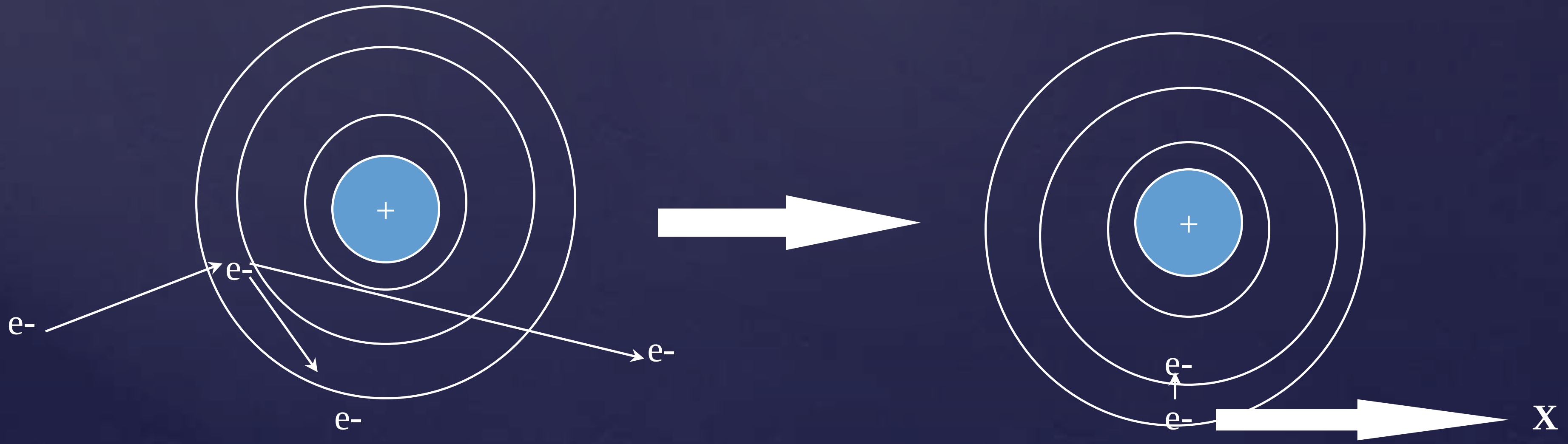
- photons that originate from the nucleus of the atom
- do not carry a charge
- can cause ionization when they interact
- photons such as gamma rays do not have definite ranges of travel as particles do, instead, the intensity of a photon beam falls off exponentially as it travels through a medium such as air
- should be shielded with high Z materials, such as lead, if appropriate

Possible Gamma Emitters

- ^{22}Na
- ^{36}Cl
- ^{125}I
- ^{131}I

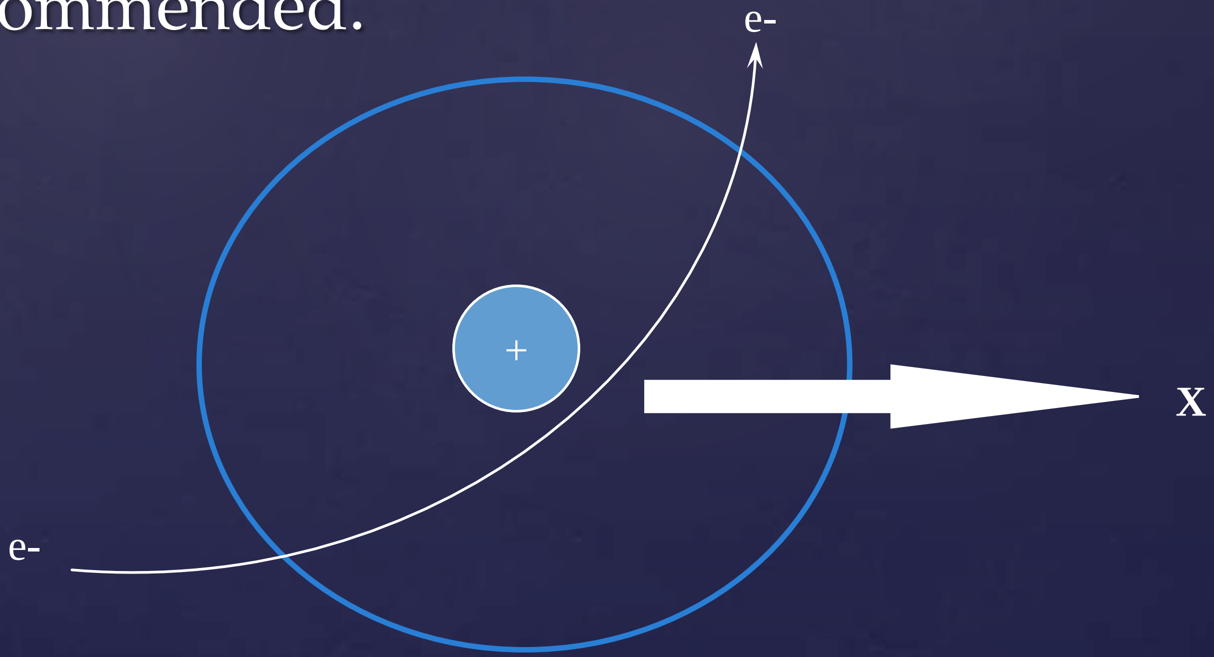
Properties - Characteristic X-rays

- X-rays are photons which originate from the electron shells of an atom, rather than from its nucleus. **Characteristic x-rays** are emitted when electrons in higher energy shells fall into vacancies in lower energy electron shells, which results in a release of energy.



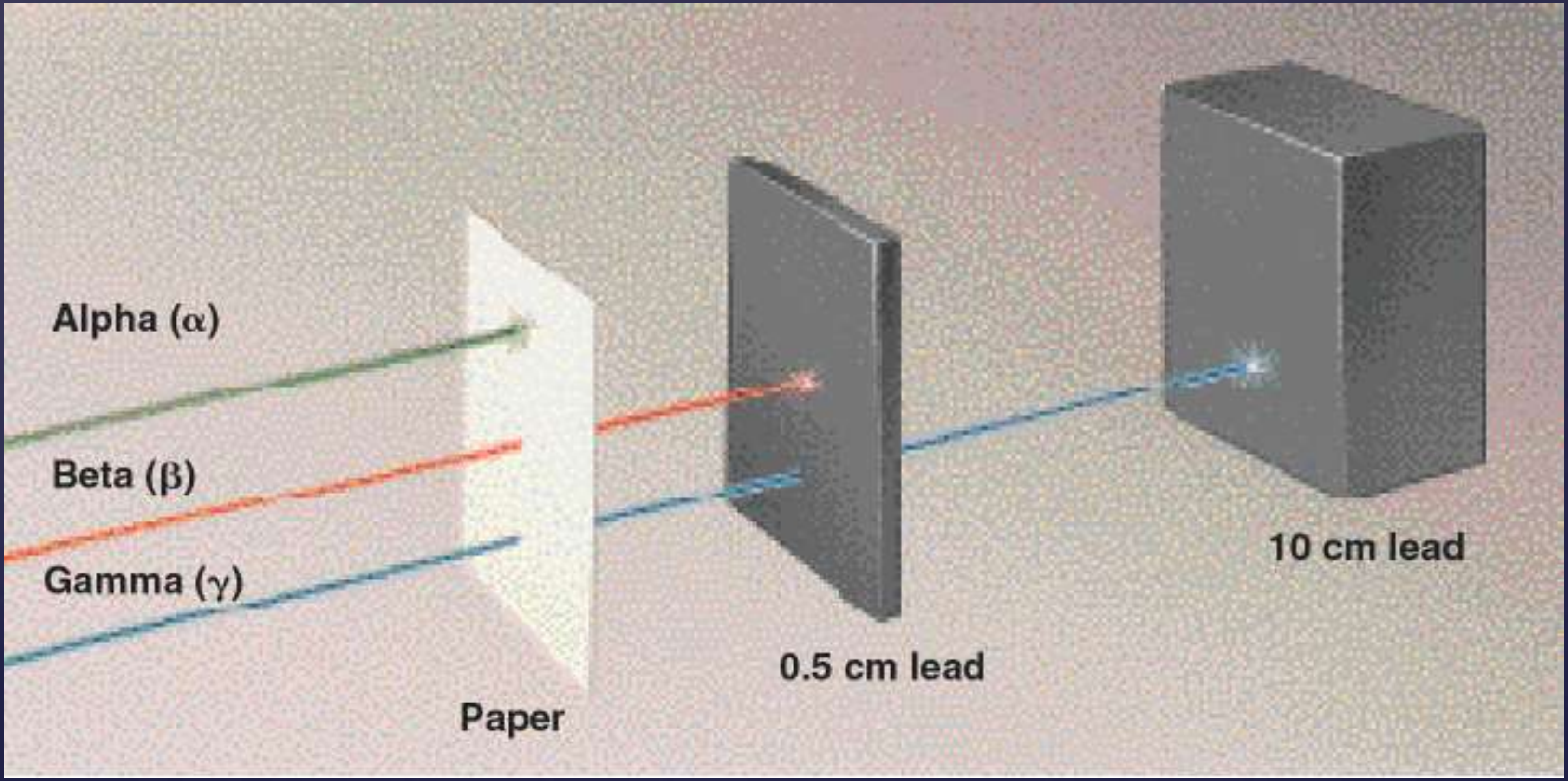
Properties - Bremsstrahlung X-rays

Bremsstrahlung X-rays are created when electrons are slowed down in the field of a nucleus. Use of a high Z material to shield beta particles can generate bremsstrahlung x-rays, which is why using lead to shield beta emitting radioisotopes such as P-32 is not recommended.



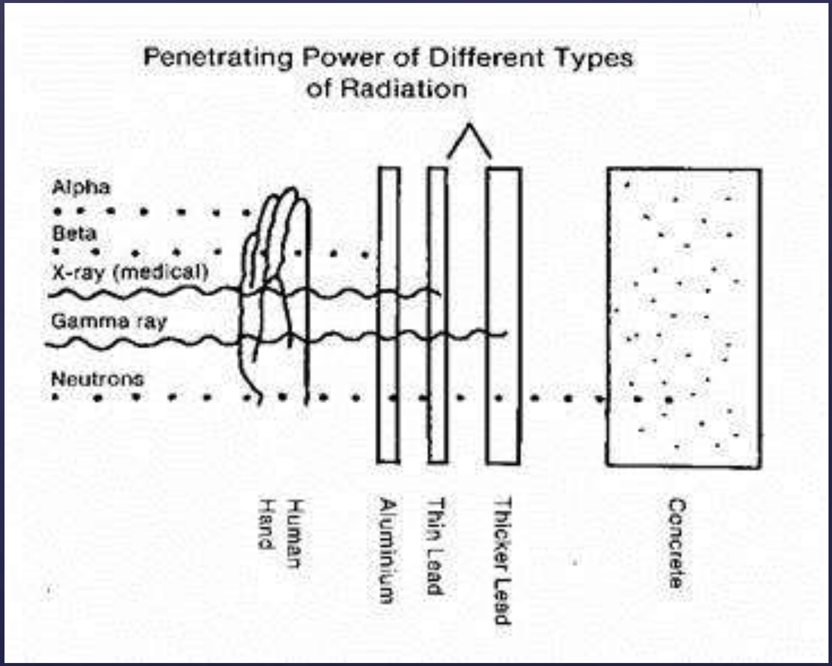
Penetrating Power

- The penetrating power of radiation varies in part due to their masses and their charges
- Protection from radiation – time, distance and shielding



Penetrating Power

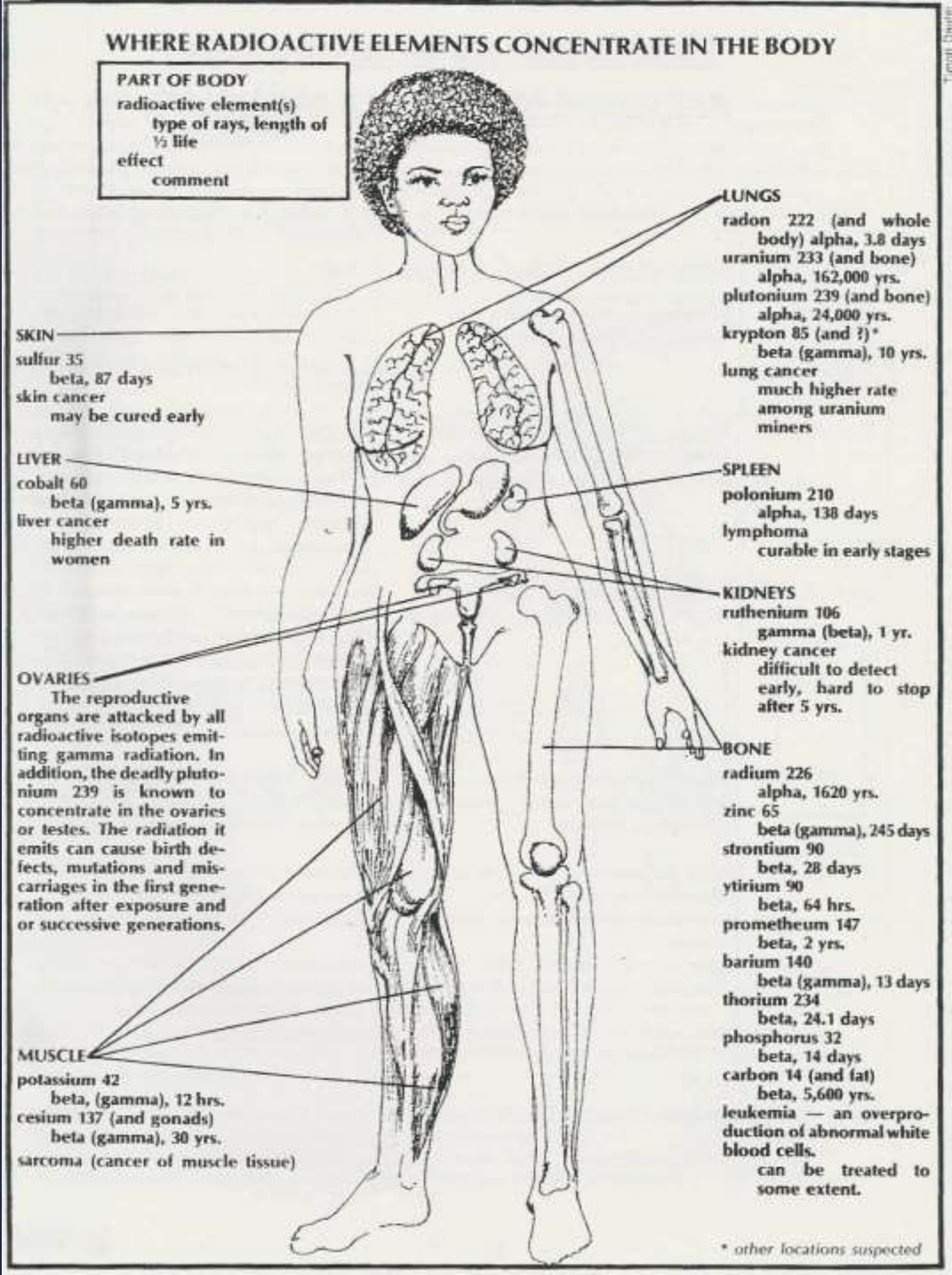
- Alpha - outside of body little damage, not able to penetrate skin. Inside of the body causes much damage to tissues cells DNA and Proteins
- Beta - some harm but much less than **inhaled** alpha’s, beta’s can go through skin
- Gamma - is the most harmful easily penetrates skin and damages DNA and cells as it “rips” through



Exposure

Elements tend to concentrate in certain parts of the body

I - Thyroid
S - Skin
P - Bone
H - Throughout



WHERE RADIOACTIVE ELEMENTS CONCENTRATE IN THE BODY

PART OF BODY
radioactive element(s)
type of rays, length of ½ life
effect
comment

SKIN
sulfur 35
beta, 87 days
skin cancer
may be cured early

LIVER
cobalt 60
beta (gamma), 5 yrs.
liver cancer
higher death rate in women

OVARIES
The reproductive organs are attacked by all radioactive isotopes emitting gamma radiation. In addition, the deadly plutonium 239 is known to concentrate in the ovaries or testes. The radiation it emits can cause birth defects, mutations and miscarriages in the first generation after exposure and or successive generations.

MUSCLE
potassium 42
beta, (gamma), 12 hrs.
cesium 137 (and gonads)
beta (gamma), 30 yrs.
sarcoma (cancer of muscle tissue)

LUNGS
radon 222 (and whole body) alpha, 3.8 days
uranium 233 (and bone)
alpha, 162,000 yrs.
plutonium 239 (and bone)
alpha, 24,000 yrs.
krypton 85 (and ?)*
beta (gamma), 10 yrs.
lung cancer
much higher rate among uranium miners

SPLEEN
polonium 210
alpha, 138 days
lymphoma
curable in early stages

KIDNEYS
ruthenium 106
gamma (beta), 1 yr.
kidney cancer
difficult to detect early, hard to stop after 5 yrs.

BONE
radium 226
alpha, 1620 yrs.
zinc 65
beta (gamma), 245 days
strontium 90
beta, 28 days
ytirium 90
beta, 64 hrs.
prometheum 147
beta, 2 yrs.
barium 140
beta (gamma), 13 days
thorium 234
beta, 24.1 days
phosphorus 32
beta, 14 days
carbon 14 (and fat)
beta, 5,600 yrs.
leukemia — an overproduction of abnormal white blood cells.
can be treated to some extent.

* *other locations suspected*

Radiation Units

There are specific units for activity or radioactive materials and for the amount of radiation you receive in a given time and for the total amount of exposure you are subjected to. A quality factor (QF) is assigned to each type of radiation and is used in determining dose rates.

QF alpha = 20

QF beta = 1

QF gamma = 1

Absorbed Dose

The energy imparted to matter by ionizing radiation per unit mass of irradiated material

Unit of expression is the Rad (0.01 J/kg)

Dose Equivalent

Numerically equivalent to absorbed dose in rads multiplied by a quality factor (to indicate biological effectiveness)

Reontgen equivalent man or Rem or simply R is the unit of dose equivalent

Rem = QF x Rad

- 100 rem causes radiation sickness and increases cancer risk by 1 – 5 %
- 500 rem is the LD50

Dose Rate

Dose equivalent per unit of time (mrem/hr, mr/hr)

U.S. radiation workers are allowed whole body dose rate of 5 rem/yr

ICRP recommends 2 rem/yr (averaged over 5 yrs)

Occupational Radiation Exposure Limits

- Whole body = 5,000 mrem/year
- Extremities = 50,000 mrem/year
- Eye = 15,000 mrem/year
- Fetus = 500 mrem/gestation period (declared pregnancy)
- Minors = 500 mrem/year
- Allowable dose to public is 100 mrem/year or 2 mrem/hour

Measuring Radioactivity – The Curie

This is the amount of radioactivity in a sample (the amount of radioactivity = activity)

- A commonly-used unit for measuring activity is the curie(Ci)
- 1 curie is equal to 2.2 x 10^{12} disintegrations per minute (dpm)
- Typical activities found in a university lab are in the microcurie (μCi) to millicurie (mCi) range

Measuring Radioactivity - The Becquerel (Bq)

- The amount of radioactive material which decays at a rate of one disintegration per second (dps)
- This is the SI unit of radioactive material or activity

Measuring Radioactivity – CPM & DPM

- CPM is the counts per minute that a detector "sees"
- DPM are the actual disintegrations (release of energy) by a radioactive sample [disintegrations per minute]

Since detectors aren't 100% efficient…

DPM = CPM / Detector Efficiency

(the detector efficiency for the specific radioisotope, that is)

- Typical efficiencies for a Geiger counter (ratemeter + Geiger-Mueller probe) are:
- 40-75% for beta particles above 300 keV
- 2-5% for alpha particles
- 0.5-5% for gamma rays and x-rays

What's Next?

This presentation provided basic information concerning radioactivity.

1) The next slide has a link to a quiz that must be passed with 75% correct to work with radioactive materials at UAH.

2) After the test has been completed contact OEHS at greenm@uah.edu to provide notice that you have taken the test.

3) Upon receipt of a passing score radiation workers must review the UAH Radiation Safety Procedures and submit a declaration of receipt of the training (link at the end of the presentation). The Radiation Safety Procedures presentation is important for you to review because it includes information on protecting yourself from radiation.

4) The Authorized User will provide radiation workers with lab specific training.

Questions

Contact
OEHS
256-824-6053
greenm@uah.edu

Take Test