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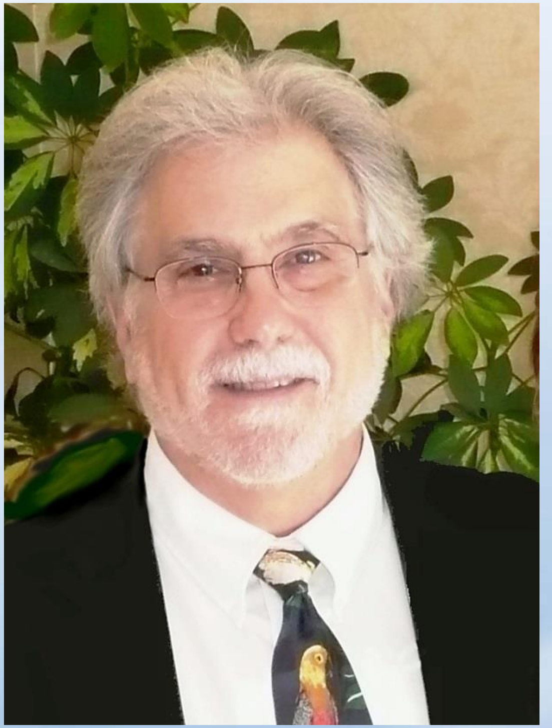
Principles of Radiation Physics and Dosimetry I



Radiation Epidemiology & Dosimetry Course

National Cancer Institute www.dceg.cancer.gov/RadEpiCourse

There is a lot of material in this lecture - it covers about 2 semesters of undergraduate physics and 2 semesters of graduate health physics.

However, it is not my intent for you to completely digest this material !

My intent is for you to become familiar with the terms and concepts presented so that they will be somewhat familiar to you in the future.

GOALS OF THIS LECTURE:

To assist you in gaining an understanding of the fundamental concepts of physics underlying the theory of dosimetry for ionizing radiation – essential to the study of radiation epidemiology

Here are the topics that I hope you will gain an understanding of:

- Basic concepts of the nucleus and the nuclear particles involved in radioactive decay
- The meaning and the differences between radioactivity and radiation
- The processes that lead to emission of radiation
- The processes that lead to absorption of radiation in tissue
- The approximate ranges of energies in which the various emission and absorption processes operate
- The basic definitions of ‘exposure’ and ‘absorbed dose’
- Which dose units to use and why.
- Sources of radiation exposure in normal life.
- Sources of information about dosimetry that might assist you in epidemiologic studies.

THE MOST BASIC CONCEPT IN DOSIMETRY IS WHAT ??

ENERGY

Energy…what's that?

Energy: The amount of work a physical system can do.

ENERGY is often defined according to type. Some types are:

Chemical energy: The potential for substances to undergo transformation or to transform other substances.

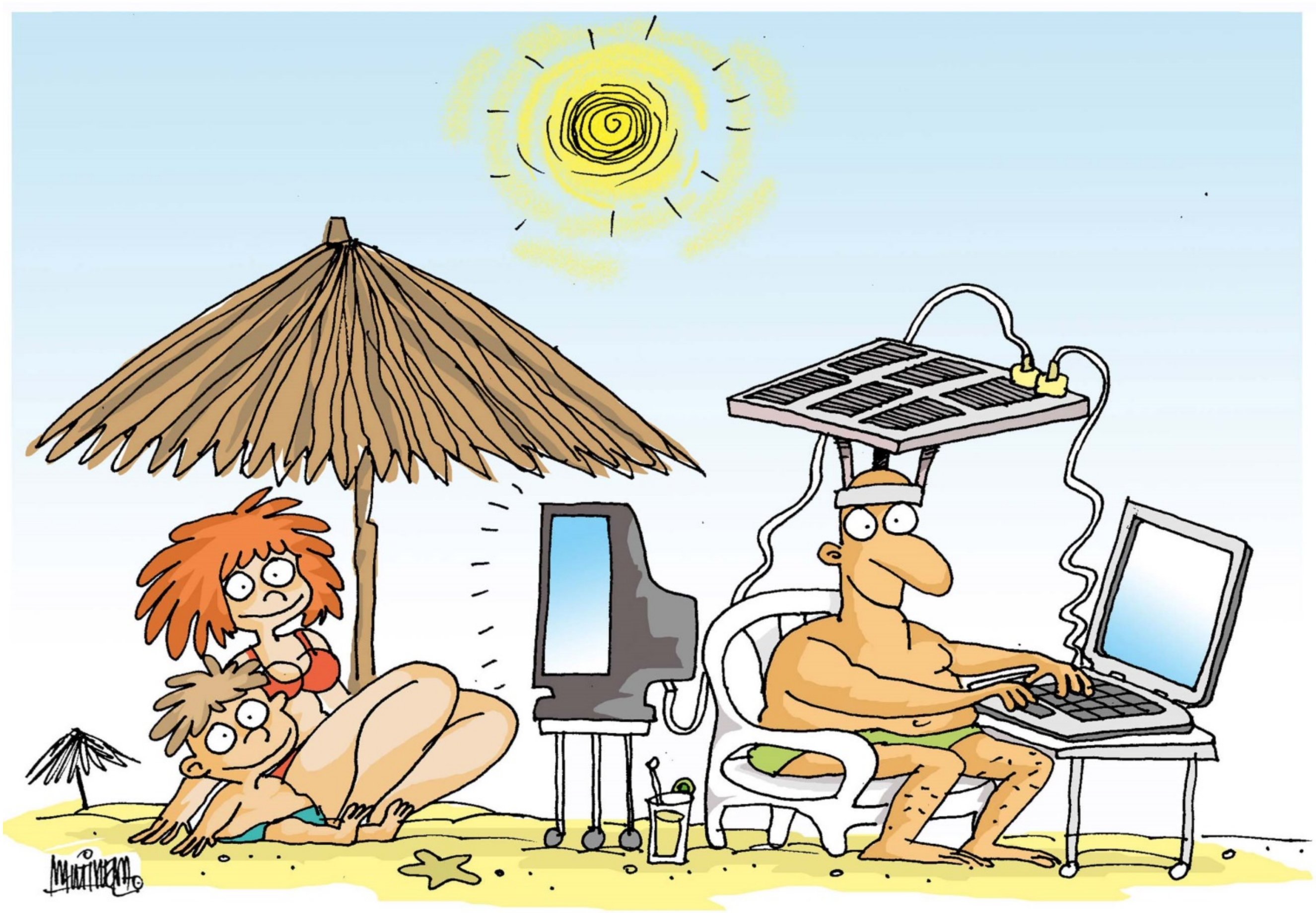
Kinetic energy: the form of energy as a consequence of the motion of an object.

Potential energy: the form of energy that is due to the position of an object.

Binding energy: the energy required to disassemble a whole into separate parts, e.g., the binding energy of electrons, nuclear particles, or even molecules.

Nuclear energy: energy that is the consequence of decomposition of an atomic nucleus.

Understanding How Energy is Transferred is Necessary for Understanding Radiation Dose

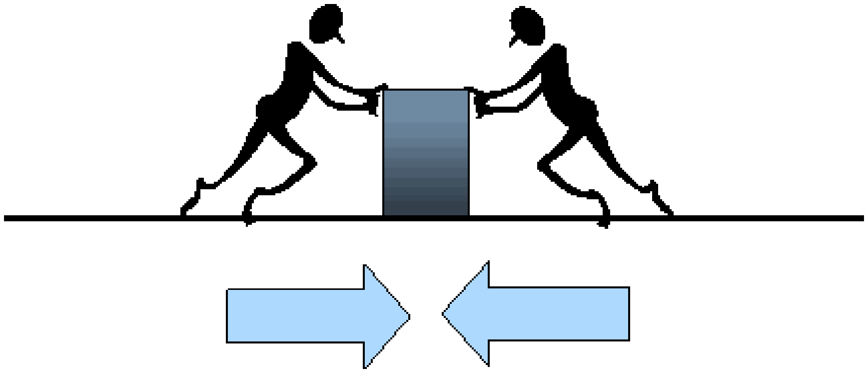


Energy can be transferred from one system to another or from one type of energy to another.

http://www.greenpatentblog.com/2011/12/

How is Energy Transferred in These Examples?

In physics, energy is transferred by a "*force*".



Only four fundamental forces are recognized in physics:

(1) Strong,

(2) Electromagnetic,

(3) Weak, and

(4) Gravitational (in order of decreasing strength).

These fundamental forces account for why the nucleus of all atoms stay together, as well as explains radioactive decay.

Q: Why are we interested in understanding ENERGY and FORCES in Radiation Epidemiology?

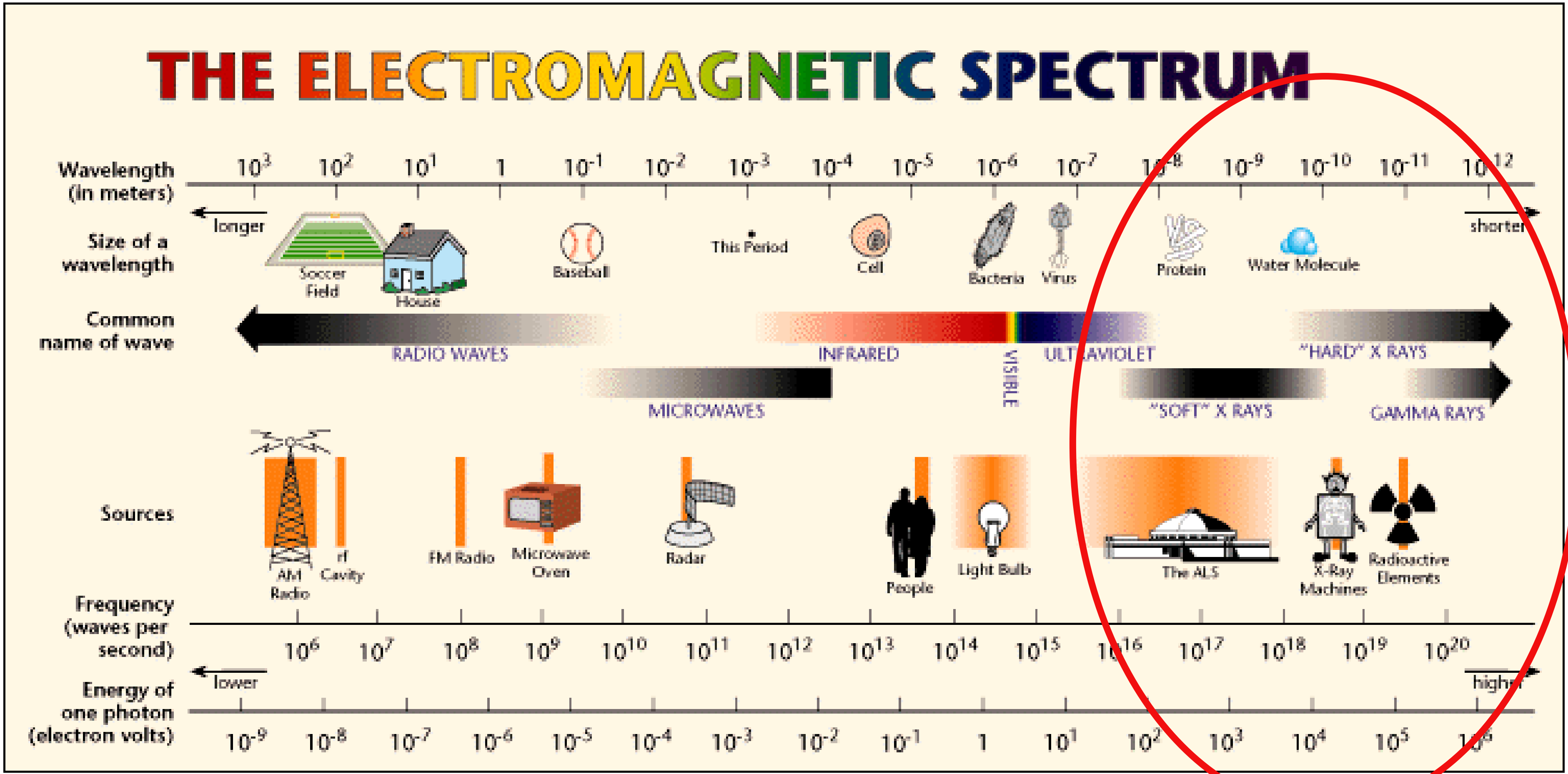
This is a lecture on dosimetry…*Right?*

The **transfer of energy** to biological materials (organisms, tissues, organs) under specific conditions is the basis for defining **radiation dose!**

The concept of force and energy explain **radioactivity**, also relevant to understanding radiation dose.

Hence, the concepts of **Energy** and **how Energy is transferred** provides the logical links between **Physics**, **Radiation Dosimetry**, and **Radiation Epidemiology**.

A Reminder of the Domain of the Energy Spectrum Addressed in this Lecture



Domain of ionizing radiation is discussed in this lecture…even though other types of radiation are of interest in epidemiology.

Radiation

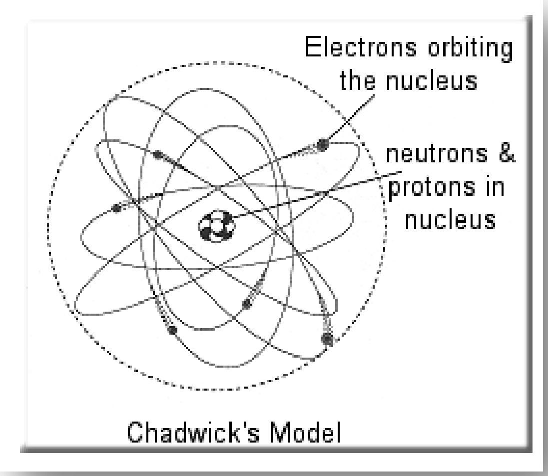
Radiation, in our context, is energy in the form of high speed particles and electromagnetic waves. Radiation is further defined into ionizing and non-ionizing components.

- ***Ionizing radiation*** is radiation with enough energy so that during an interaction with an atom, **it can remove bound electrons**, causing the atom to become charged or to become 'ionized'. Examples of ionizing radiation are **X-rays and electrons**.
- ***Non-ionizing radiation*** is radiation without enough energy to remove bound electrons from their cloud around atoms. Examples are **microwaves and sunlight.**

Part I.
CONCEPTS OF NUCLEAR AND RADIATION PHYSICS

Nuclear Properties and Terminology

- The atom, for all practical purposes, consists of three basic particles, electrons, neutrons, and protons.
- The nucleus contains protons, which have positive charge, and neutrons, which have no charge.
- Both the proton and neutrons have masses approximately 1,836x that of electrons which are generally described as surrounding the nucleus, either as discrete particles, are part of an electron 'cloud'.



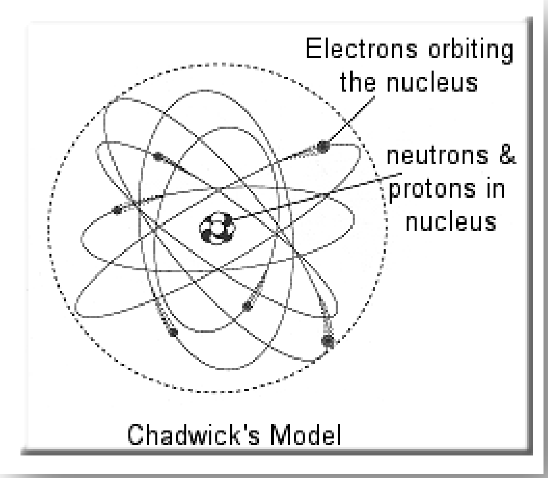
This model of the atom is simplistic, though it is sufficient for the discussion here.

Diameter of nucleus ~10^{-12} cm
Diameter of atom ~10^{-8} cm

Number of **protons** = **Z**, where Z is called the **“atomic number”**

Number of **neutrons** = N

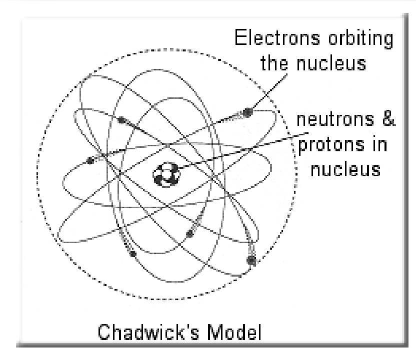
A = Z + N, where is the **“atomic mass”**



A nuclide is an atom of a particular atomic mass A

Nuclides are written as: $^{A}_{Z}\mathbf{X}$ **(where X is the chemical symbol).**

Example is Iodine-131: $^{131}_{53}\mathbf{I}$ **or simply as:** $^{131}\mathbf{I}$



IMPORTANT FACT: The actual mass of an atomic nucleus is always a little smaller than the sum of the rest masses of all its components (protons and neutrons) !!

The **reason** is that some of the mass of the nucleons is changed into energy to form the nucleus (and overcome the electrostatic repulsion among like charges).

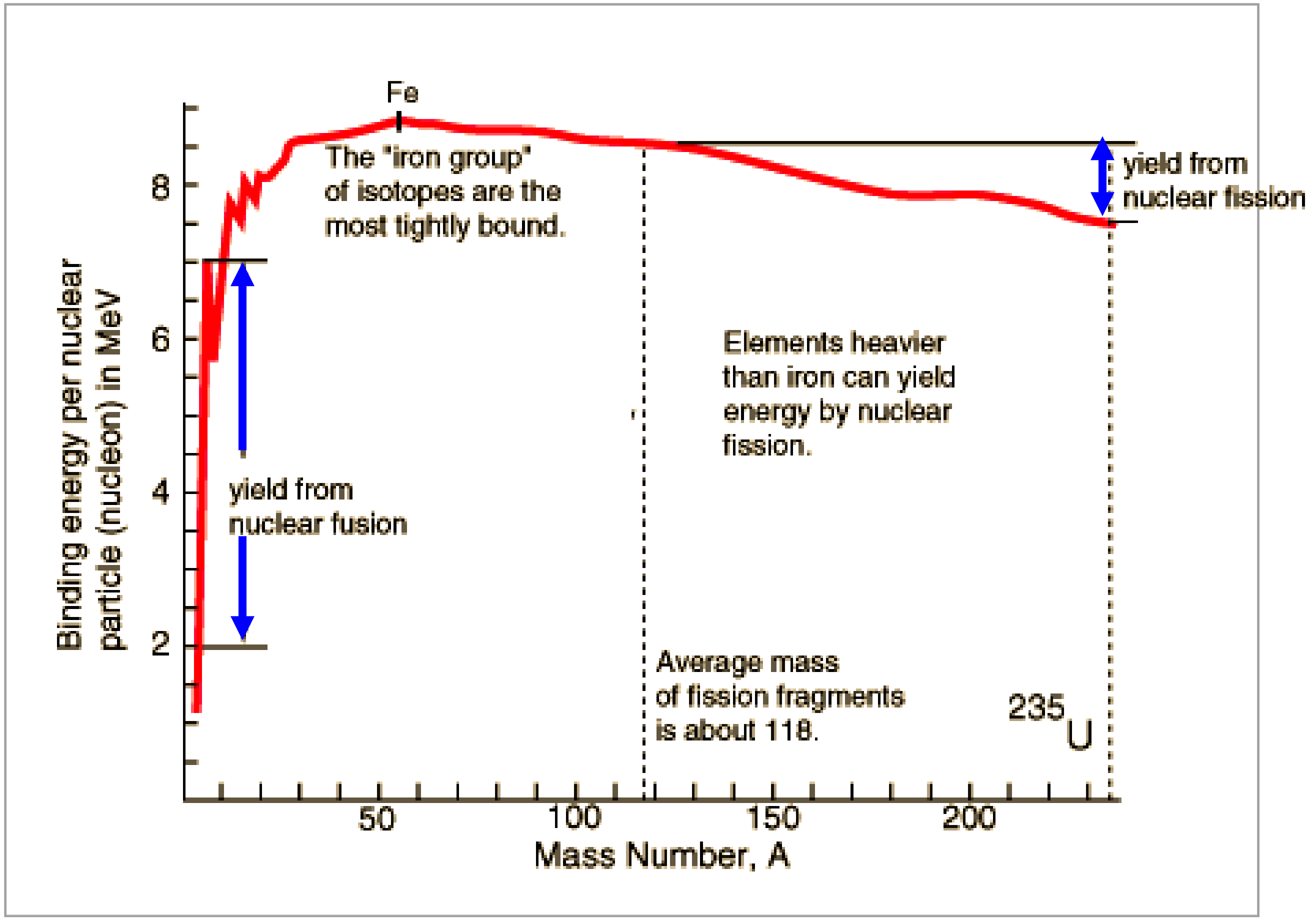
Using the $E=mc^2$ formulation, the **Binding Energy** can be written as difference in the sum of the rest masses of the individual nucleons and the rest mass of the assembled nucleus:

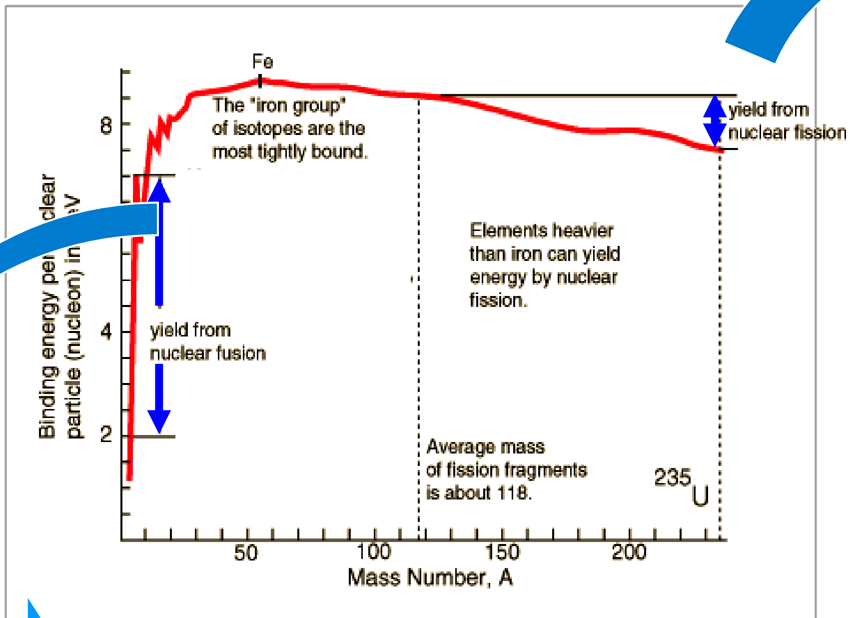
$$\mathbf{BE = [Zm_p + (A\text{-}Z)m_n - {}^{A}_{Z}m]\, c^2}$$

The binding energy explains the source of the energy released by radioactive decay processes.

That energy is of great import-ance in nuclear energy production, radiation science, and dosimetry.

Binding Energy for nucleons varies with mass number, A




Fe
The "iron group" of isotopes are the most tightly bound.
yield from nuclear fission
Elements heavier than iron can yield energy by nuclear fission.
yield from nuclear fusion
Average mass of fission fragments is about 118.
235U
8
4
2
50
100
150
200
Mass Number, A

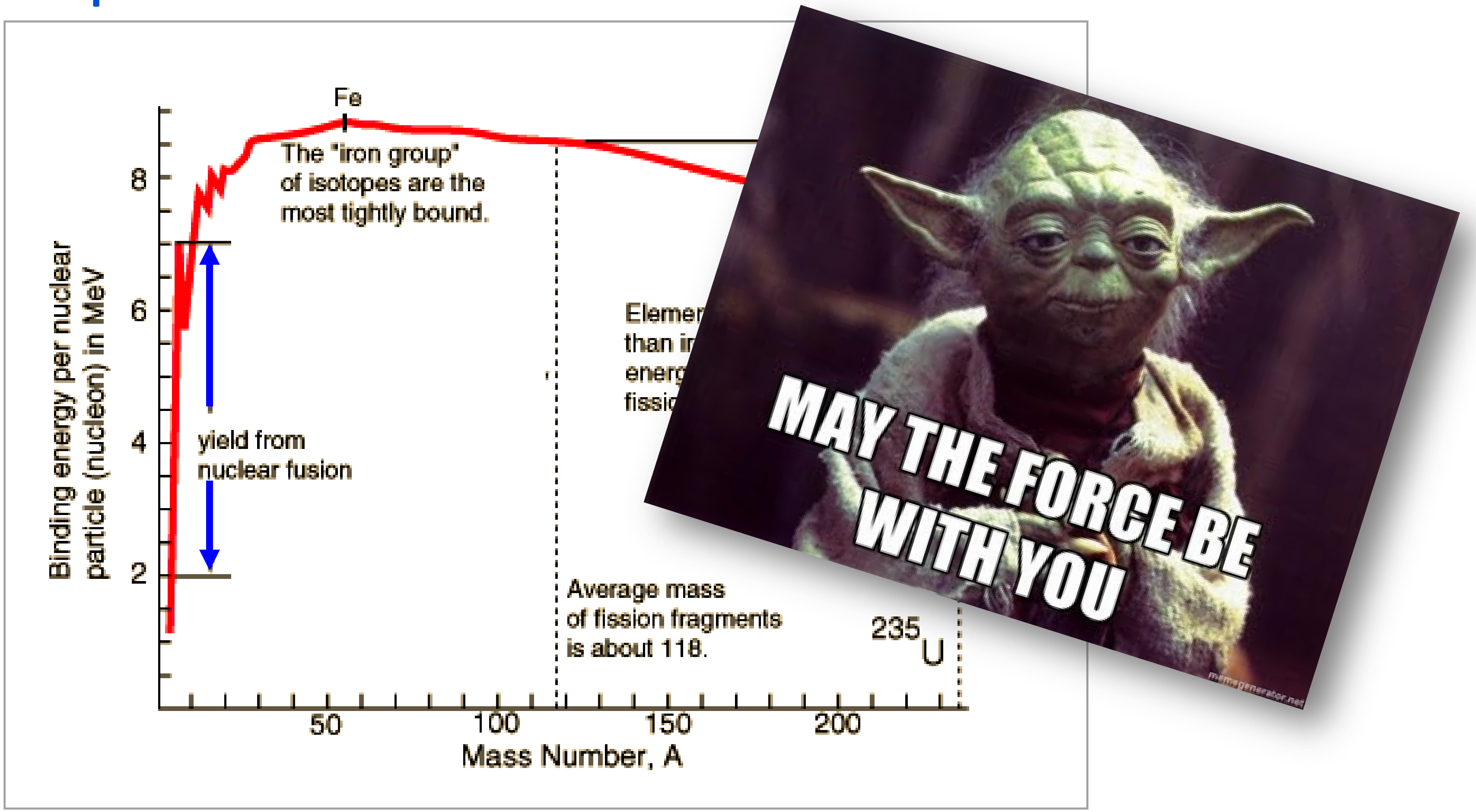

Nuclear fission power plant


Nuclear fission weapon

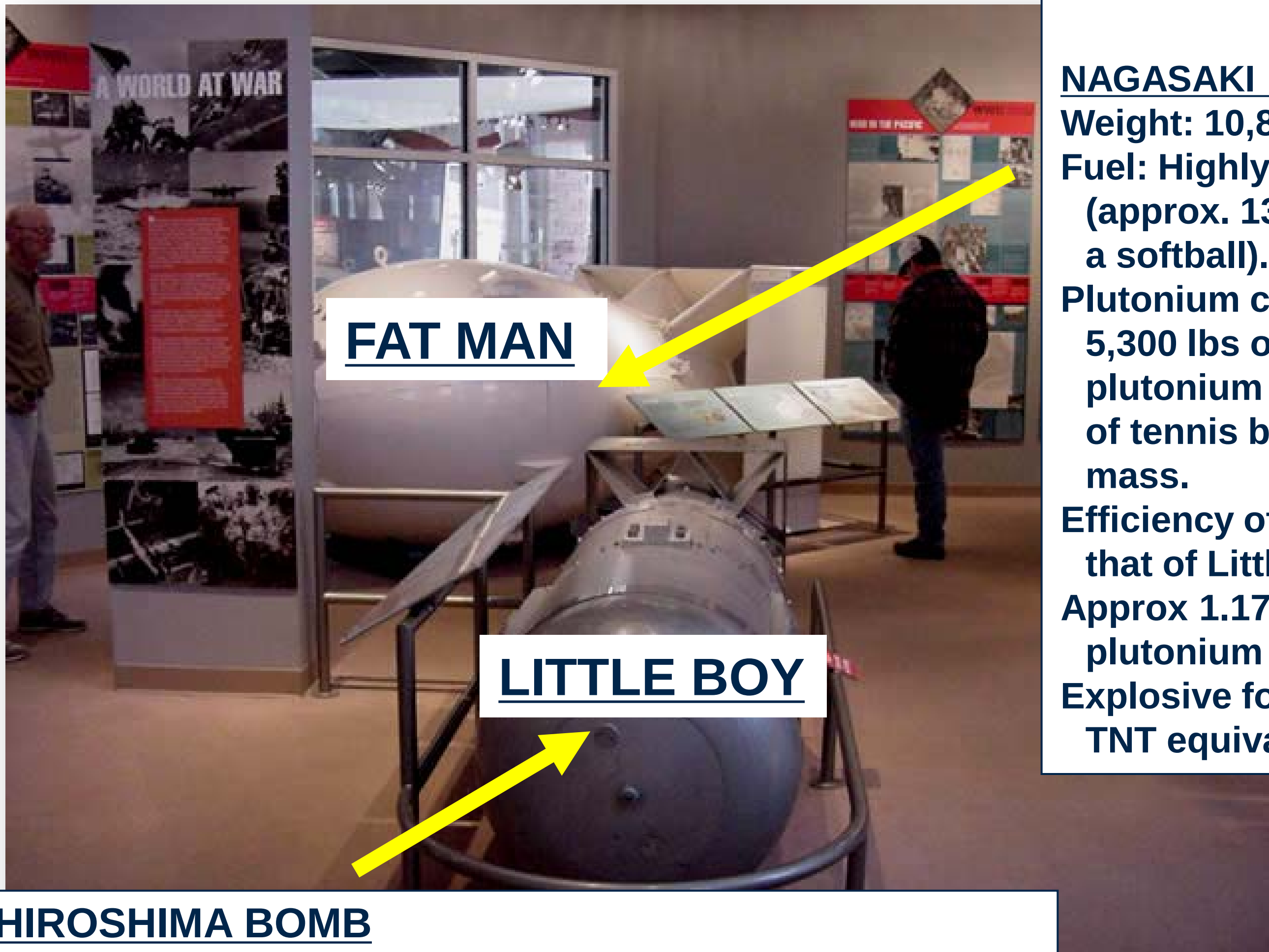

The sun


Thermonuclear weapon (H-bomb)

The release of Binding Energy explains the capability of reactors to produce electrical power and the destructive forces of nuclear weapons.



Historical Sidebar on Releasing the Binding Energy



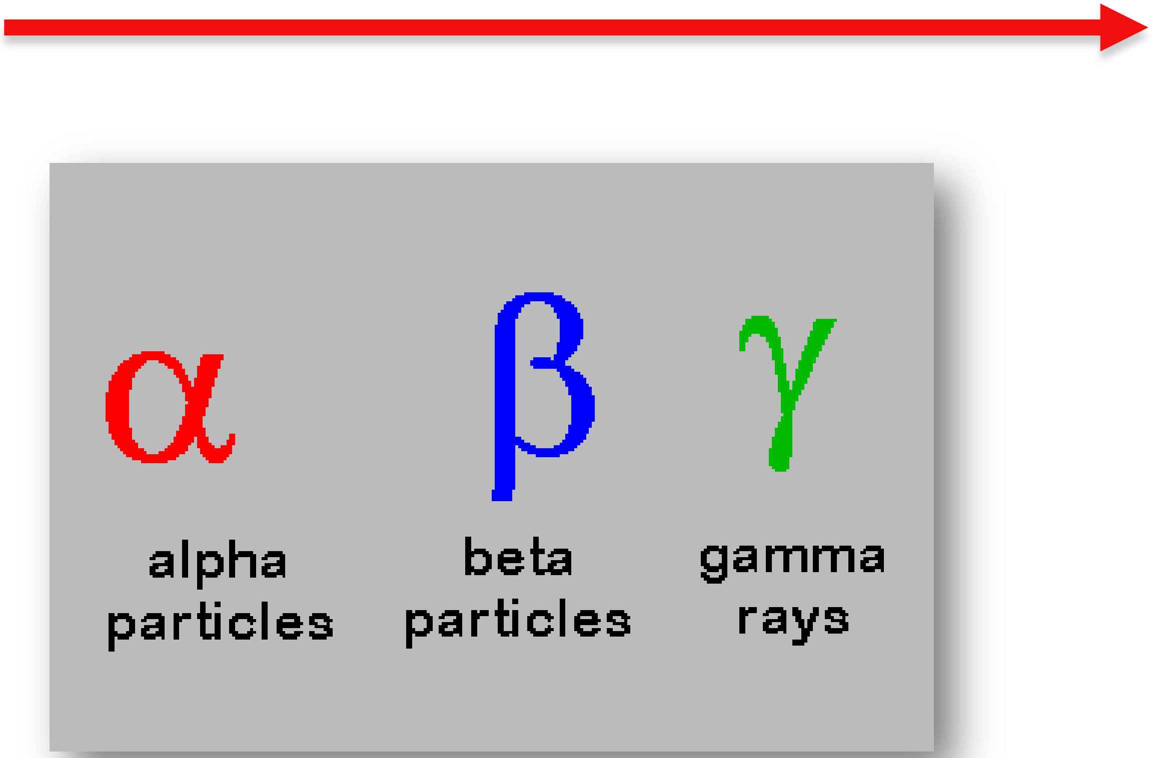
NAGASAKI BOMB
Weight: 10,800 lbs
Fuel: Highly enriched Pu-239 (approx. 13.6 lbs; approx. size of a softball).
Plutonium core surrounded by 5,300 lbs of high explosives; plutonium core reduced to size of tennis ball to form critical mass.
Efficiency of weapon: 10 times that of Little Boy.
Approx 1.176 Kilograms of plutonium converted to energy
Explosive force: ~21,400 tons of TNT equivalent.

HIROSHIMA BOMB
Weight: 9,700 lbs
Fuel: Highly enriched uranium (approx. 140 lbs); target - 85 lbs and projectile - 55 lbs
Efficiency of weapon: poor
Approx. 1.38% of the uranium fuel actually fissioned
Explosive force: ~16,000 tons of TNT equivalent.

Nuclear Decay Processes

- This transformation process of an unstable atoms towards a more stable condition is termed ***nuclear transformation or radionuclide decay*****.**
- The process of **nuclear transformation** occurs primarily because of instability in the neutron to proton ratio of atoms or because the atom is an excited state following a previous transformation.
- **Radioactivity** refers to the property of unstable atoms to transform themselves and **move to a more stable configuration**.
- The nuclear transformation process **releases energy** via **photons** (**packets of energy**) or emission of **particles**.
- **The energy and/or particles released are loosely termed *radiation* !!!**

Processes that lead to the emission of radiation (because those processes also lead to radiation 'dose')



(1) Alpha decay

All nuclei of atoms heavier than lead (Pb) are unstable; most decay by **alpha particle** emission.

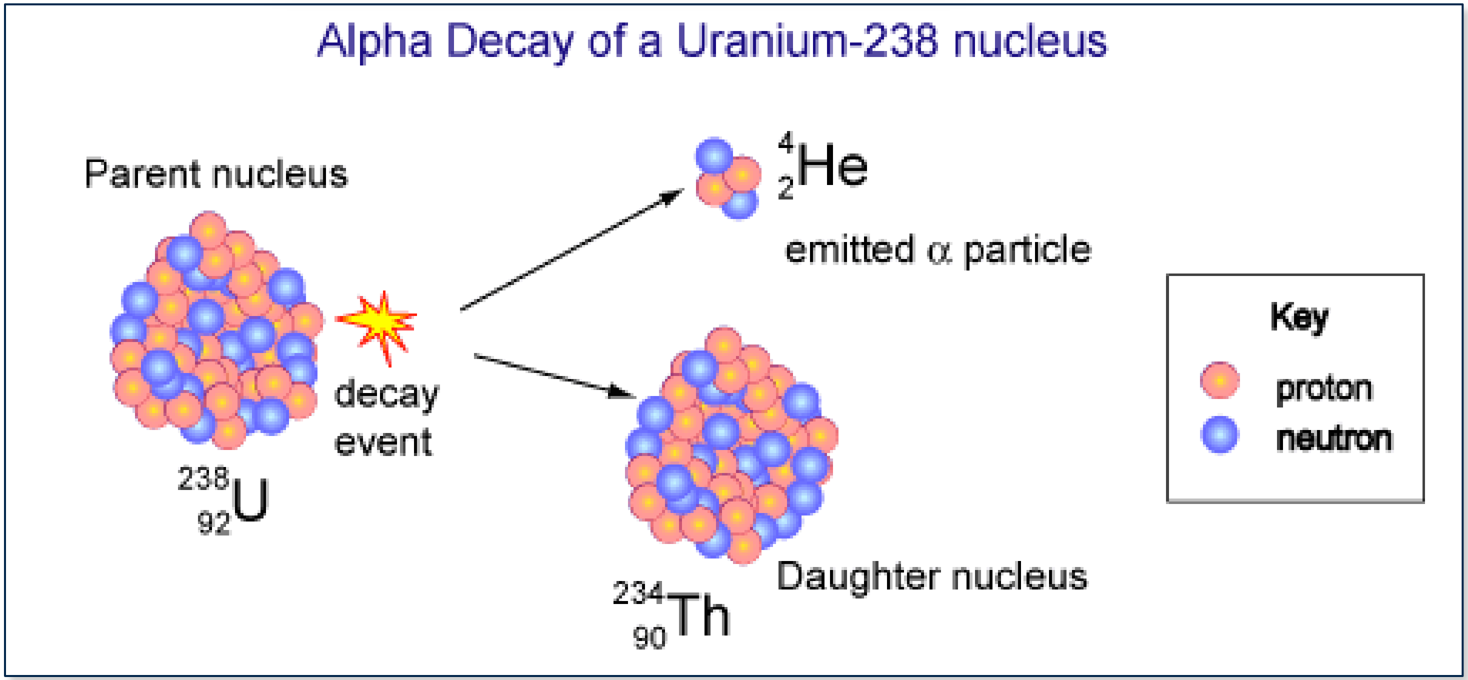
In alpha decay, a single alpha (α) particle consisting of **2 protons and 2 neutrons** leaves the nucleus .

For example, natural uranium-238 decays by alpha emission:

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha$$

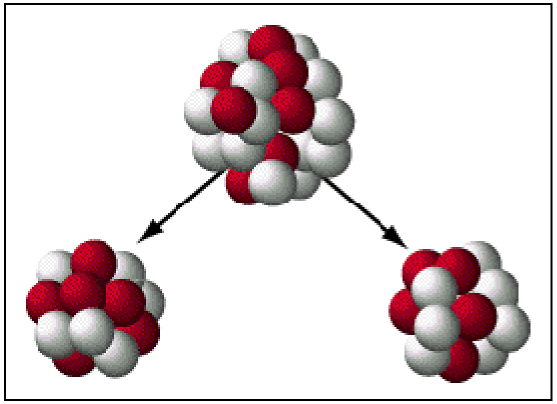
Energy released = 4.268 MeV (Kinetic energy of particle)

$t_{1/2}$ = 4.51 x 10^9 years



(2) Spontaneous fission

Some heavy nuclei can split (fission) into several smaller fragments plus neutrons.



Most nuclides that can undergo spontaneous fission are more likely to decay by alpha decay.

For example, ^{238}U (>99.3% of all uranium), alpha decay is about 2 million times more probable than spontaneous fission.

In contrast, ^{256}Fm, 3% of the nuclei undergo alpha decay and 97% undergo spontaneous fission.

The fragments of the fission are generally radioactive and decay by a chain of **β decays** toward stable nuclei.

What's β decay??

(3) Beta (β) decay

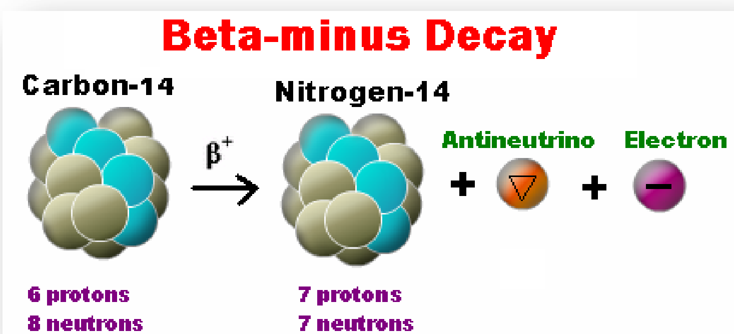
Beta decay involves a class of particles called 'leptons' which include electrons (e-), positrons (e+), neutrinos (ν), and anti-neutrinos ($\bar{\nu}$).

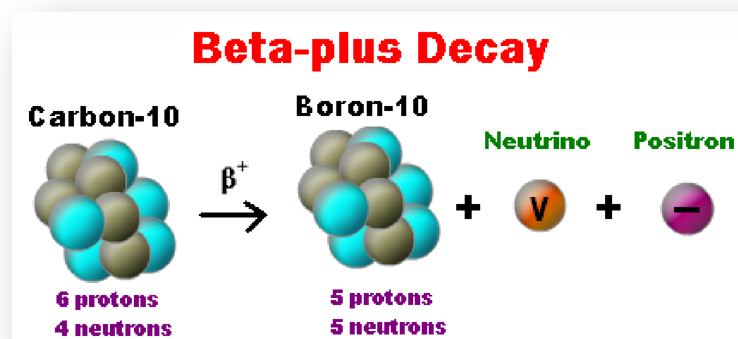
In β decay, there are 3 processes:

$n \rightarrow p + \beta^- + \bar{\nu}$ (**negative β decay**)

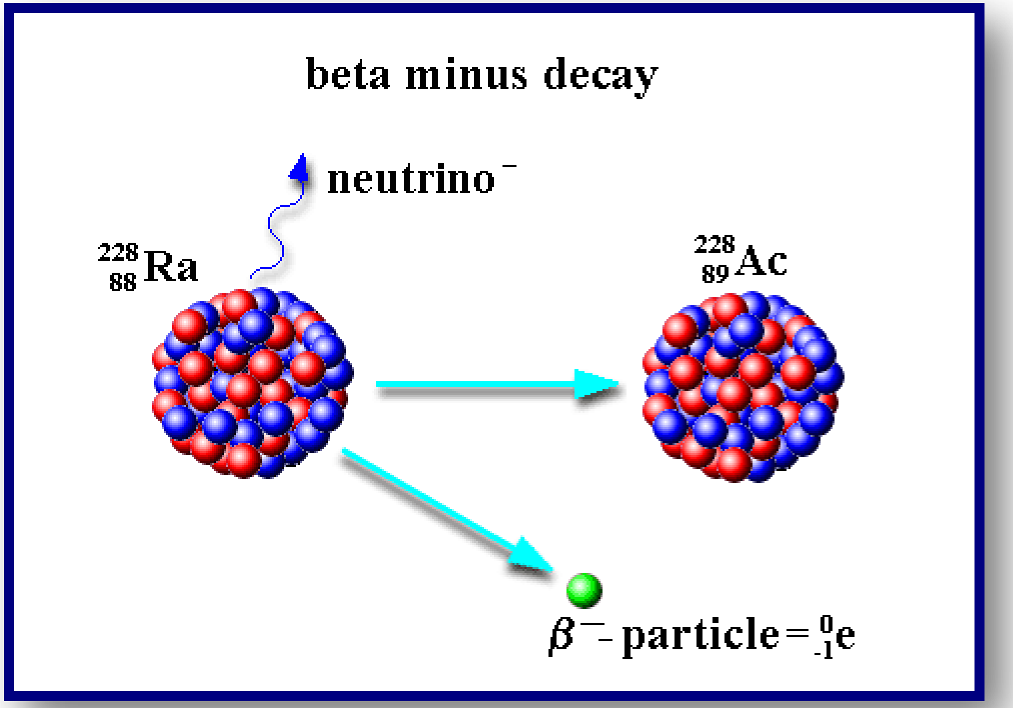
$p \rightarrow n + \beta^+ + \nu$ (**positive β decay**)

$p + e^- \rightarrow n + \nu$ (**electron capture, not discussed**)

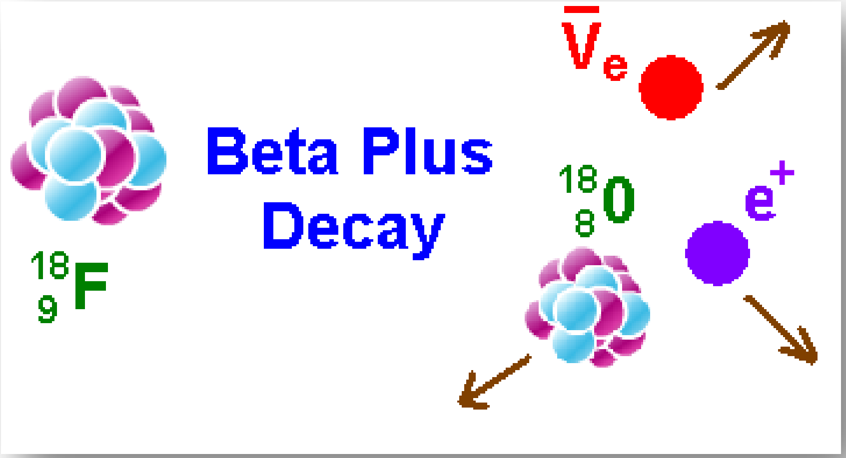




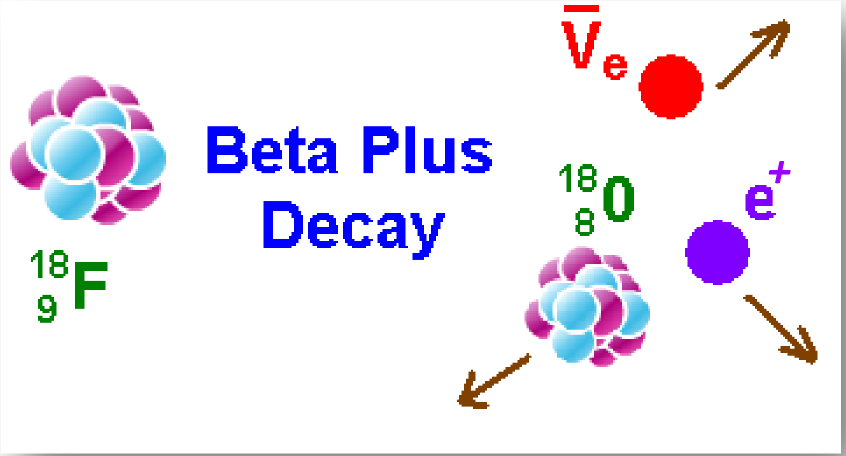
Negative Beta Decay: the decay of a neutron into a proton which remains in the nucleus and an electron which is emitted as a netative (-) **beta particle**.

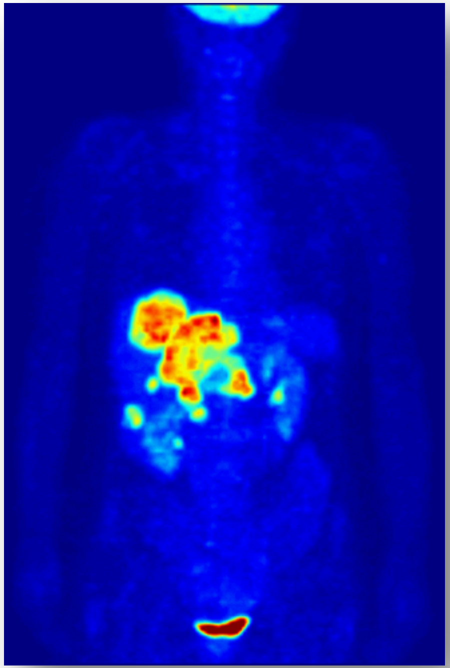


Positive Beta Decay: the decay of a proton into a neutron, which remains in the nucleus, and a positive electron which is emitted as a positive (+) **beta particle**.



SIDEBAR on Positive Beta Decay





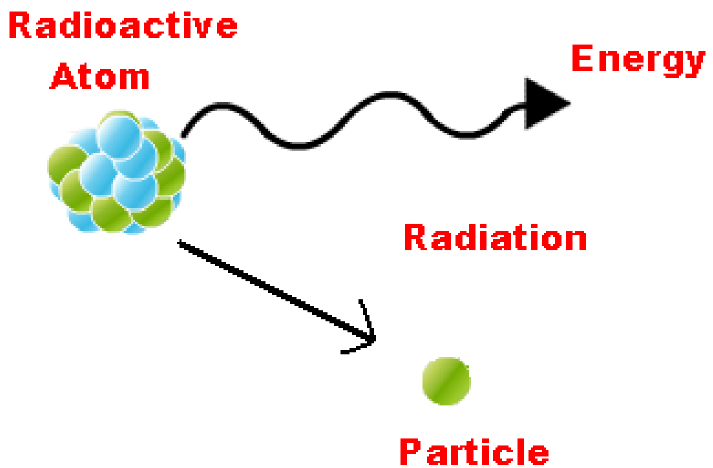
Whole-body PET scan using ^{18}F-FDG

*Fluorine-18 (**a positive electron emitter**), attached to glucose molecule is used to image cancer metastases. The positive electron emitted from F-18, when absorbed, produces 2 gamma photons of 0.511 Mev which are detected for the image.*

(4) Gamma Emission

Nuclei can be left in excited states following another type of transformation.

Depending on the available energy, the atoms can emit heavy particles or by emission of **electromagnetic energy (i.e., x-ray or gamma-ray).**



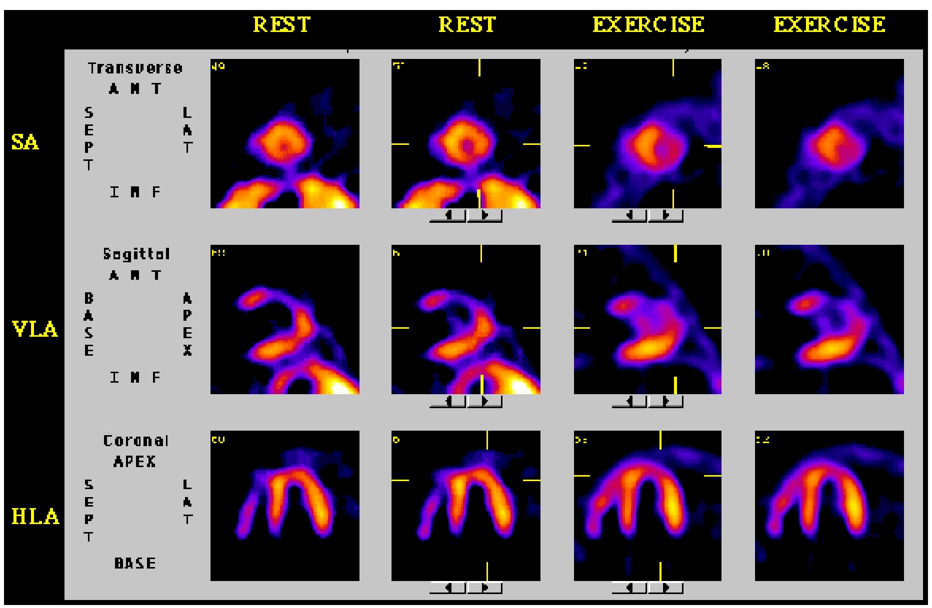
The emitted x-ray or gamma ray is called a *photon* and has a characteristic wavelength determined by its energy. For example, a 0.5 MeV gamma photon has a wavelength on the order of 50 nuclear diameters.

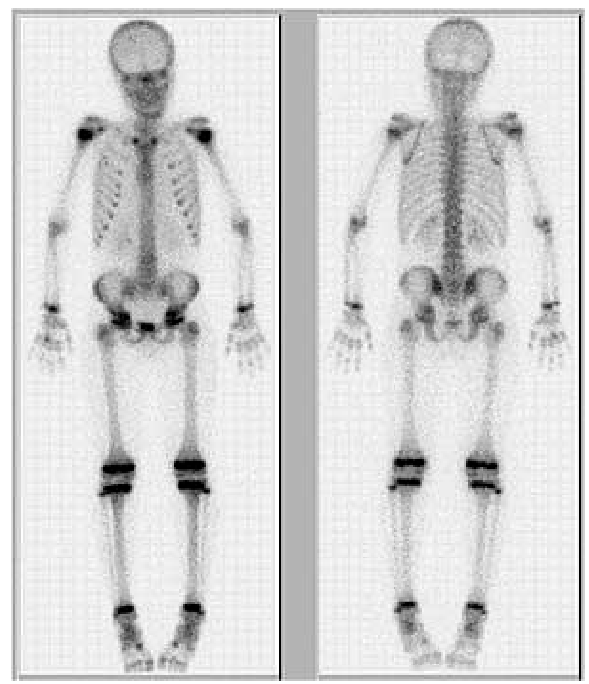
Example: decay of Technetium-99m (the primary radionuclide used today in diagnostic nuclear medicine)

$$^{99m}_{43}\mathrm{Tc} \rightarrow \, ^{99}_{43}\mathrm{Tc} + \gamma$$

E_γ = 140 keV, $t_{1/2}$ = 6.02 hr

Note that neither Z or A changes as a result of gamma emission.





Summary of radiation types and selected characteristics

Radiation Type	Charge	Approximate energy range	Approximate range In air	In water	Primary Source

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	Energetic Particles				
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X-ray	None	A few eV to several MeV	A few mm to 10 m	Up to a few cm	Orbital electron transitions and *Bremsstrah-ung*

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	Electromagnetic Radiation				
X-ray	None	A few eV to several MeV	A few mm to 10 m	Up to a few cm	Orbital electron transitions and *Bremsstrah-ung*
Gamma ray	None	~10 keV to 10 MeV	A few cm to 100 m	From a few mm to several cm	Nuclear transitions

RADIOACTIVITY

Some things you should understand about it….

What are radionuclides?

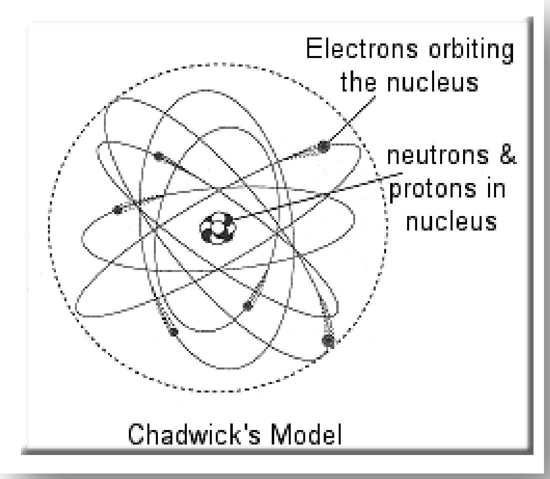
What are their half-lives?

What are their origins?

Which of their properties are relevant to dosimetry?

What is activity?

What is its units?



REMINDER

protons = Z where Z is called the 'atomic number.'

neutrons = N

A = Z + N, where is the 'atomic mass.'

- A nuclide is an atom of a particular atomic mass A
- Nuclides are written as: $^{A}_{Z}X$
- A radionuclide is a nuclide which is unstable, in other words, it is likely to decay and emit radiation !

Nuclides with identical Z are called "isotopes."
Nuclides with identical A are called "isobars."
Nuclides with identical N are called "istotones."
A nuclide in an 'excited' (excess energy) state is called an "isomeric" or "meta-stable" state.

TYPES of NUCLIDES

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

Isotopes (identical Z): (same chemical element!)

$$^{123}_{53}I,\ ^{124}_{53}I,\ ^{125}_{53}I,\ ^{126}_{53}I,\ ^{127}_{53}I,\ ^{128}_{53}I,\ ^{129}_{53}I,\ ^{130}_{53}I,\ ^{131}_{53}I,\ ^{132}_{53}I$$

Isobars (identical Z):

$$^{131}_{50}Sn,\ ^{131}_{51}Sb,\ ^{131}_{52}Te,\ ^{131}_{53}I,\ ^{131}_{54}Xe,\ ^{131}_{55}Cs$$

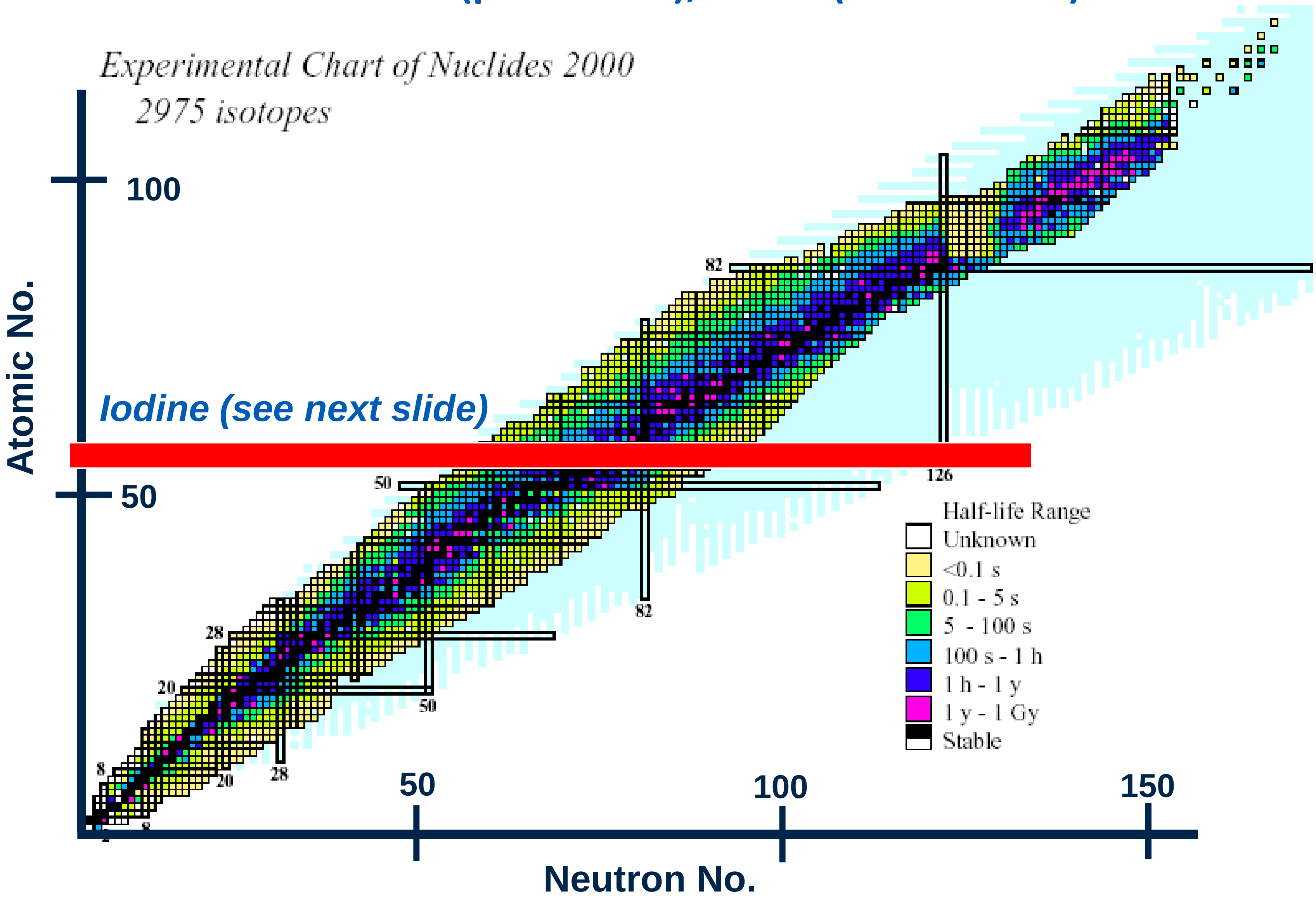
Isotones (identical N):

$$^{125}_{48}Cd,\ ^{126}_{49}In,\ ^{127}_{50}Sn,\ ^{128}_{51}Sb,\ ^{129}_{52}Te$$

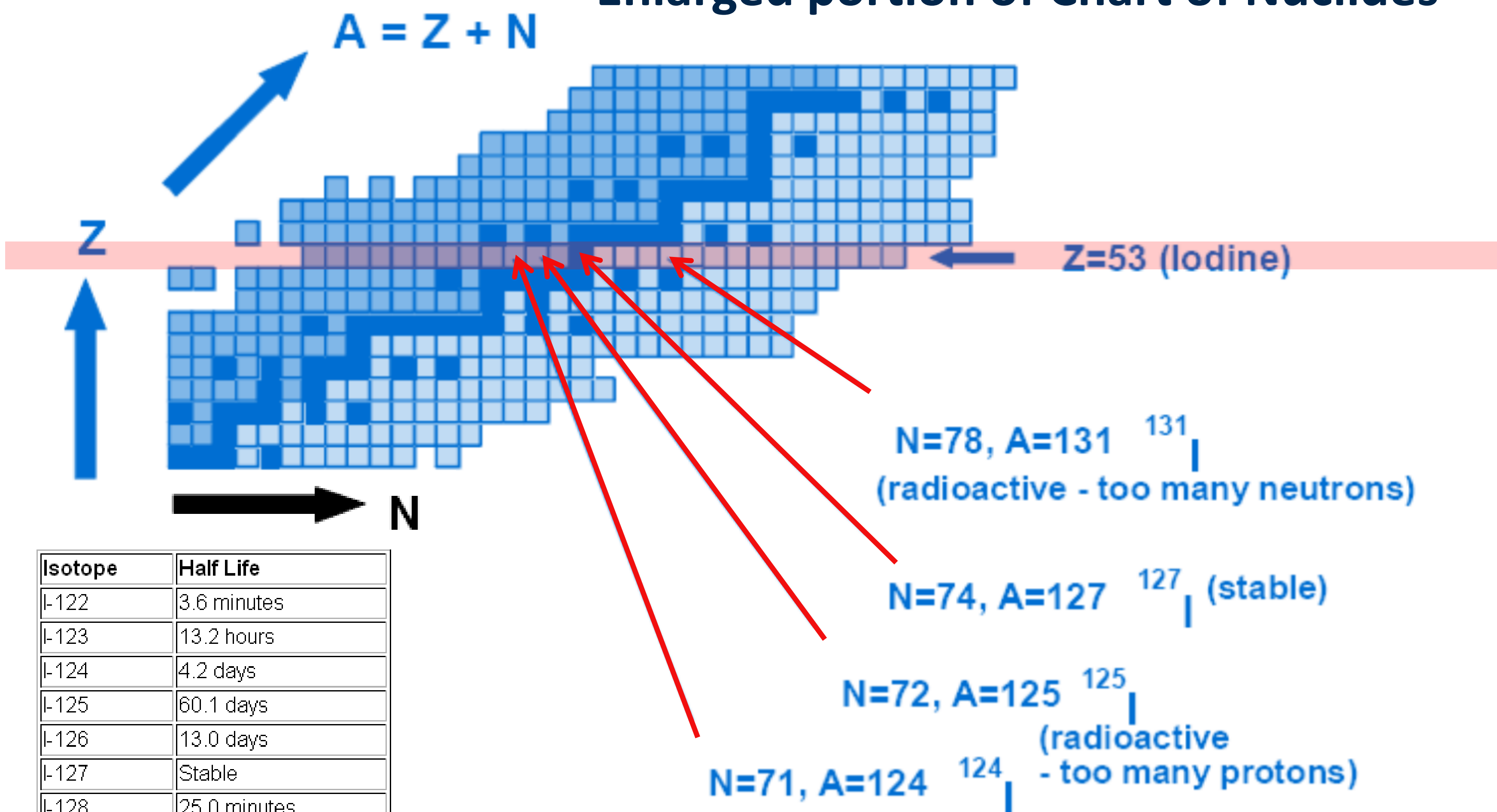
Metastable state (excess energy state, also called 'isomeric' or 'meta-stable':

$^{130m}_{53}I$ ($t_{1/2}$ = 9 min), $^{132m}_{53}I$ ($t_{1/2}$ = 1.4 hr)

The Occurrence of Nuclides Follows a Pattern When Viewed in Terms of Z (proton no.), and N (neutron no.)



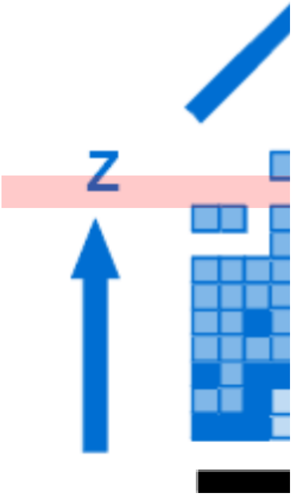
Enlarged portion of Chart of Nuclides



Isotope	Half Life
I-122	3.6 minutes
I-123	13.2 hours
I-124	4.2 days
I-125	60.1 days
I-126	13.0 days
I-127	Stable
I-128	25.0 minutes
I-129	1.57E7 years
I-130	12.4 hours
I-131	8.0 days
I-132	2.3 hours
I-133	20.8 hours
I-134	52.6 minutes
I-135	6.6 hours
I-136	1.4 minutes

Isotopes of Iodine

Chart of Nuclides



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I-130	12.4 hours
I-131	8.0 days
I-132	2.3 hours
I-133	20.8 hours
I-134	52.6 minutes
I-135	6.6 hours
I-136	1.4 minutes

Z=53 (Iodine)

=131 ^{131}I

ve - too many neutrons)

:127 ^{127}I (stable)

5 ^{125}I

(radioactive

- too many protons)

Some important points about radionuclides

- While there are about 113 known chemical elements, there about 3,100 nuclides found in nature.

- About 25 nuclides have sufficiently long half-lives to half survived from the formation of the earth until now.

- Another 35 nuclides have shorter half-lives but are being continuously produced by the decay of parent nuclides.

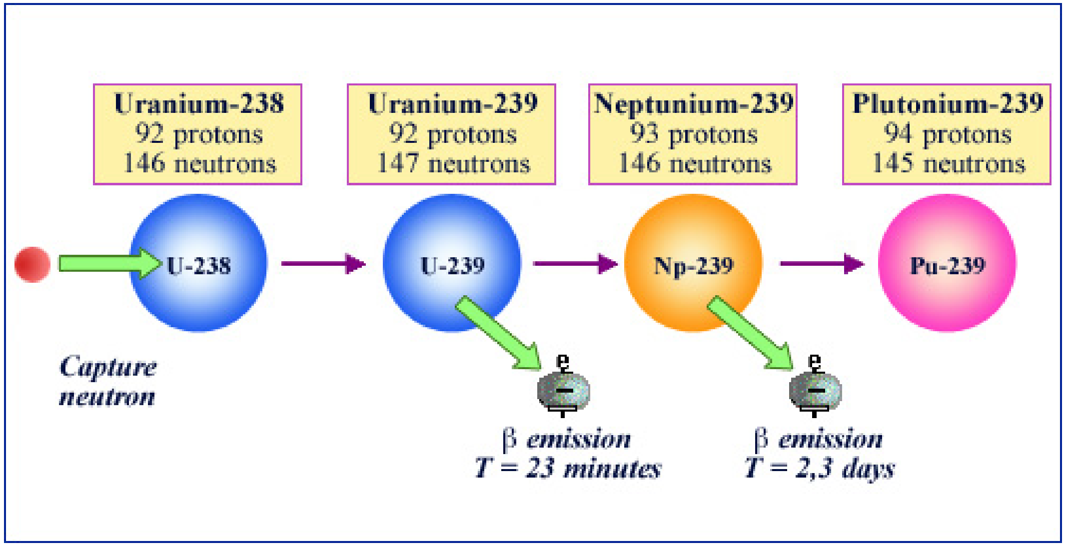
- About 1,000 artificially produced nuclides have been discovered.

Artificially produced nuclides with Z>92 (uranium) have been produced by bombarding lighter atoms with neutrons and/or alpha particles.

Those artificially produced elements heavier than U are called '**transuranics**.'

Radionuclides important points (con't.):

- Possibly the most important transuranic is ^{239}Pu which is produced by bombardment of ^{238}U with neutrons.



- Plutonium-239 can be induced to fission and thus constitutes the primary fuel for nuclear reactors as well as fission-type nuclear weapons.

- Human exposure to transuranics is generally related to activities of the nuclear weapons program. The importance of transuranics to doses received from nuclear power is usually minor.

There are 4 families of *naturally* occurring radionuclides.

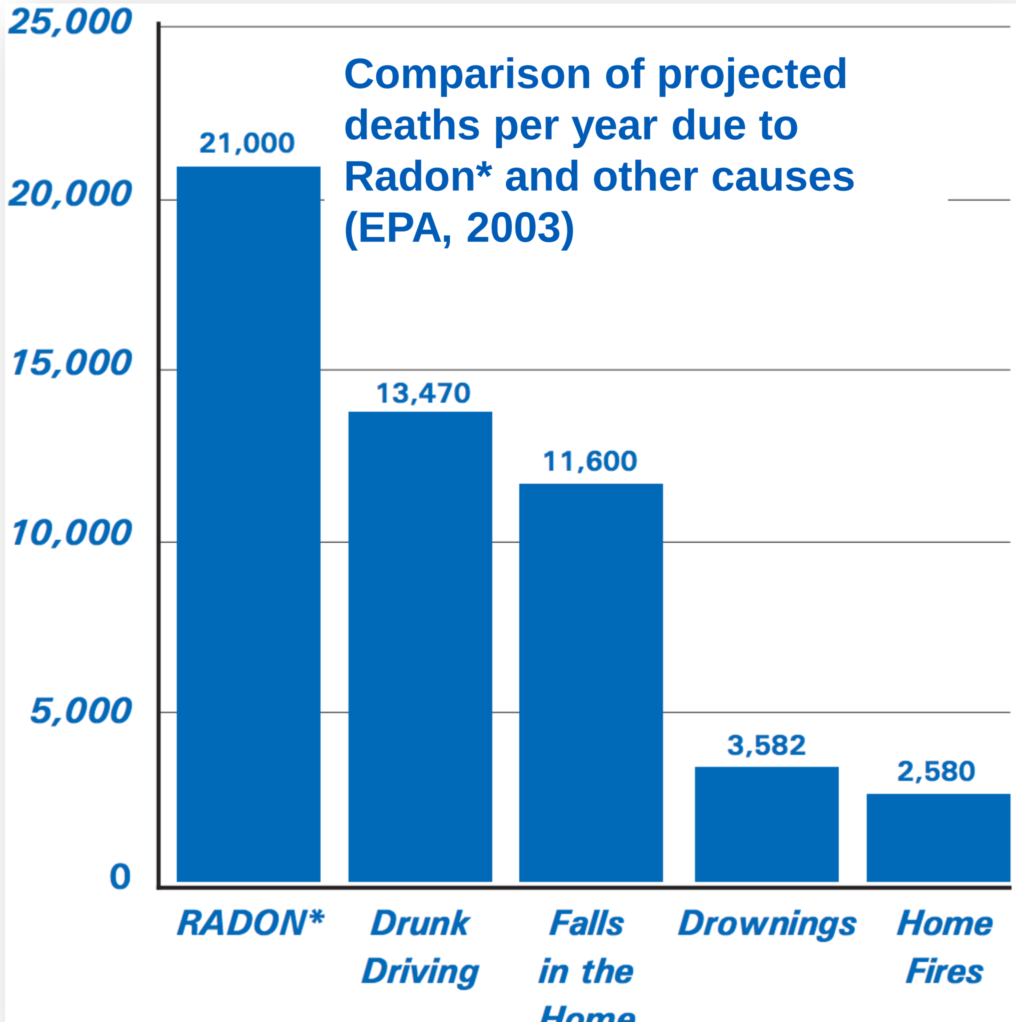
Eacl h
a nu

The r
mor d
beta

Two :
Urai

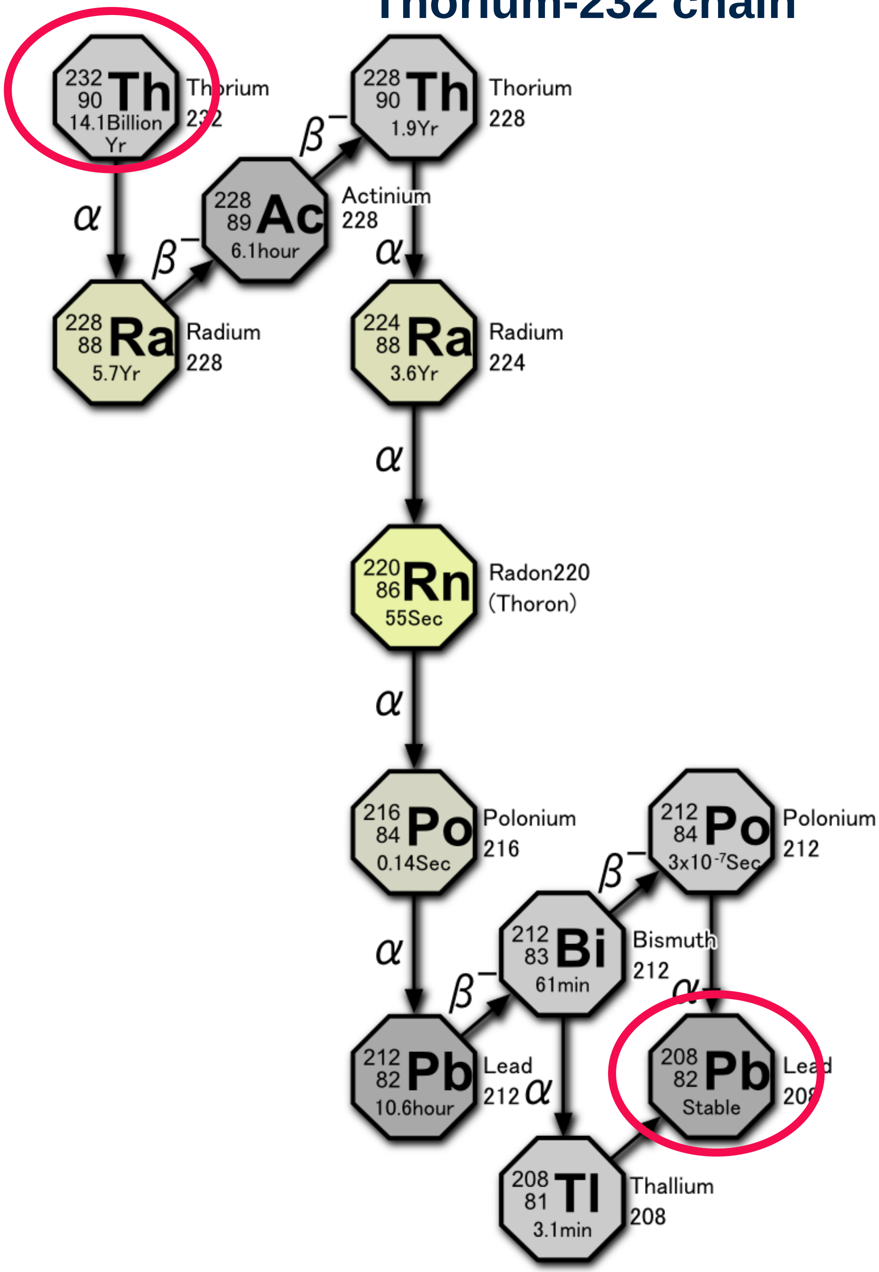
Tl
Tl e
n

The c
exp

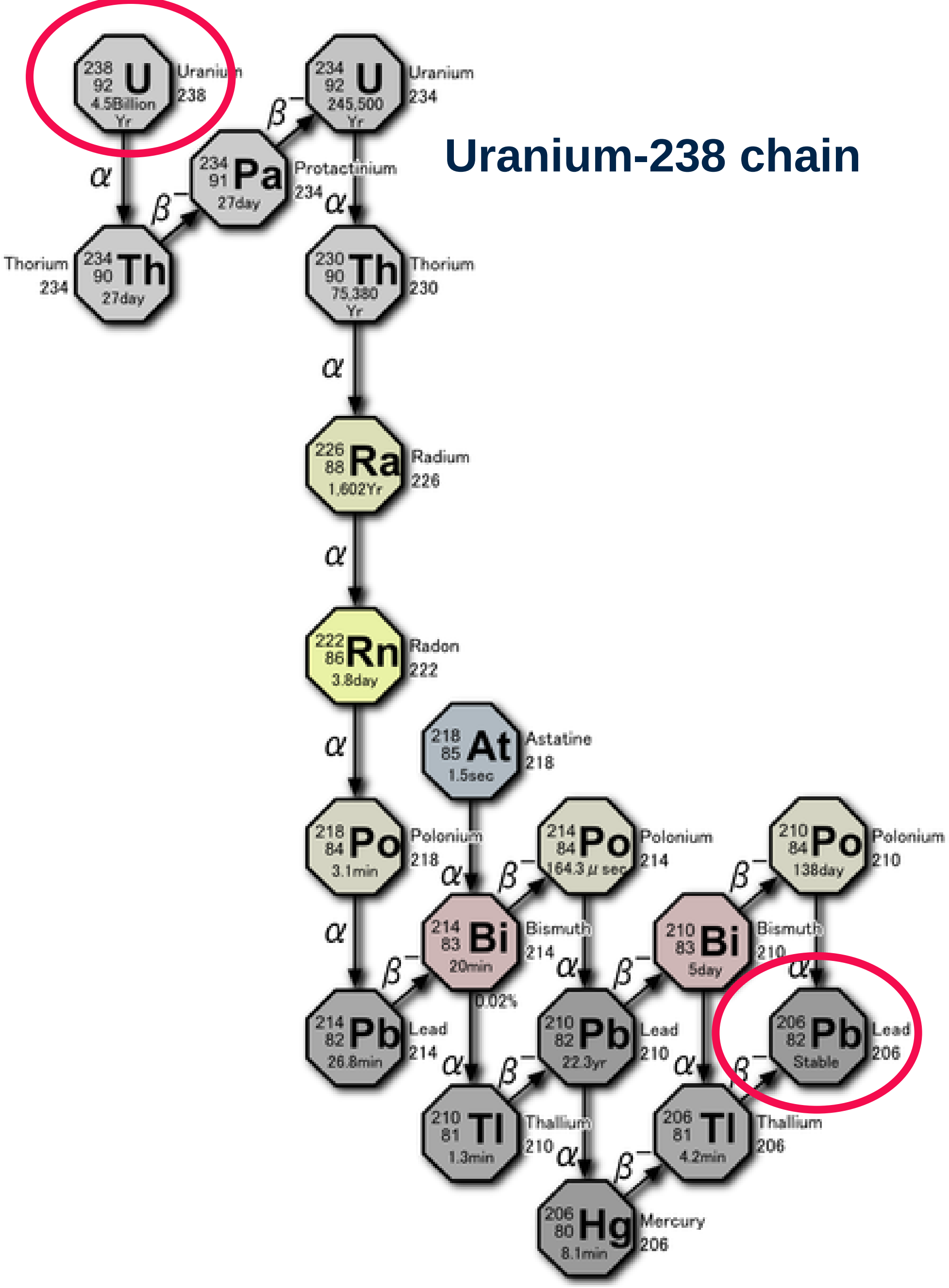


The 2 most important naturally-occurring radionuclide chains (families)…

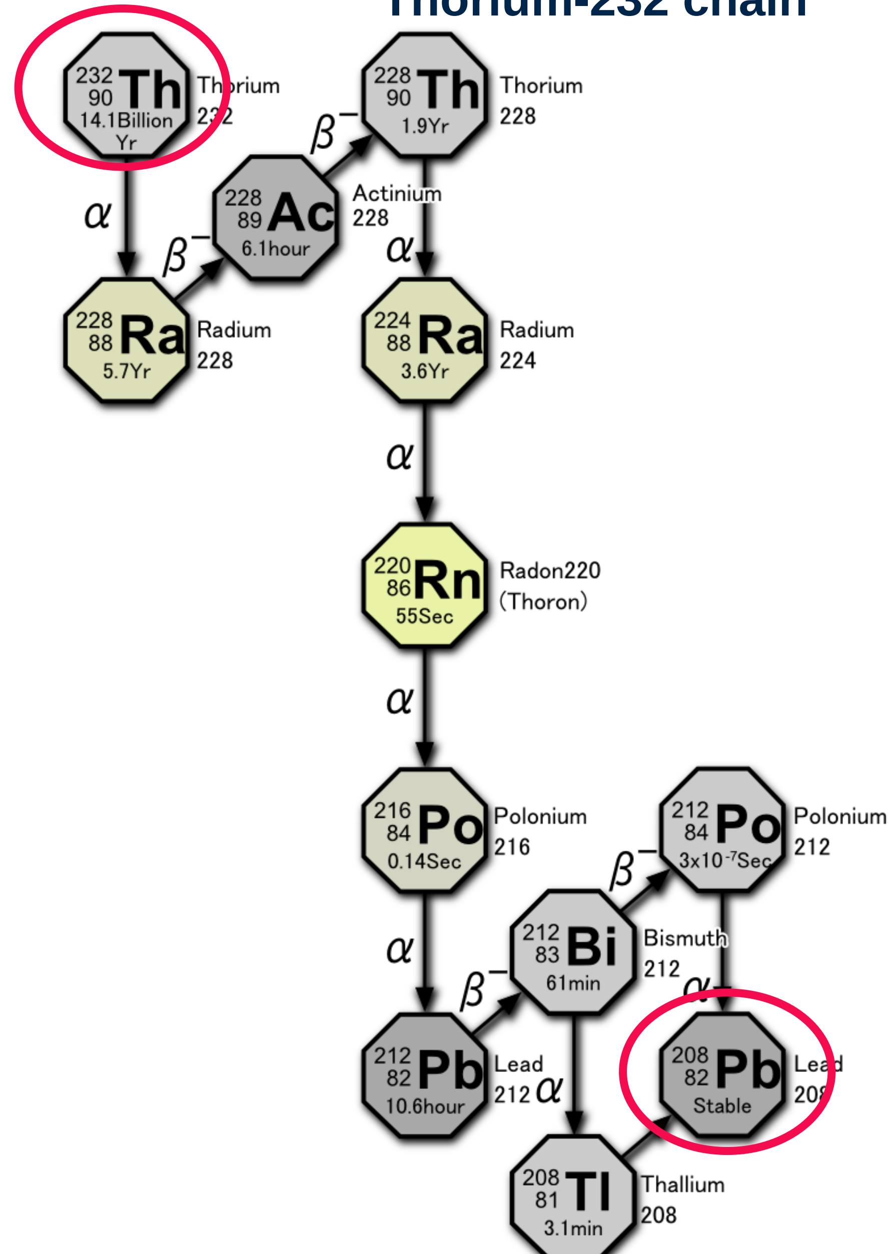
Thorium-232 chain



Uranium-238 chain

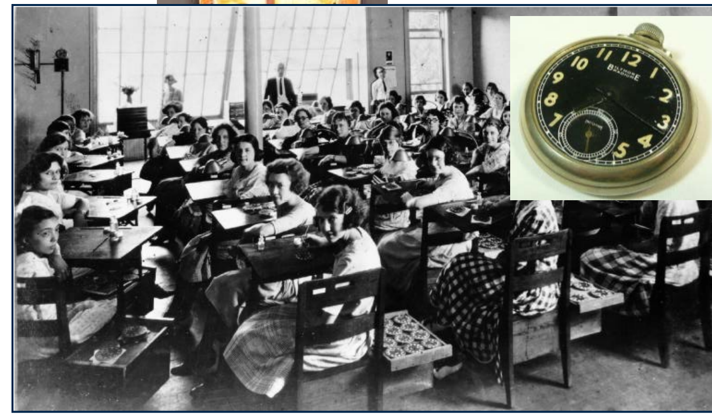


Thorium-232 chain



Some ways the U-238 chain impacts our lives

Mantles for gas lanterns



U238
4.5 × 10^9 Years
α
Th234
24.1 days
(UX1)
β
Pa234
1.18 min.
(UX2)
β
U234
2.5 × 10^5 Years
α
Th230
8.0 × 10^4 Years
α
Ra226
~1600 Years
α
Rn222
3.82 days
α
Po218
3.05 min
(RaA)
α
Pb214
26.8 min
(RaB)
β
Bi214
19.7 min
(RaC)
β
Po214
1.5 × 10^-4 sec (RaC')
α
Pb210
22 Years
(RaD)
β
Bi210
5.0 days
(RaE)
β
Po210
138 days
(RaF)
α
Pb206
Stable
(RaG)

Used to make luminous watches in early 1900s and the cause of bone cancers among radium dial painters

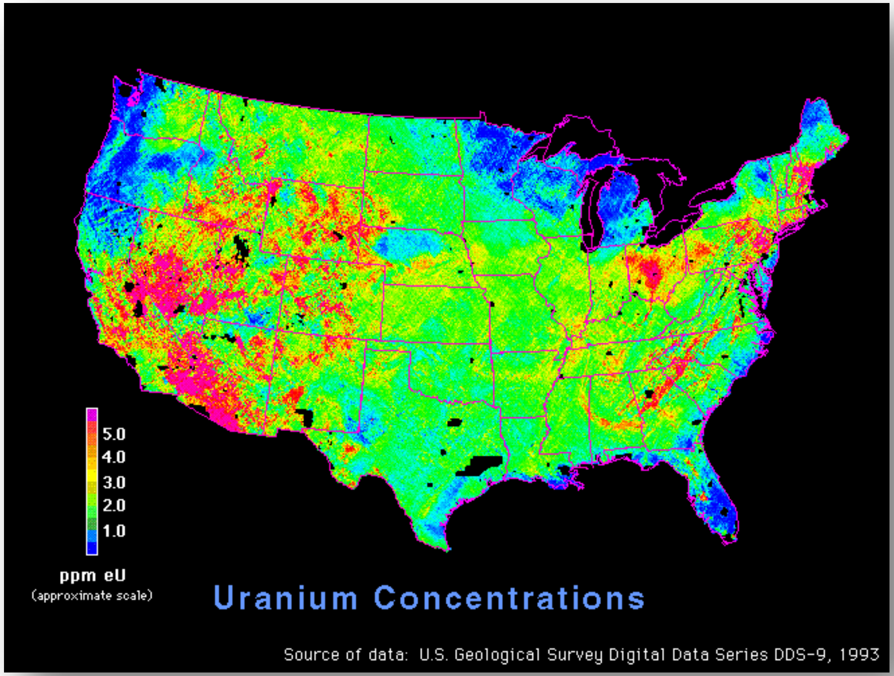
Used to make depleted uranium bullets (anti-tank weapons) and to make Pu-239 for nuclear reactors

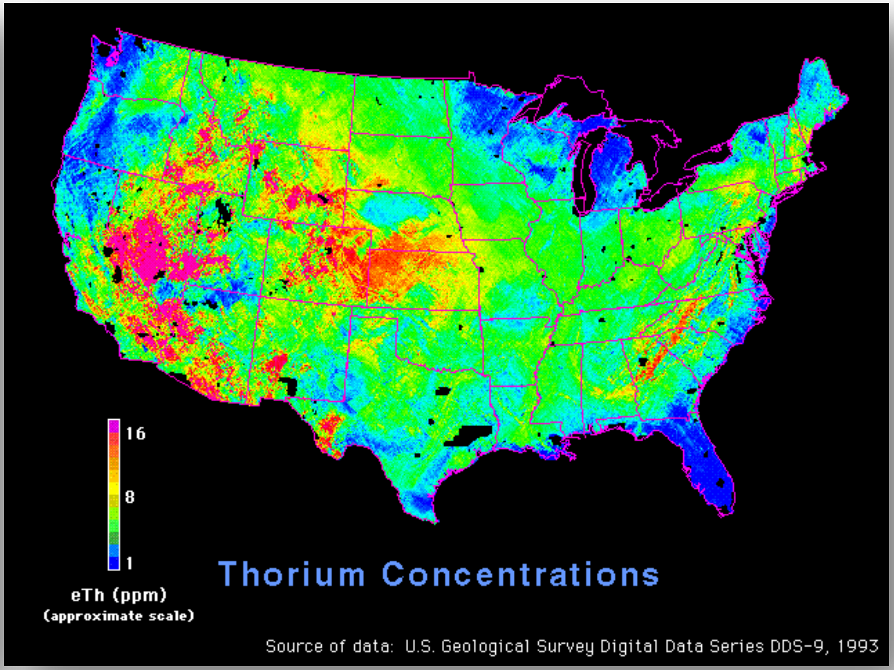
Radon (lung cancers among Uranium miners attributed to exposure to Rn-222 and its decay products)

^{210}Po- the "spy killer"

Metallic lead, heaviest natural nuclide, used make radiation shields

Distribution of natural radionuclides in the continental U.S.





Source: USGS

"**Activity**" is simply a measure of the **rate of decay** (i.e., rate of spontaneous disintegration) of the atoms of a nuclide.

The unit of radioactivity historically was the **Curie** and was defined to be equal to the disintegration rate of 1 gm of ^{226}Ra, or 3.7×10^{10} disintegrations per second (d/s).

All nuclides use the definition of 3.7×10^{10} d/s to define 1 Curie (Ci).

You can have subunits of:

- milliCi (mCi, 10^{-3} Ci),
- microCi (μCi, 10^{-6} Ci)
- nanoCi (nCi, 10^{-9} Ci)
- picoCi (pCi, 10^{-12} Ci)

The units of radioactivity in the international system of units is the **Becquerel (Bq) which is simply equal to 1 d/s**. Hence, 1 Bq ≈ 27 pCi.

The Bq is much simpler to understand and to use. The U.S. should adopt it!

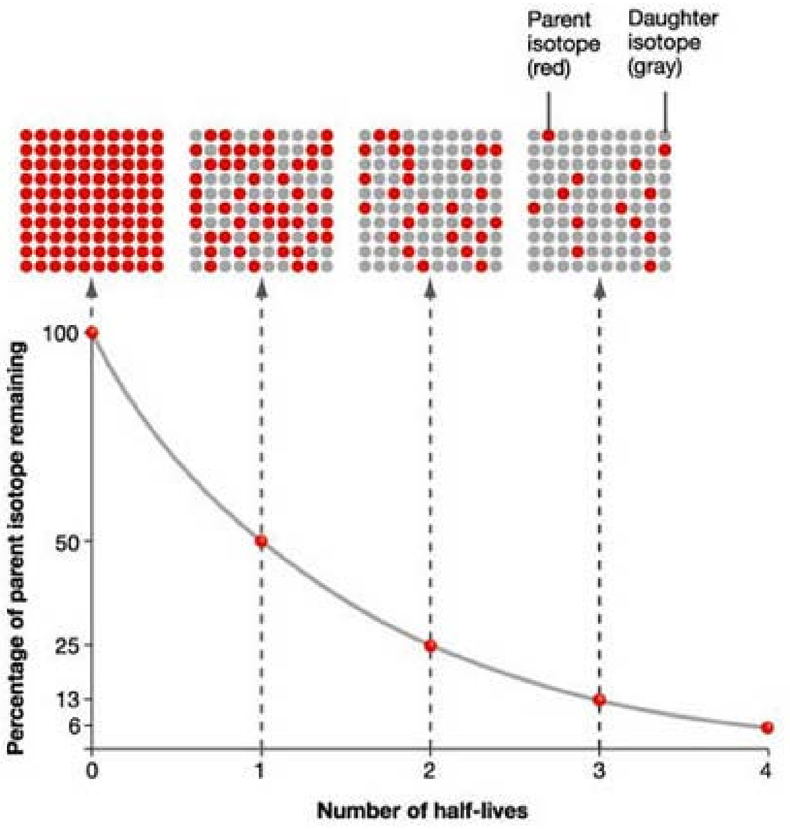
Half-Life

Half-life is the length of time for **half of the atoms** of a given nuclide to decay.

The half-life is a unique characteristic of each nuclide.

Half-lives range from millionths of a second to millions of years.

The half-life also determines the rate at which the nuclide releases energy.



Half-Life

(example of isotopes of iodine)

Isotope	Half Life
I-122	3.6 minutes
I-123	13.2 hours
I-124	4.2 days
I-125	60.1 days
I-126	13.0 days
I-127	Stable
I-128	25.0 minutes
I-129	1.57E7 years
I-130	12.4 hours
I-131	8.0 days
I-132	2.3 hours
I-133	20.8 hours
I-134	52.6 minutes
I-135	6.6 hours
I-136	1.4 minutes

Radionuclides are uniquely distinguished by:

Half-life

Type of radiations emitted

Energy of emitted radiations

The number of atoms of the nuclide determines the “activity” at any moment.

The “radiation dose rate” that a specific nuclide source can deliver is determined, in part, by all of these factors.

The decay schemes of some radionuclides can be very complex. For example, the well-known **Iodine-131 has a complex emission spectrum.**

Beta Decays of ^{131}I (8.02 d)

E_β endpoint (keV)	I_β (%)	Decay mode
247.89	2.10	β^-
303.86	0.651	β^-
333.81	7.27	β^-
606.31	89.9	β^-
629.66	0.050	β^-
806.87	0.48	β^-

X-rays from ^{131}I (8.02 d)

E (keV)	I (%)	Assignment
4.11	0.215	Xe $L_{\alpha1}$
4.41	0.133	Xe $L_{\beta1}$
29.46	1.40	Xe $K_{\alpha2}$
29.78	2.59	Xe $K_{\alpha1}$
33.56	0.24	Xe $K_{\beta3}$
33.62	0.46	Xe $K_{\beta1}$
34.42	0.14	Xe $K_{\beta2}$

Gammas from ^{131}I (8.02)

$E\gamma$ (keV)	$I\gamma$ (%)	Decay mode
80.185	2.62	β^-
85.9	0.00009	β^-
163.93		β^-
177.21	0.270	β^-
232.18	0.0032	β^-
272.50	0.0578	β^-
284.31	6.14	β^-
295.8 *2*	0.0018	β^-
302.4 *2*	0.0047	β^-
318.09	0.0776	β^-
324.65	0.0212	β^-
325.79	0.274	β^-
358.4 *2*	0.016	β^-
364.49	81.7	β^-
404.81	0.0547	β^-
503.00	0.360	β^-
636.99	7.17	β^-
642.72	0.217	β^-
722.91	1.773	β^-

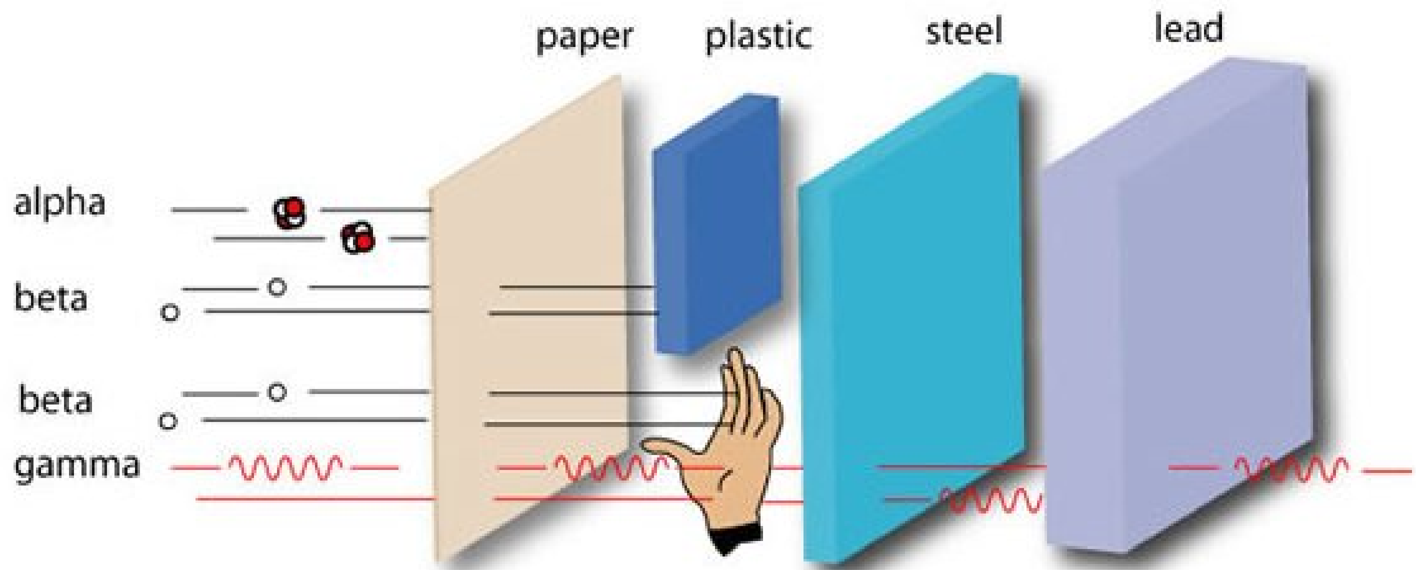
Part II.
INTERACTIONS OF RADIATION AND MATTER

To understand radiation dose (i.e., the energy absorbed by tissue), one needs to understand the processes by which radiation interacts with tissue - as it those interactions that result in the **transfer of energy to the tissue**.

Now…a discussion of the interactions of ionizing radiation with matter

Understanding how radiation interaction with matter leads to an understanding of why different types of radiation have greater penetrating power and how to protect against each type of radiation.

Penetrating power: Gamma rays > β particles > α particles



Interaction of Radiation with Matter: Photon (x and g ray) radiation

- Photon beams interact with the matter through which they pass and consequently, the beam intensity is attenuated.

- These interactions attenuate the beam as well as deliver energy to the matter through which the particles pass. It is that energy that is the concern of dosimetry.

- There are 3 types of interactions for photons that are of primary importance in radiation dosimetry:

  Photoelectric absorption,

  Incoherent (Compton) scattering,

  Pair production.

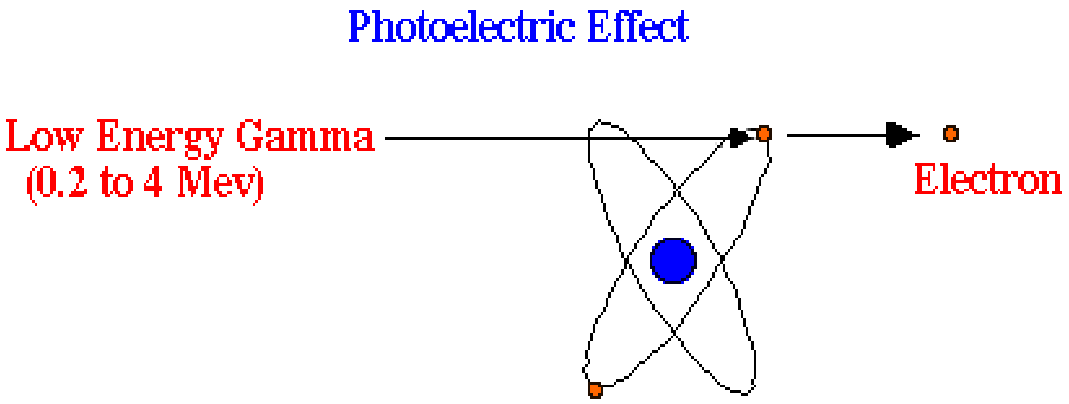
- The likelihood of each of these phenomenon taking place is dependent on a number of factors, in particular, the energy of the incident photons and the Z (# protons in nucleus) of the irradiated material.

Photon Interactions: Photoelectric Effect

This process completely removes the incident photon.

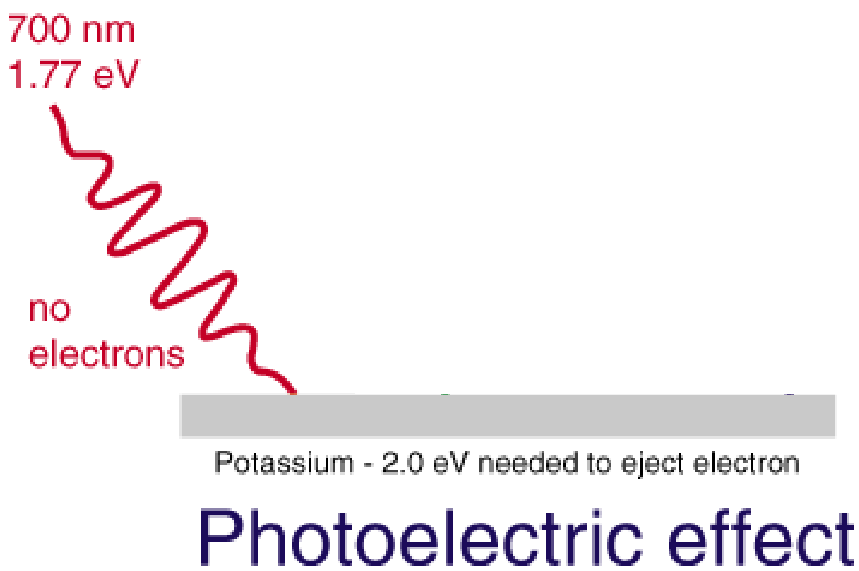
The photon is absorbed by an atom, and an electron is ejected with kinetic energy (KE) from the atom:

$KE = E_i - BI$ (E_i is the incident photon energy, BE is the binding energy of the atomic shell from which the electron is ejected)



The probability for interaction of this type is proportional to Z^4/E_i^3.

Energy is inversely proportional to wavelength (shorter wavelengths have more energy.



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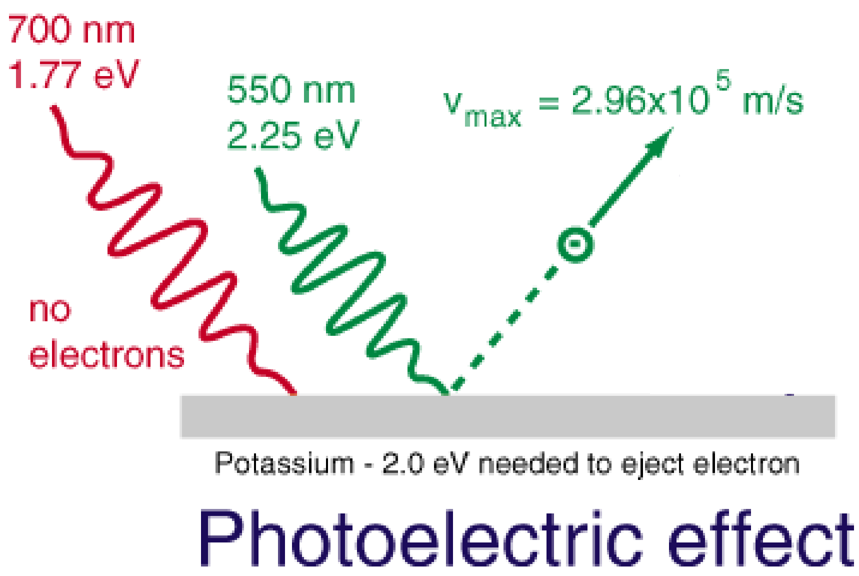

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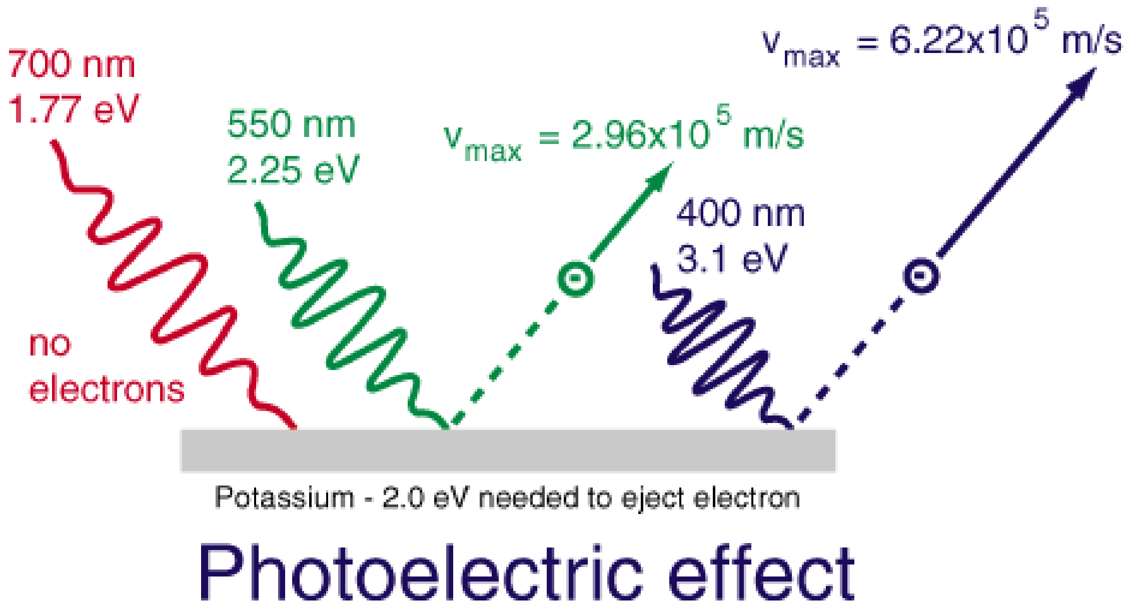
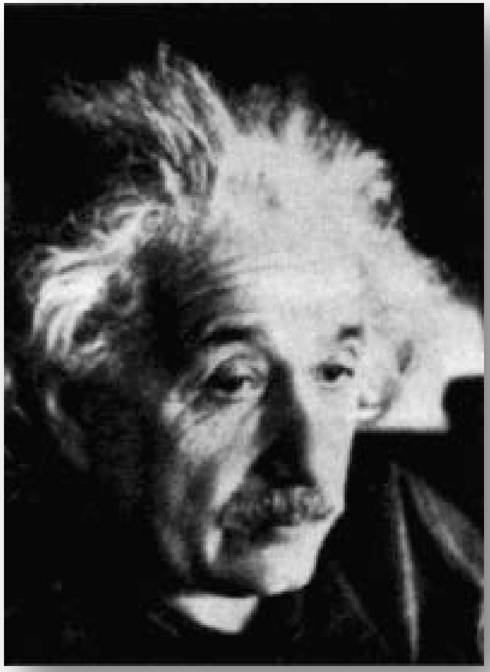


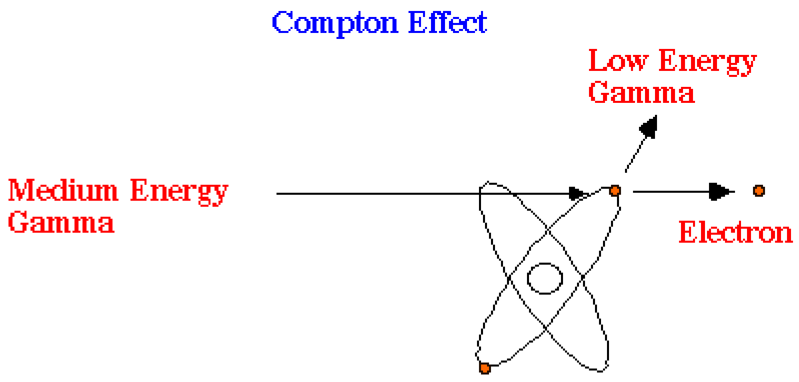


The photoelectric effect was such an important discovery, that Albert Einstein was awarded the Nobel Prize in 1921 for his 1905 discovery.

Photon Interactions: Compton Scattering (Effect)

Named for nuclear physicist Arthur Compton, this process describes the scattering between an incident photon and an atomic electron.

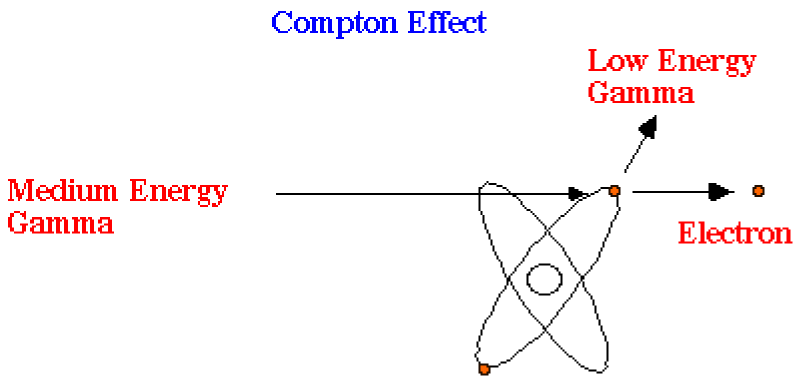
The incident photon is not completely absorbed but rather scattered out of the incident beam with a reduced energy (or conversely, with an increased wavelength). **An electron is also ejected.**



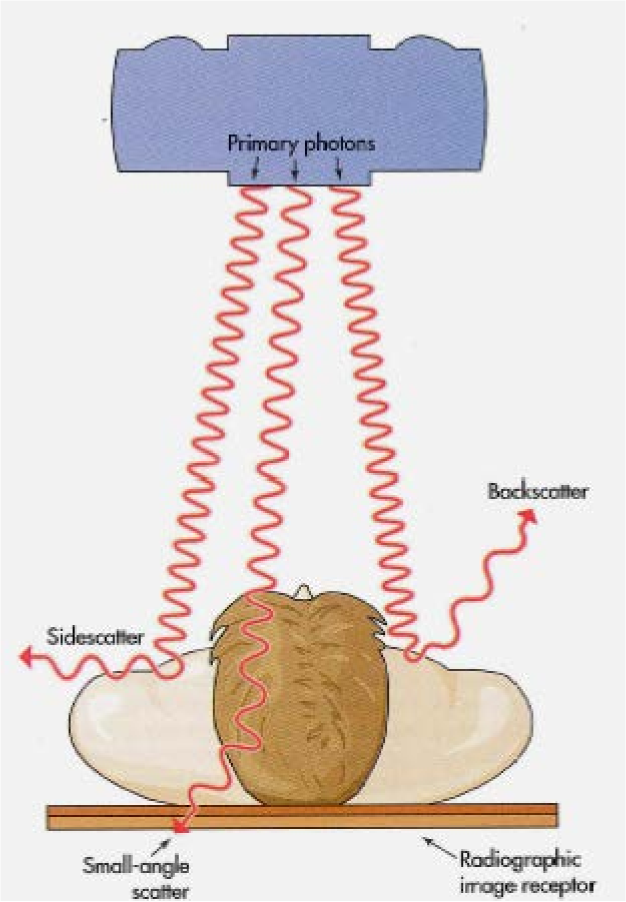
Multiple interactions (scattering events) are likely for the same incident photon.

The Compton cross-section increases rapidly with increasing Z, and decreases with increasing energy, approximately as $1/E_i^2$.

SIDEBAR on Compton Scattering



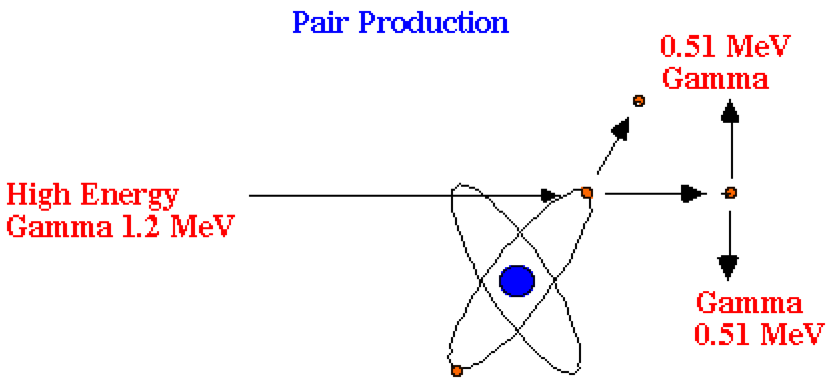
Compton scatter has important consequences, e.g., scatter of x-rays from a patient - which exposes medical personnel.



<u>Photon Interactions</u>: Pair Production

The incident photon disappears and an electron and positron (positive electron) pair are created with a total energy equal to the energy of the incident photon.

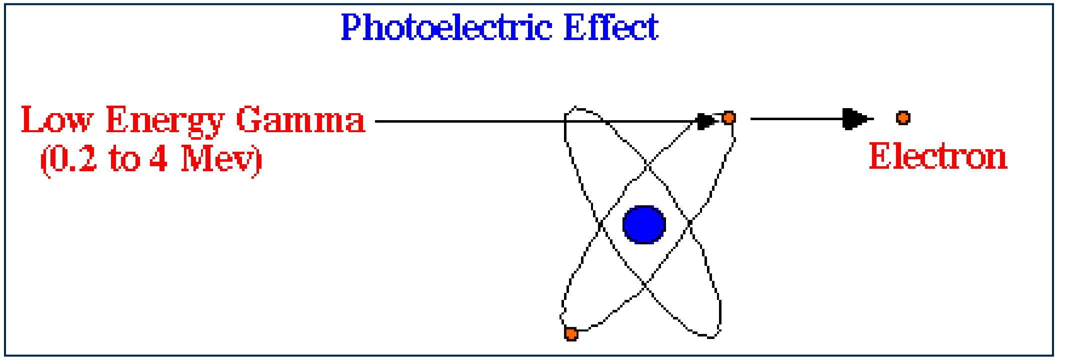
Pair production can only take place when the incident photon energy exceeds the energy equivalent of the rest mass of the electron/positron pair, i.e., E_i must > $2m_oc^2$ or 1.02 MeV.



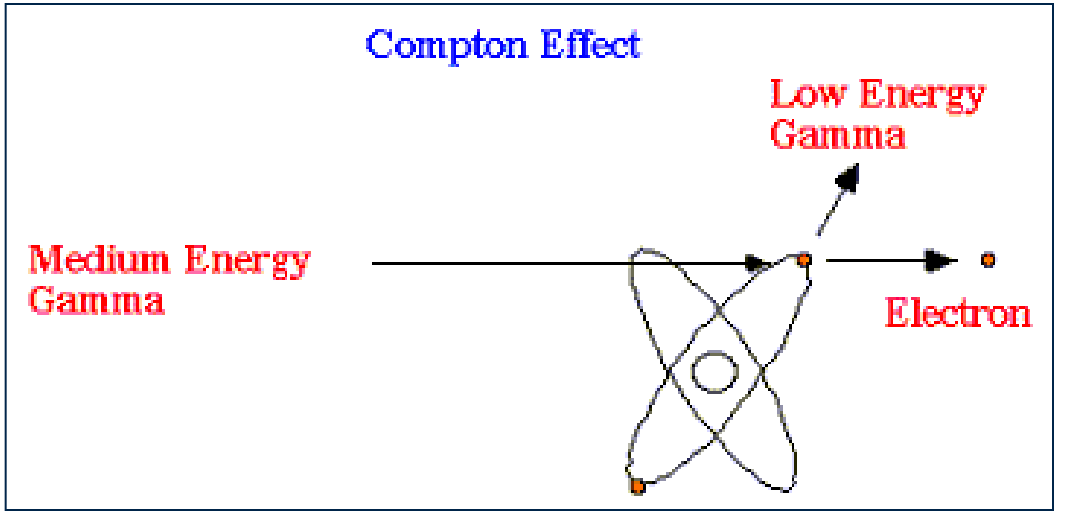
The cross-section increases ~Z^2 and ~ln(E_i).

SUMMARY OF PHOTON INTERACTIONS

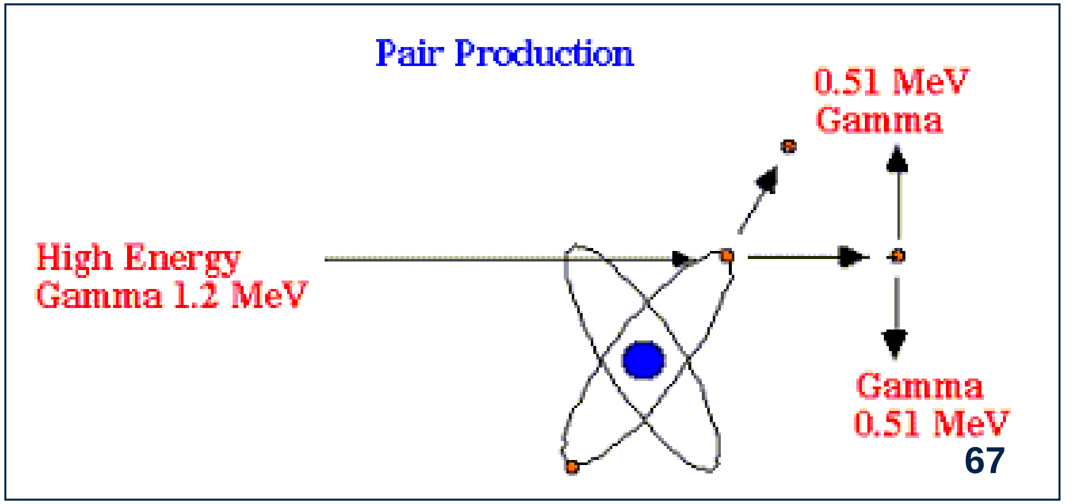
Interaction at low photon energies



Interaction at intermediate photon energies



Interaction at high photon energies



The single common outcome of the photon interactions in materials is the release of <u>electrons</u>!

What happens to those <u>electrons</u>?

WHAT HAPPENS TO THOSE PARTICLES IS TERMED PARTICLE INTERACTIONS

- Particles, unlike photons, have mass, and some have charge.
- Hence, the processes that govern what happens to particles differ from those than govern what happens to photons
- **Understanding particle interactions in matter (e.g., tissue) is the last major requirement to understanding the phenomenon that contribute to radiation dose.**

Electrons are charged and cause atomic ionization or excitation as they move through matter as a result of Coloumb (electric) forces.

Opposite charges attract.

+ -

Like charges repel.

+ +

Electrons are charged and cause atomic ionization or excitation as they move through matter as a result of Coulomb (electric) forces.

Opposite charges attract.

+ -

Like charges repel.

- -

Remember that electrons are released by all photon interactions and from β decay and will be moving in the tissue with some kinetic energy.

Coulomb interactions with neighboring atoms will gradually slow them down.

Rate of energy loss with distance is proportional to '*e*' (electron charge), and electron density of the material.

Electrons cause ionization and excitation and as they lose their energy in the material, energy is imparted to the material through which they pass, and the "dose" is delivered !!

Electrons not only cause ionization in the material…but also re-radiate some energy through ***brehmsstrahlung***

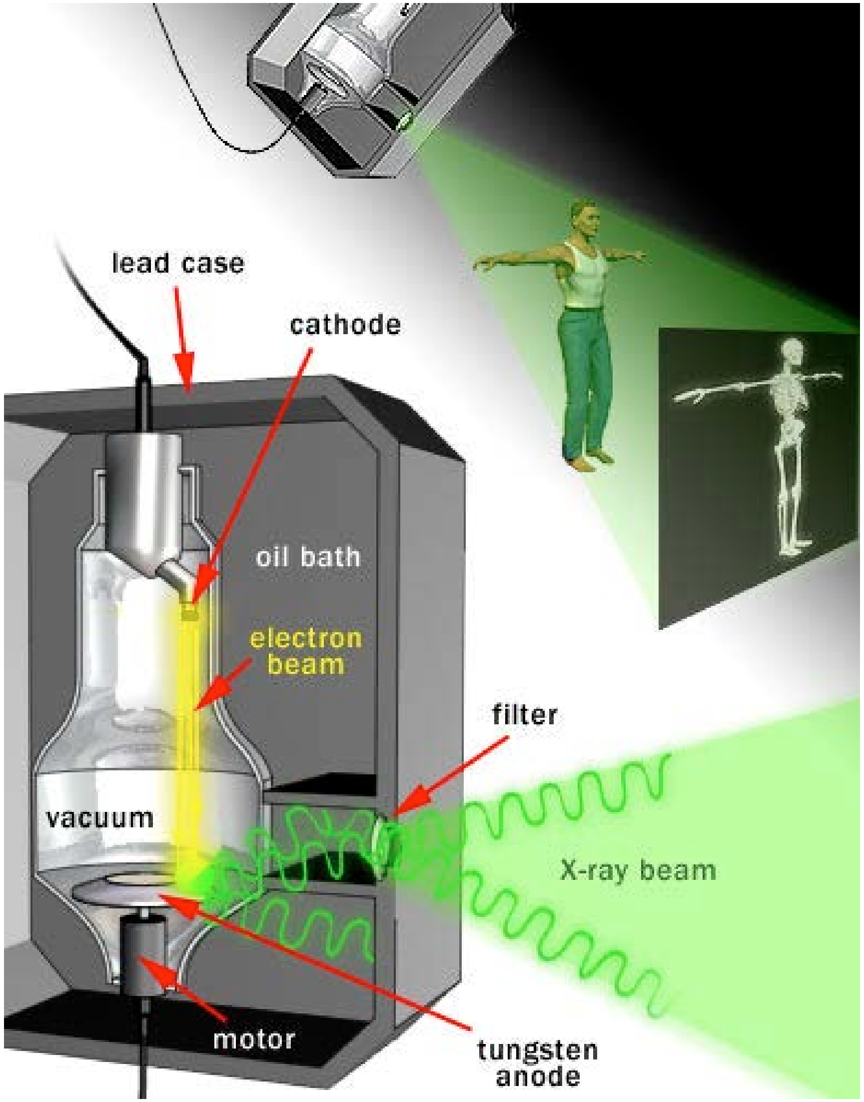
Brehmsstrahlung? What's that?

Charged particles (e.g. electrons) when (de)accelerated in the electric field of the nucleus or of the orbital electrons, will radiate energy, known as "braking" or "**brehmsstrahlung**" radiation.

The radiation loss is proportional to the kinetic energy (KE) of the incident electron and Z of the material.

Sidebar on the use of Brehmsstrahlung radiation

Sidebar on how medical x-rays are produced.



Brehmsstrahlung is the mechanism used to generate x-rays for medical use.

Electrons are emitted by a hot filament and drawn to metal target of opposite charge.

When the electrons interact or "brake" inside the target, x-rays are emitted.

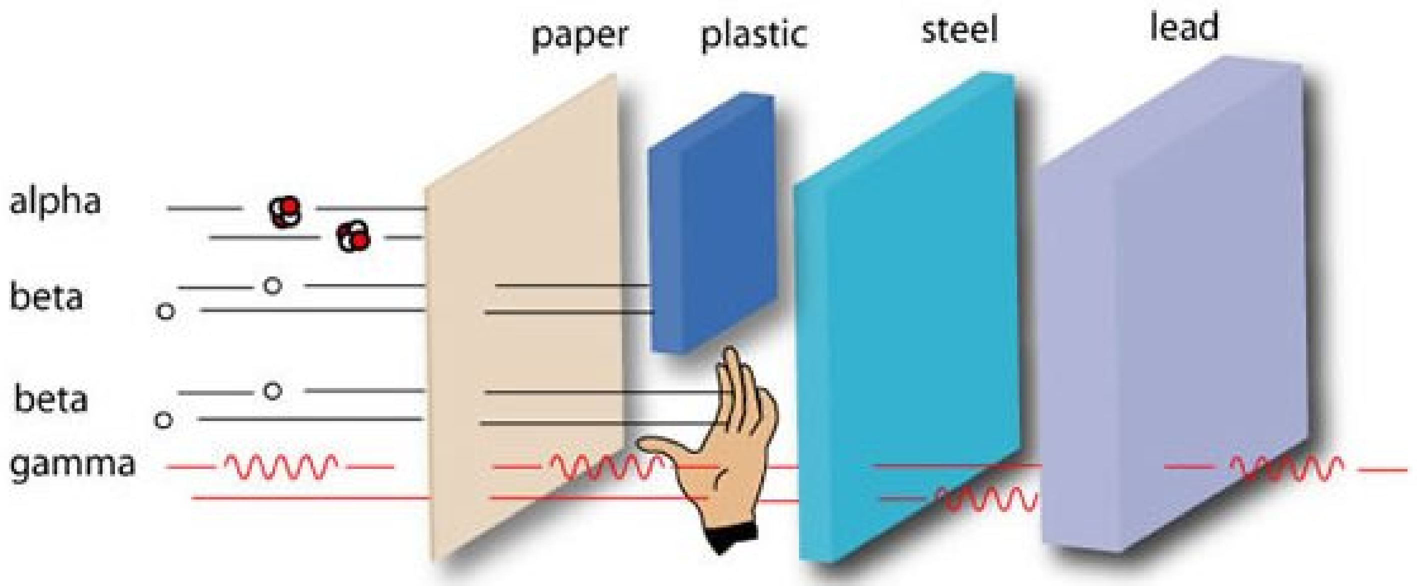
http://science.howstuffworks.com/x-ray2.htm

Coulomb forces account for different penetration power of alpha and beta particles.

Alpha particles are relatively heavy (~7300x that of electron) and have 2 units of charge, thus, they have much shorter range…because each Coloumb interaction is 2x greater than for electrons.

Typical range of alpha particles in tissue is 40 um. This explains why alpha particles are normally only a hazard as an "internal emitter."

Beta particles (electrons) have intermediate range, depending on energy.



Comparing Interactions of Photons and Other Charged Particles

From what you've learned so far: *Why can bones be distinguished from soft tissue in an x-ray image?*


Time for a Break!!

Questions and Answers

U.S. Department of Health and Human Services
National Institutes of Health | National Cancer Institute
www.dceg.cancer.gov/RadEpiCourse
1-800-4-CANCER
Produced May 2015