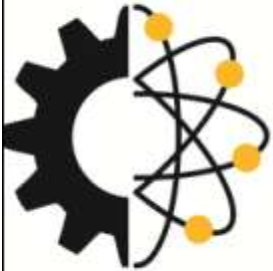




V i r g i n i a C o m m o n w e a l t h U n i v e r s i t y



Department of Mechanical  
& Nuclear Engineering

# **Fundamentals of Nuclear Power**

Osher Lifelong Learning Institute  
Spring 2012

# Course Description

- This course will provide an overview of nuclear science and technology and its application to the production of electricity.
- The course will explain how a nuclear reactor works and will describe the various types of nuclear reactor technologies currently available or under development.
- The course will also cover the entire nuclear fuel cycle including uranium mining, enrichment and fuel fabrication, as well as reprocessing and used nuclear fuel management and disposal.
- In addition, the course will explore the complex socio-political issues that are often intertwined in any discussion about a sustainable long-term environmental and energy policy that includes nuclear power.

# Nuclear Engineering Faculty

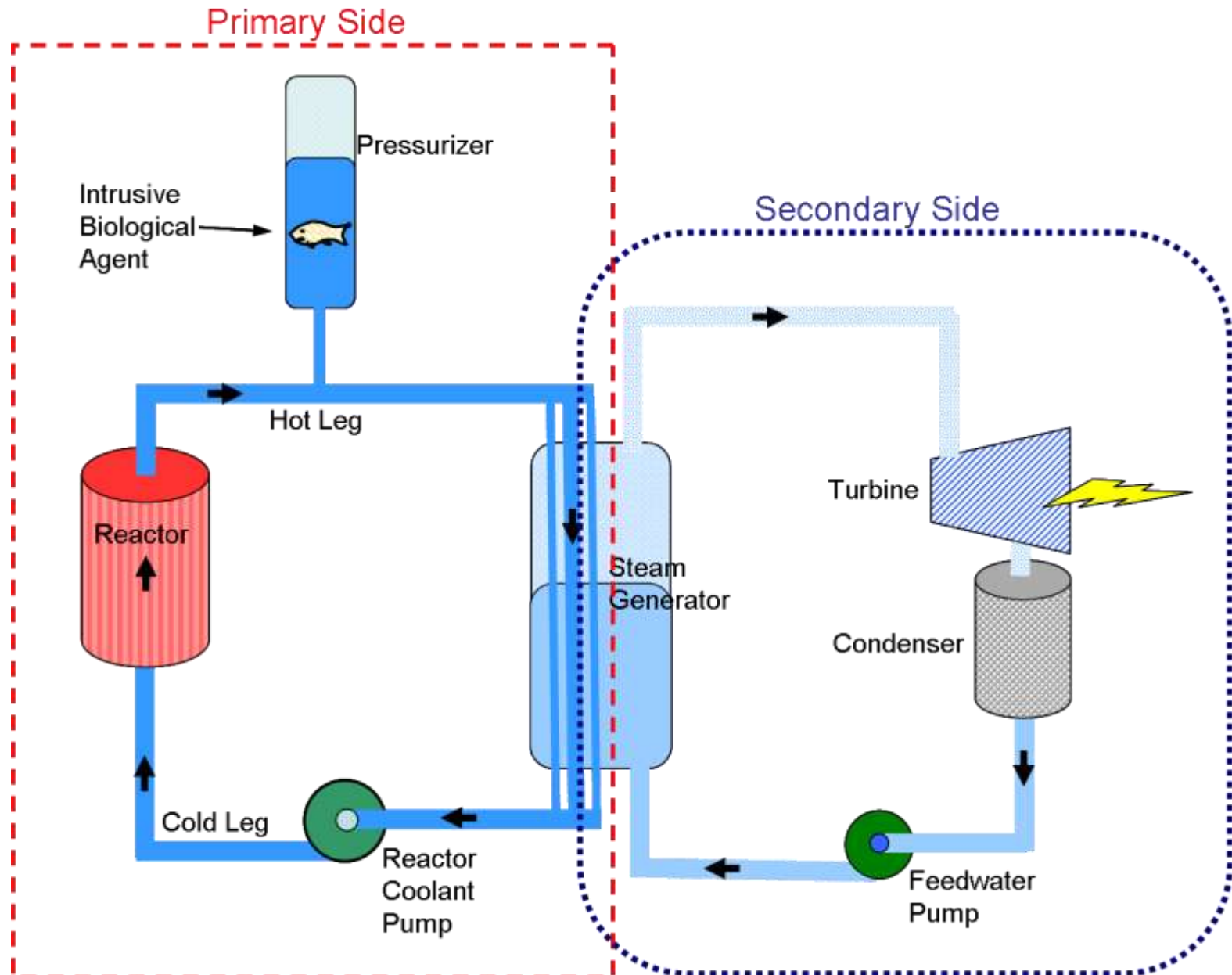
- **Dr. Sama Bilbao y Leon (Director of Nuclear Engineering)**
  - PhD, Nuclear Engineering, University of Wisconsin, Madison
- **Dr. Ross Anderson**
  - PhD, Nuclear Engineering, University of Virginia
- **Dr. Brian Hinderliter**
  - PhD, Engineering Physics, University of Virginia
- **Dr. Gokul Vasudevamurthy**
  - PhD, Nuclear Engineering, University of South Carolina, Columbia
- **Mr. Jim Miller**
  - MS, Nuclear Engineering, Penn State

# Proposed Program

SESSION	TOPIC	INSTRUCTOR
# 1 March 21	Basic concepts in nuclear physics, types of radiation, radioactive decay, etc	James Miller
#2 March 28	Radiation health effects	Brian Hinderliter
#3 April 4	Nuclear power plant design, types of nuclear power plants, nuclear safety	Gokul Vasudevamurthy
#4 April 11	Current status of nuclear power in the world, advanced reactors, SMRs, nuclear power construction projects	Sama Bilbao y León
#5 April 18	The nuclear fuel cycle	James Miller
#6 April 25	Survey of large nuclear power accidents: Three Mile Island, Chernobyl and Fukushima Daiichi	Josh Bell  Sama Bilbao y León
#7 May 2	Sociopolitics and nuclear power: used nuclear fuel management, Yucca Mountain, uranium mining	Invited Speakers
#8 May 8	Choice Topic:  <ul style="list-style-type: none"> <li>•Nuclear medicine and other applications of nuclear science and technology</li> <li>•The future of nuclear power: fast breeder reactors, fusion technology, nuclear power and other power sources.</li> <li>•History of the US Nuclear Navy</li> </ul>	TBD

Thanks to Keith Welch of Jefferson Lab for selected slides.

# Nuclear Reactor

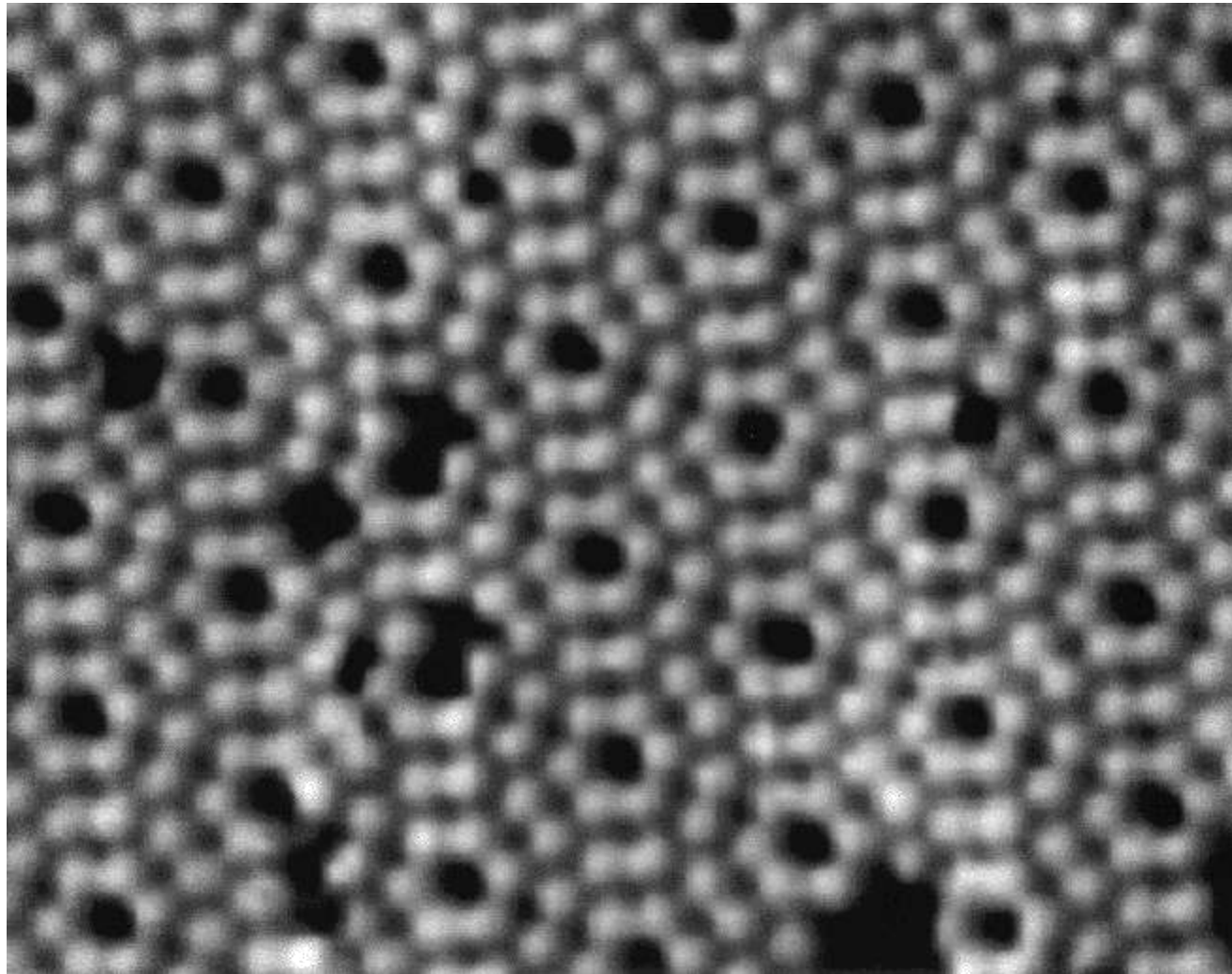


# Atomic Hypothesis

If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the *atomic hypothesis* ... that *all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.*


-- Richard P. Feynman





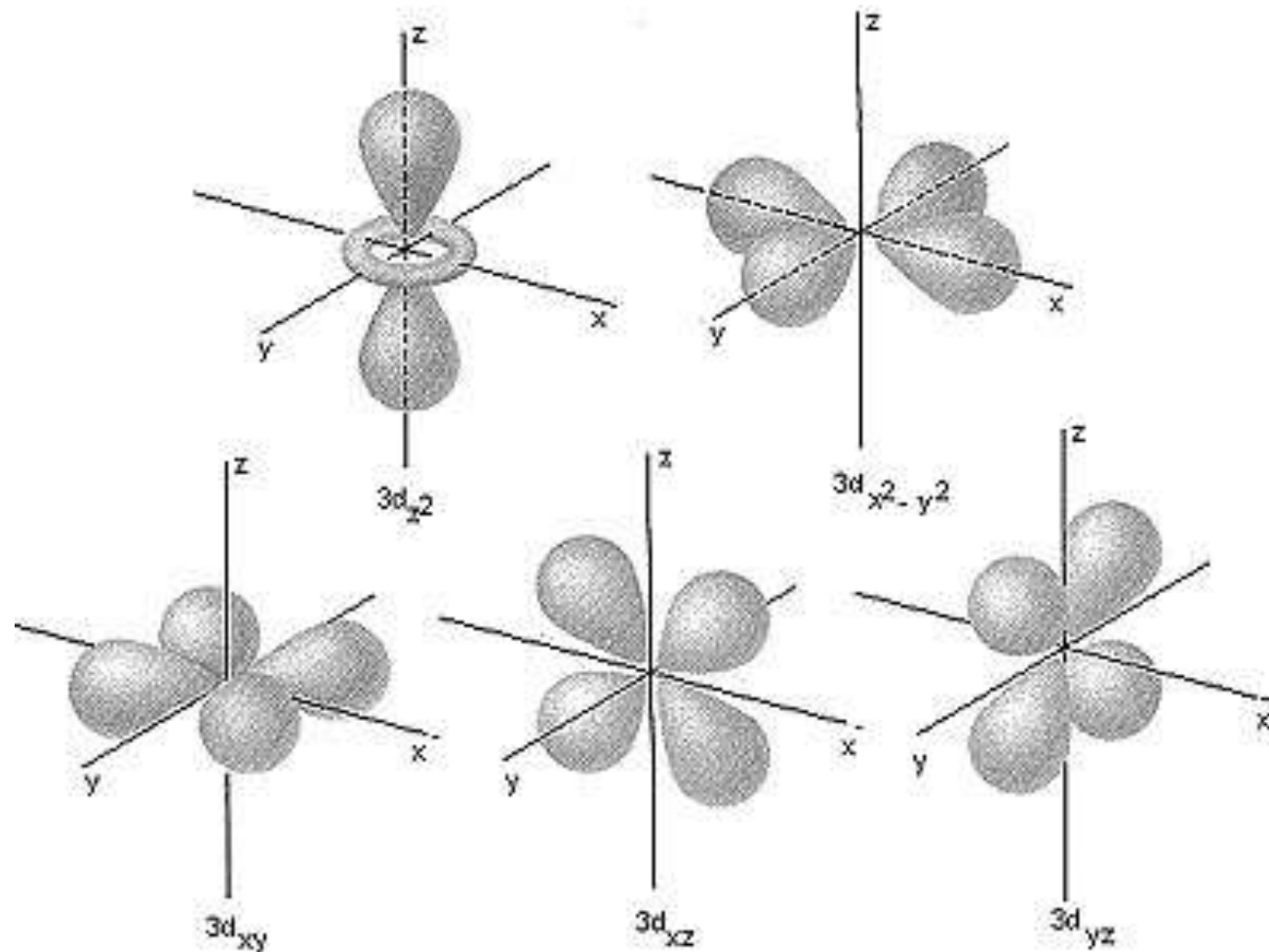


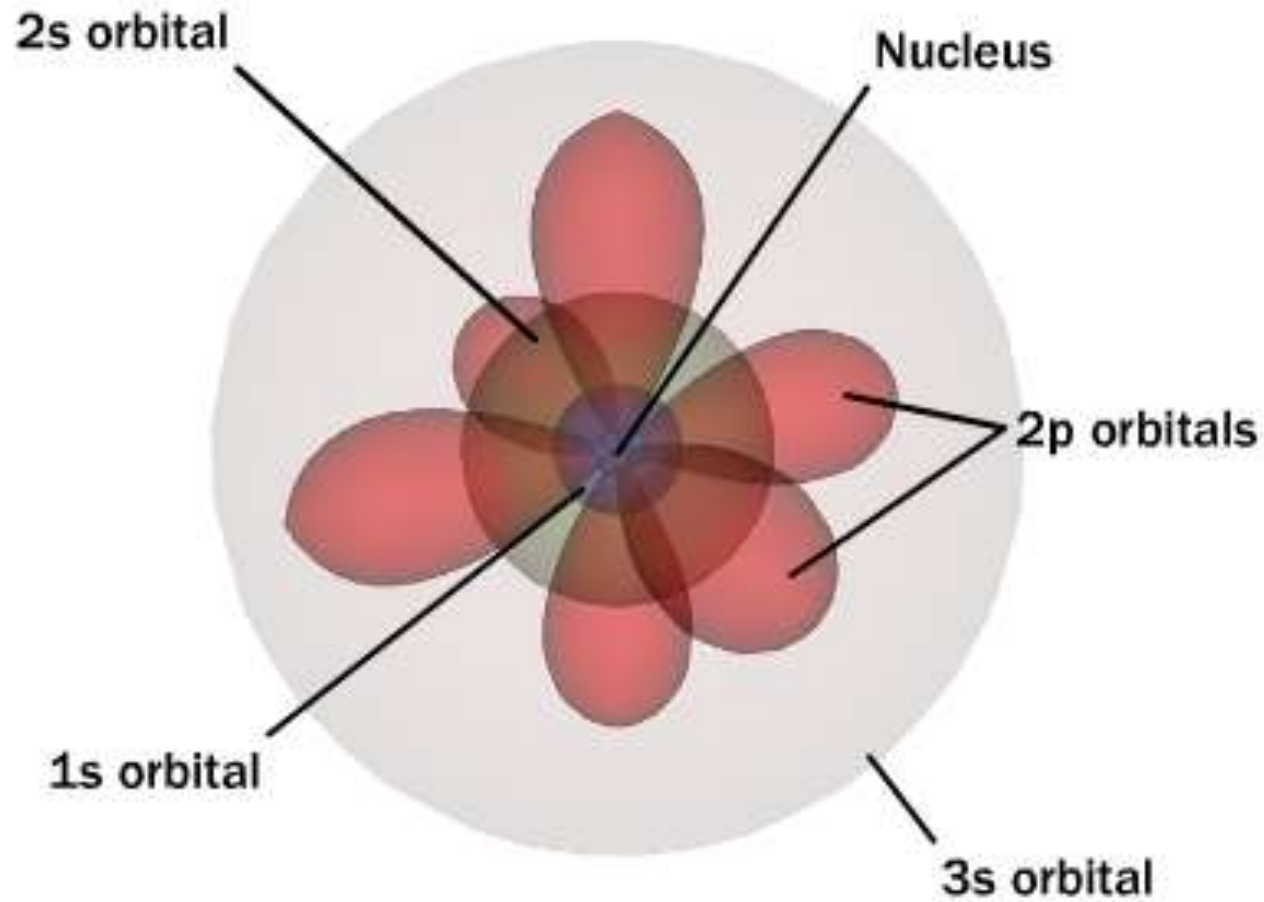
# Elementary Particles

proton – positively charge nucleon 

neutron – neutral nucleon 

electron – negatively charged 





©2001 How Stuff Works

**Chart Key:**

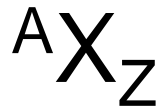
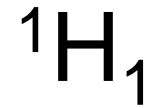
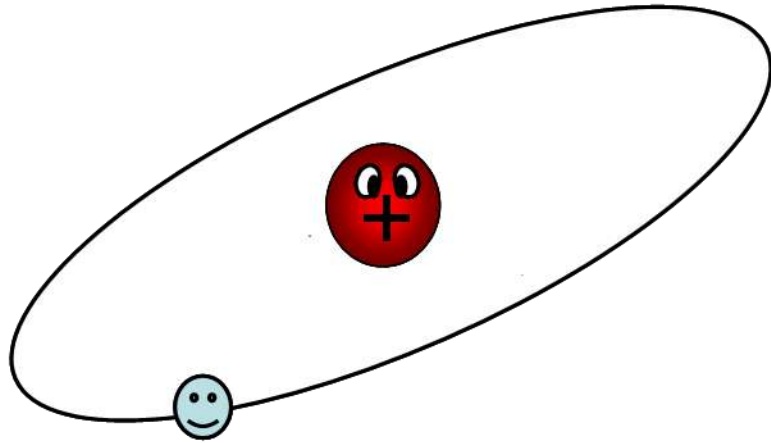
element name
atomic number
<b>symbol</b>
atomic weight

■ Alkali Metals  
■ Alkaline Earth Metals  
■ Transition Metals  
■ Other Metals  
■ Non-metals  
■ Noble Gases  
■ Lanthanoids  
■ Actinoids

		solid				liquid				gas				synth			
		C				Br				He				Tc			
hydrogen 1 <b>H</b> 1.00794	helium 2 <b>He</b> 4.002602																
lithium 3 <b>Li</b> 6.941	beryllium 4 <b>Be</b> 9.012182																
sodium 11 <b>Na</b> 22.98977	magnesium 12 <b>Mg</b> 24.3050																
potassium 19 <b>K</b> 39.0983	calcium 20 <b>Ca</b> 40.078	scandium 21 <b>Sc</b> 44.95591	titanium 22 <b>Ti</b> 47.867	vanadium 23 <b>V</b> 50.9415	chromium 24 <b>Cr</b> 51.9961	manganese 25 <b>Mn</b> 54.93805	iron 26 <b>Fe</b> 55.845	cobalt 27 <b>Co</b> 58.9332	nickel 28 <b>Ni</b> 58.6934	copper 29 <b>Cu</b> 63.546	zinc 30 <b>Zn</b> 65.409	gallium 31 <b>Ga</b> 69.723	germanium 32 <b>Ge</b> 72.64	arsenic 33 <b>As</b> 74.9216	selenium 34 <b>Se</b> 78.96	bromine 35 <b>Br</b> 79.904	krypton 36 <b>Kr</b> 83.798
rubidium 37 <b>Rb</b> 85.4678	strontium 38 <b>Sr</b> 87.62	yttrium 39 <b>Y</b> 88.90585	zirconium 40 <b>Zr</b> 91.225	niobium 41 <b>Nb</b> 92.90638	molybdenum 42 <b>Mo</b> 95.94	technetium 43 <b>Tc</b> [98]	ruthenium 44 <b>Ru</b> 101.07	rhodium 45 <b>Rh</b> 102.9055	palladium 46 <b>Pd</b> 106.42	silver 47 <b>Ag</b> 107.8682	cadmium 48 <b>Cd</b> 112.411	indium 49 <b>In</b> 114.818	tin 50 <b>Sn</b> 118.710	antimony 51 <b>Sb</b> 121.760	tellurium 52 <b>Te</b> 127.60	iodine 53 <b>I</b> 126.9045	xenon 54 <b>Xe</b> 131.293
cesium 55 <b>Cs</b> 132.90545	barium 56 <b>Ba</b> 137.327	lutetium 71 <b>Lu</b> 174.967	hafnium 72 <b>Hf</b> 178.49	tantalum 73 <b>Ta</b> 180.9479	tungsten 74 <b>W</b> 183.84	rhenium 75 <b>Re</b> 186.207	osmium 76 <b>Os</b> 190.23	iridium 77 <b>Ir</b> 192.217	platinum 78 <b>Pt</b> 195.078	gold 79 <b>Au</b> 196.96655	mercury 80 <b>Hg</b> 200.59	thallium 81 <b>Tl</b> 204.3833	lead 82 <b>Pb</b> 207.2	bismuth 83 <b>Bi</b> 208.9804	polonium 84 <b>Po</b> [209]	astatine 85 <b>At</b> [210]	radon 86 <b>Rn</b> [222]
francium 87 <b>Fr</b> [223]	radium 88 <b>Ra</b> [226]	lawrencium 103 <b>Lr</b> [262]	rutherfordium 104 <b>Rf</b> [261]	dubnium 105 <b>Db</b> [262]	seaborgium 106 <b>Sg</b> [271]	bohrium 107 <b>Bh</b> [270]	hassium 108 <b>Hs</b> [269]	meitnerium 109 <b>Mt</b> [278]	damastadium 110 <b>Ds</b> [281]	roentgenium 111 <b>Rg</b> [281]	copernicium 112 <b>Cn</b> [285]						

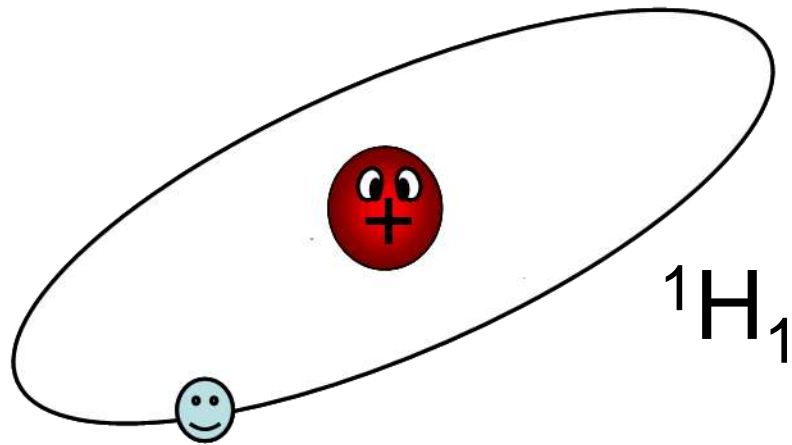
www.Had2Know.com

lanthanum 57 <b>La</b> 138.9055	cerium 58 <b>Ce</b> 140.116	praseodymium 59 <b>Pr</b> 140.90765	neodymium 60 <b>Nd</b> 144.24	promethium 61 <b>Pm</b> [145]	samarium 62 <b>Sm</b> 150.36	europium 63 <b>Eu</b> 151.964	gadolinium 64 <b>Gd</b> 157.25	terbium 65 <b>Tb</b> 158.9253	dysprosium 66 <b>Dy</b> 162.50	holmium 67 <b>Ho</b> 164.930	erbium 68 <b>Er</b> 167.259	thulium 69 <b>Tm</b> 168.934	ytterbium 70 <b>Yb</b> 173.04
actinium 89 <b>Ac</b> [227]	thorium 90 <b>Th</b> 232.038	protactinium 91 <b>Pa</b> 231.0359	uranium 92 <b>U</b> 238.0289	neptunium 93 <b>Np</b> [237]	plutonium 94 <b>Pu</b> [244]	americium 95 <b>Am</b> [243]	curium 96 <b>Cm</b> [247]	berkelium 97 <b>Bk</b> [247]	californium 98 <b>Cf</b> [251]	einsteinium 99 <b>Es</b> [252]	fermium 100 <b>Fm</b> [257]	mendeleevium 101 <b>Md</b> [258]	nobelium 102 <b>No</b> [259]

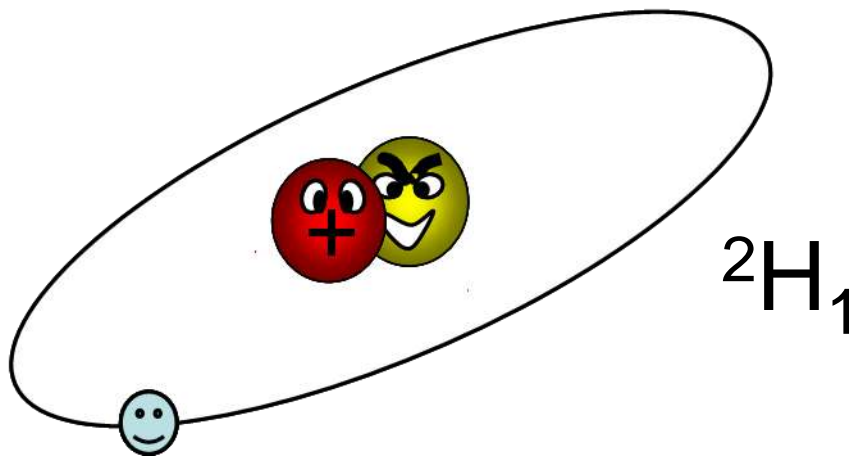


A = total number of nucleons

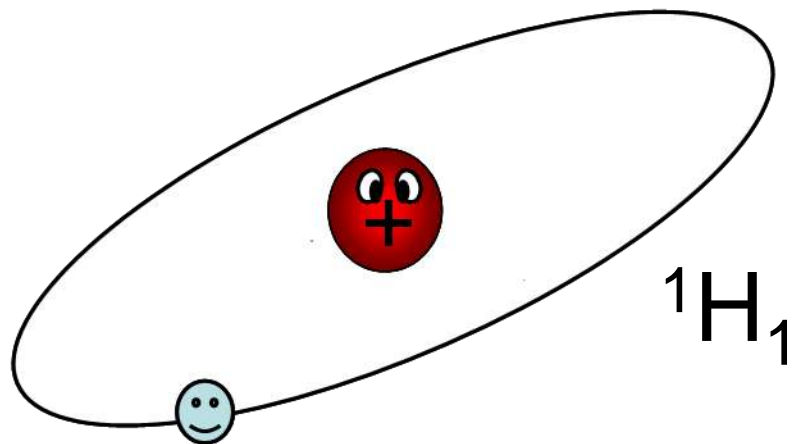
Z = number of protons



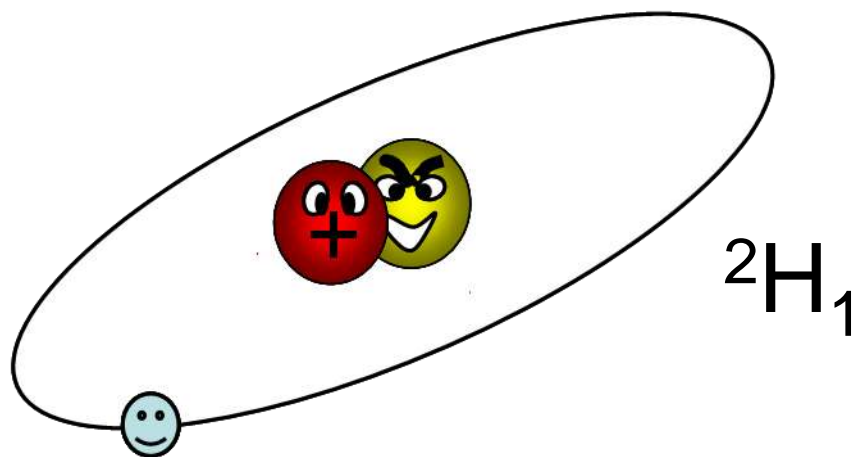
$^1\text{H}_1$



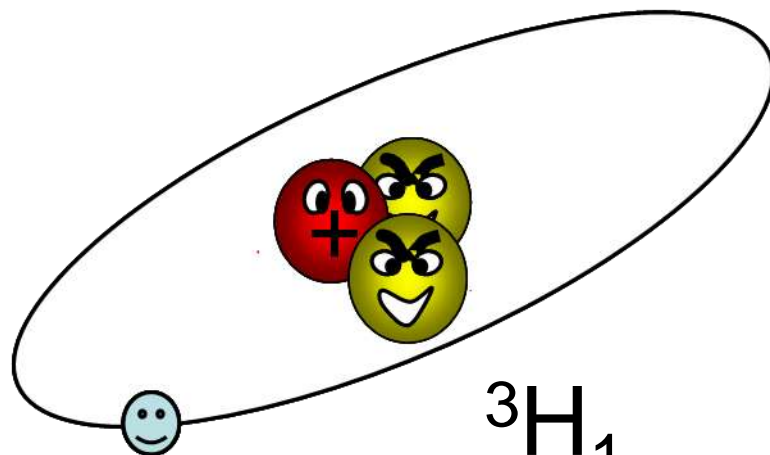
$^2\text{H}_1$



${}^1\text{H}_1$



${}^2\text{H}_1$

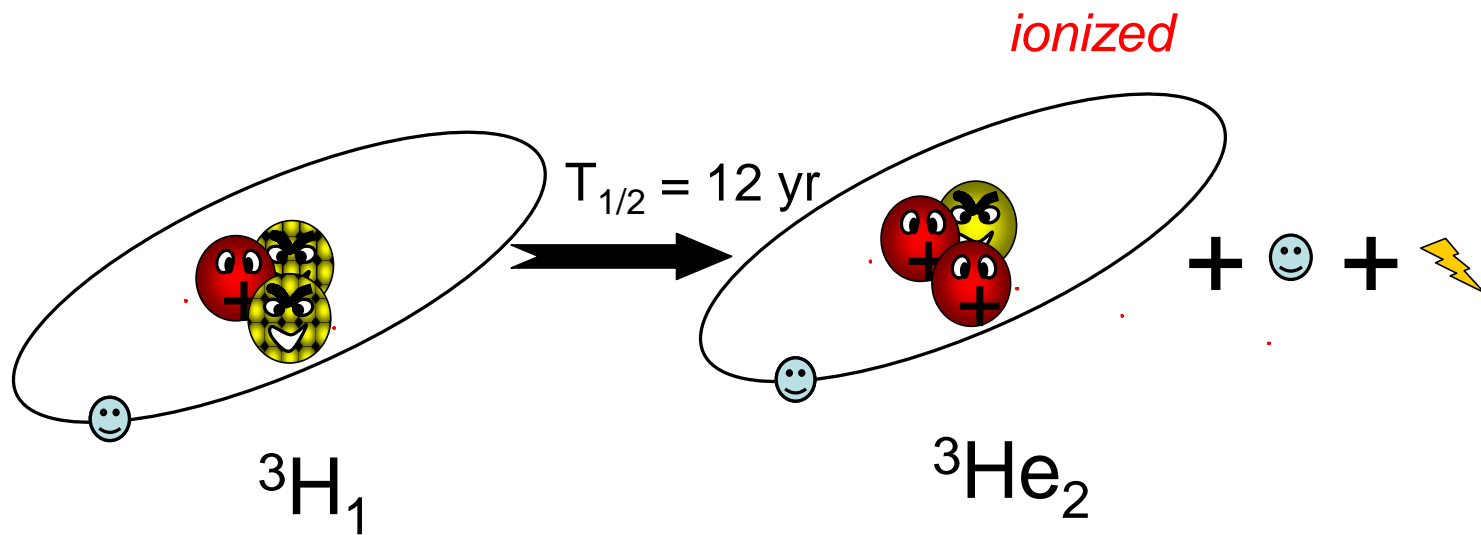
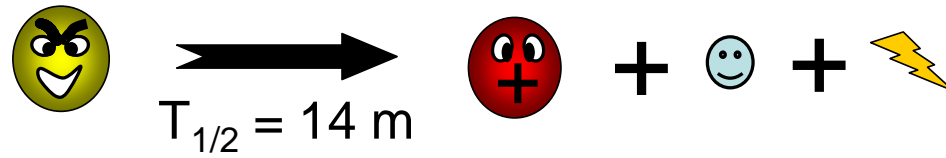


${}^3\text{H}_1$

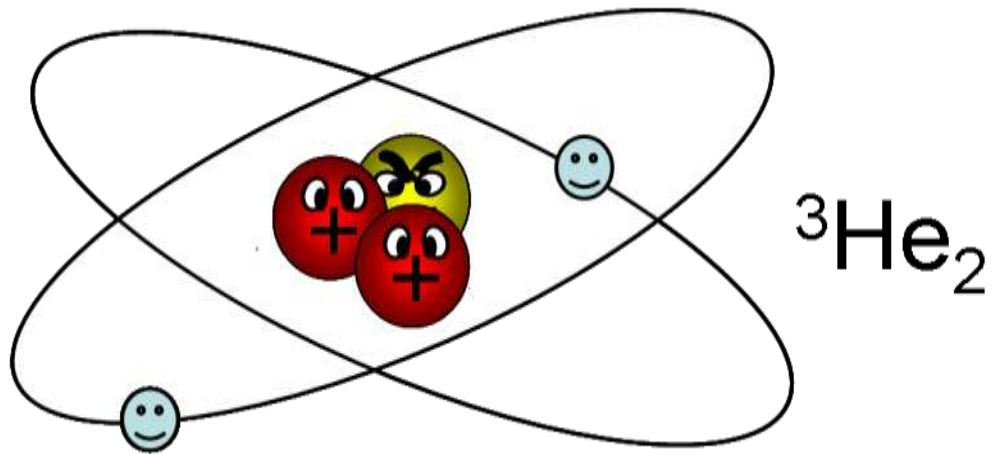


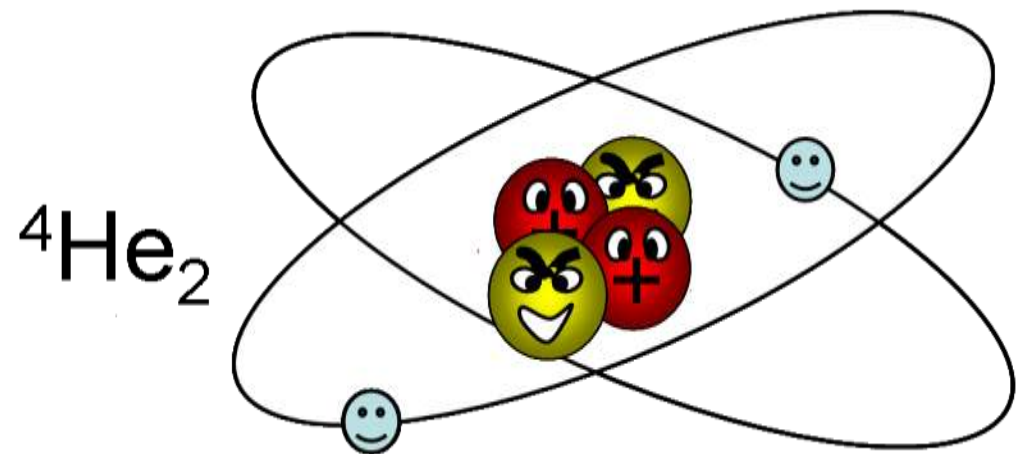
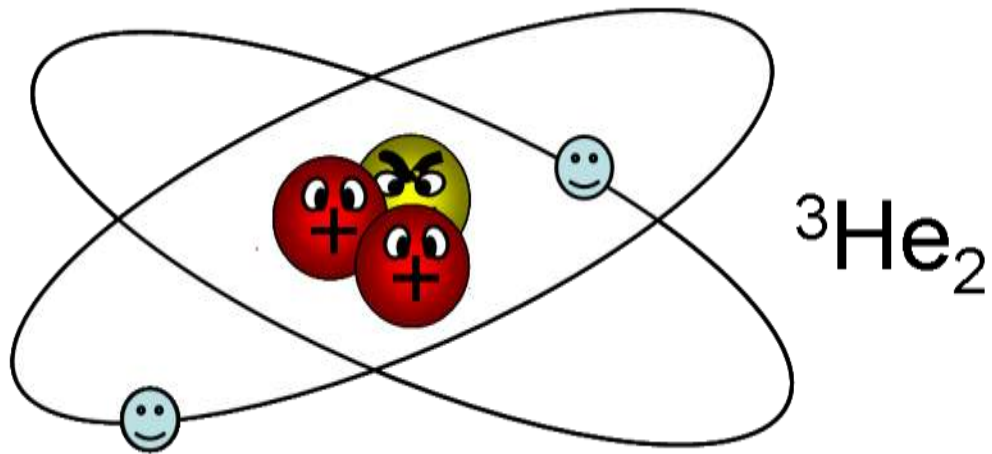
Virginia Commonwealth University

Department of Mechanical  
& Nuclear Engineering





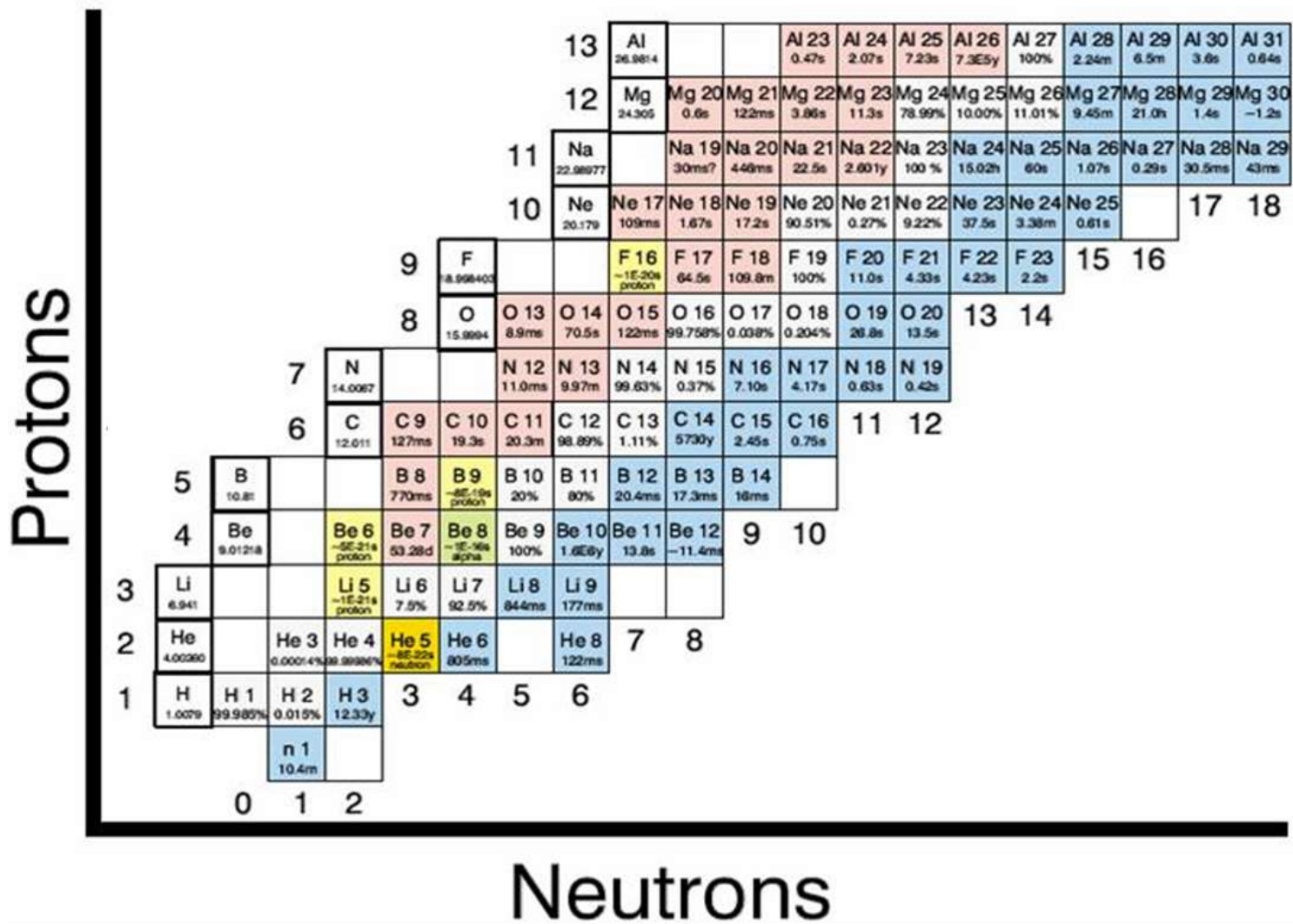




# NUCLIDE = ISOTOPE

*Chart of the Nuclides* – a  
nuclear engineer or physicist's  
Periodic Table of the elements.

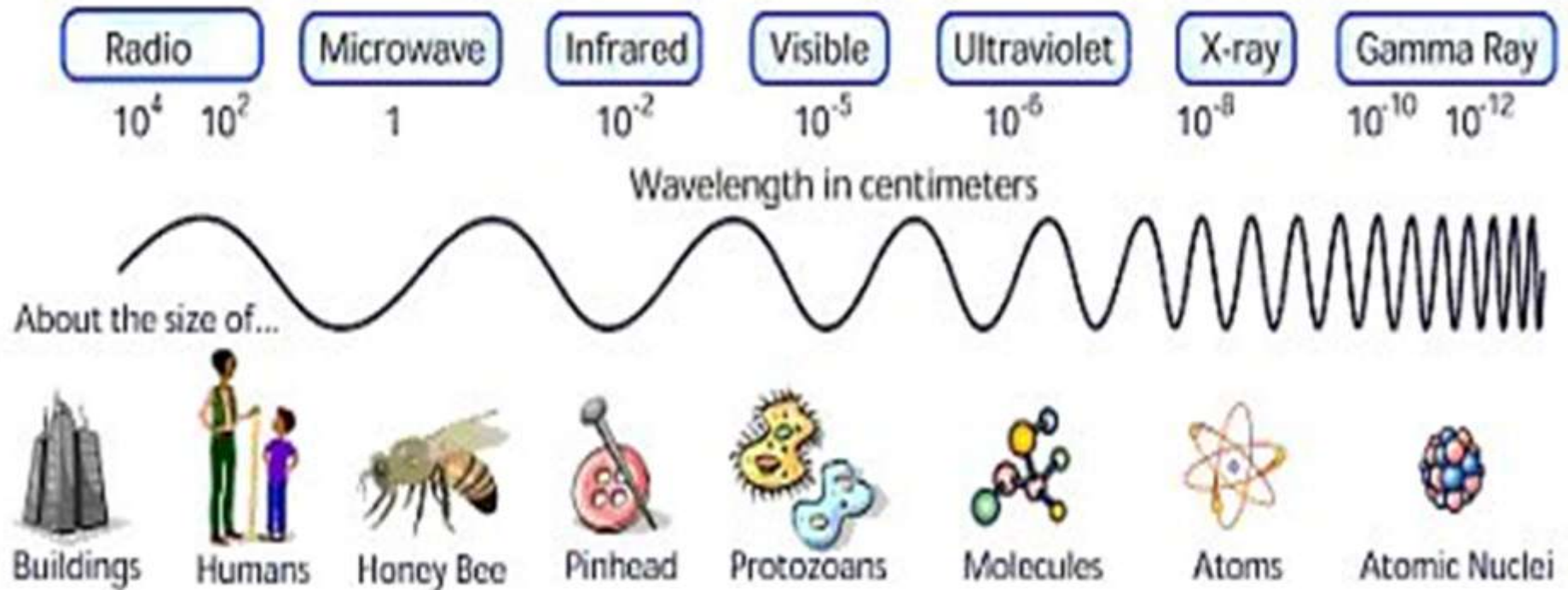
# CHART OF THE NUCLIDES



# Forces of Nature

- Gravity
- Electromagnetic –  $\sim 10^{39}$  stronger than gravity (between proton and electron)
- Weak nuclear – responsible for radioactive decay
- Strong nuclear – binds the nucleus,  $\sim 10^{38}$  stronger than gravity (between two nucleons)
  - Scaled to our size, you and the person next to you would feel an attraction of  $2.5 \times 10^{32}$  N (about a billion-trillion-trillion tons of force)

# Electromagnetic Spectrum



Particles can also be described by

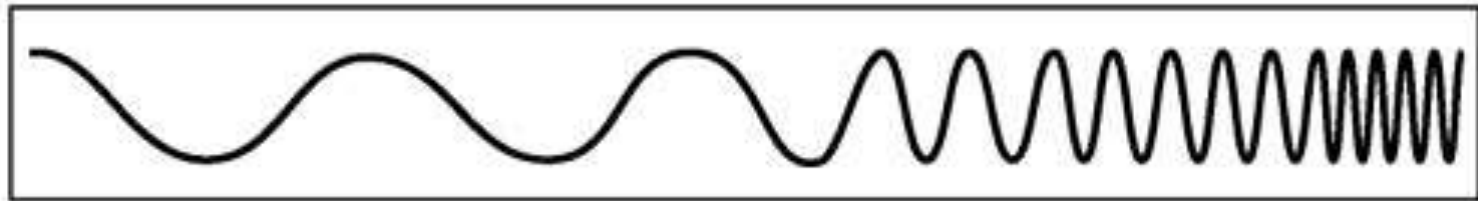
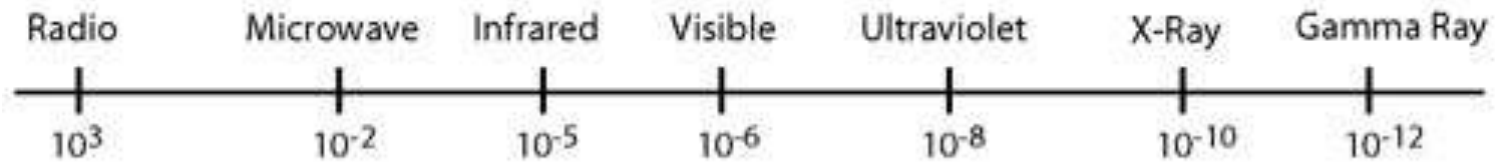


Virginia Commonwealth University

Department of Mechanical  
& Nuclear Engineering

## THE ELECTRO MAGNETIC SPECTRUM

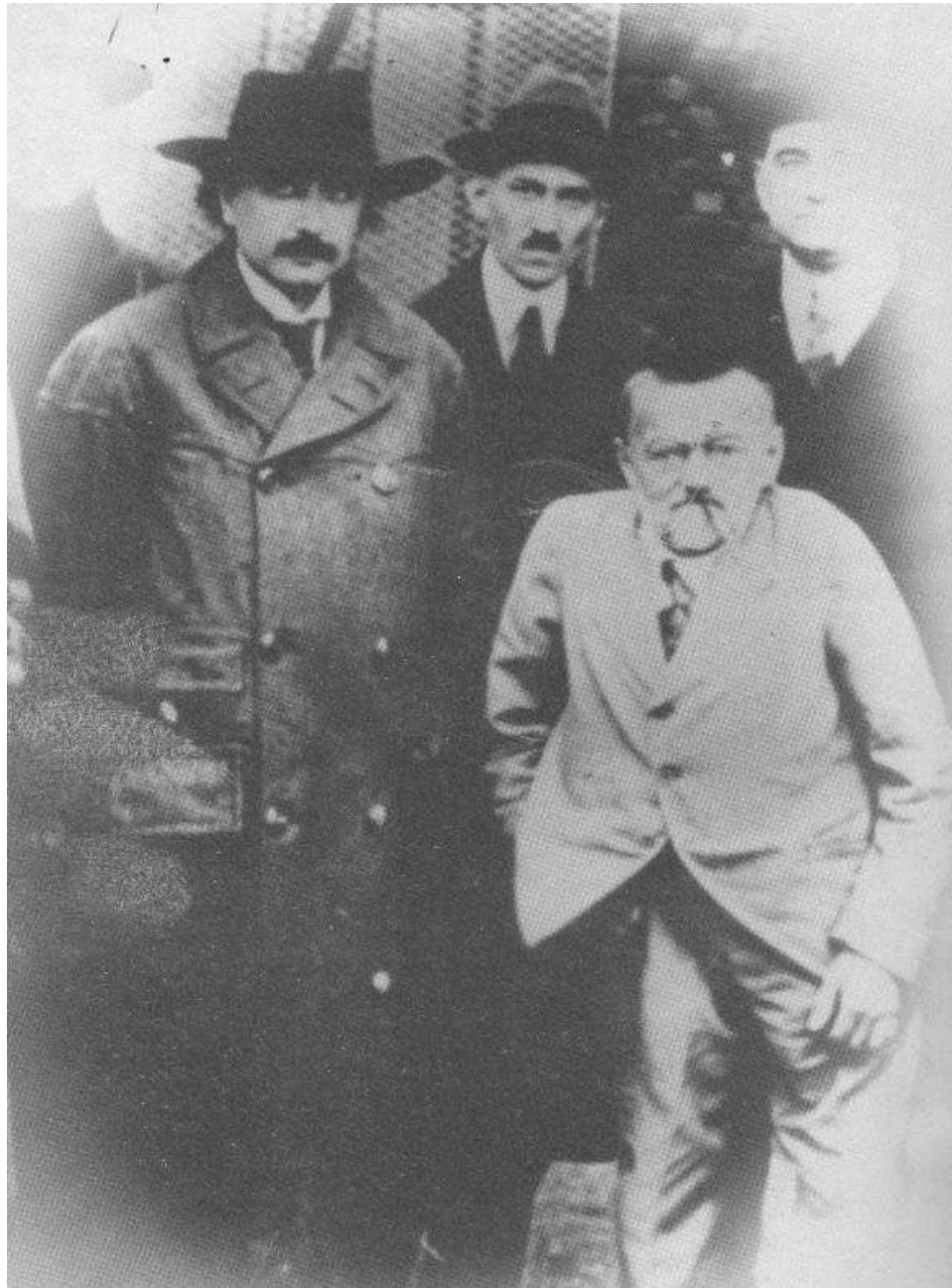
Wavelength  
(metres)



Frequency  
(Hz)





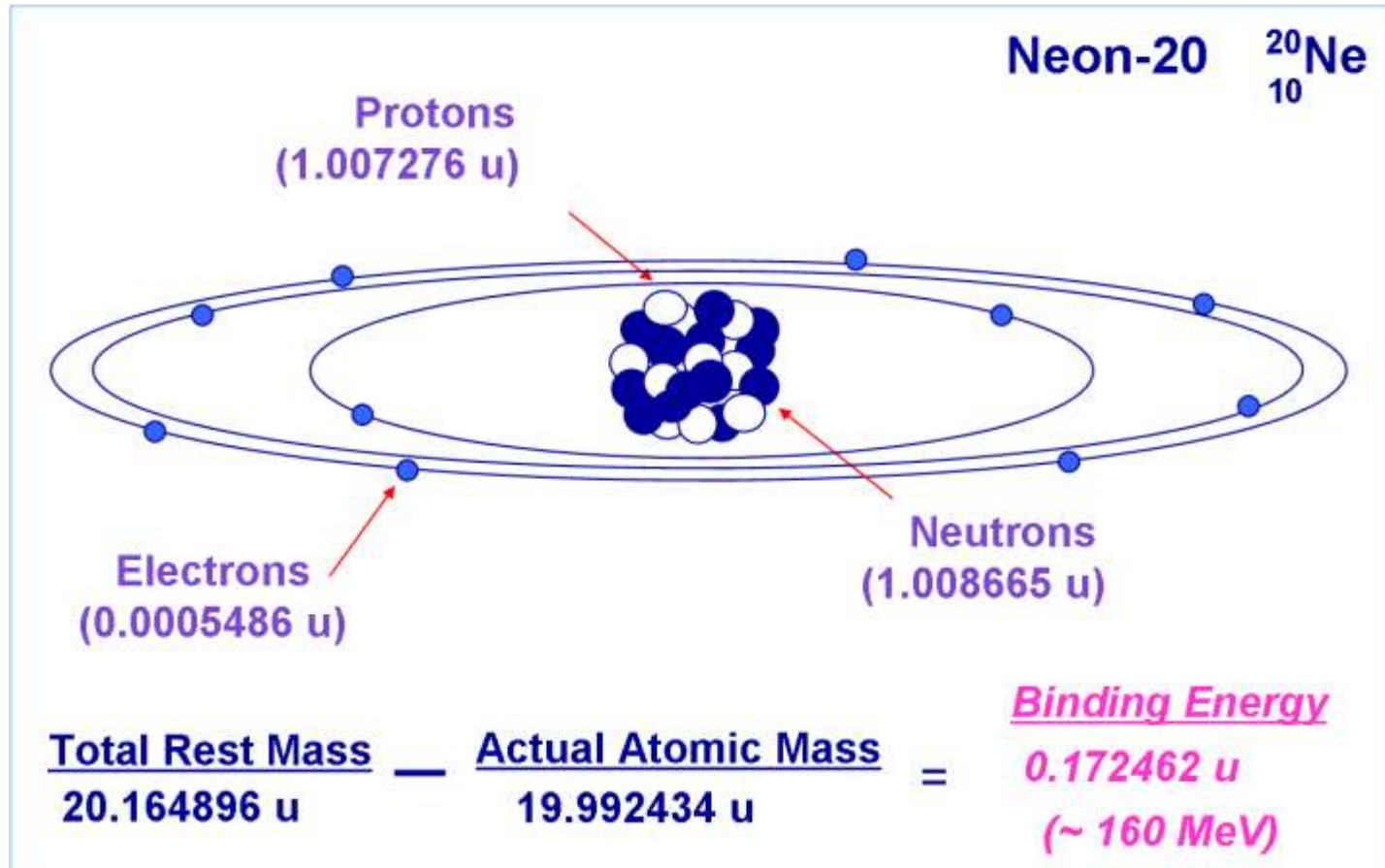


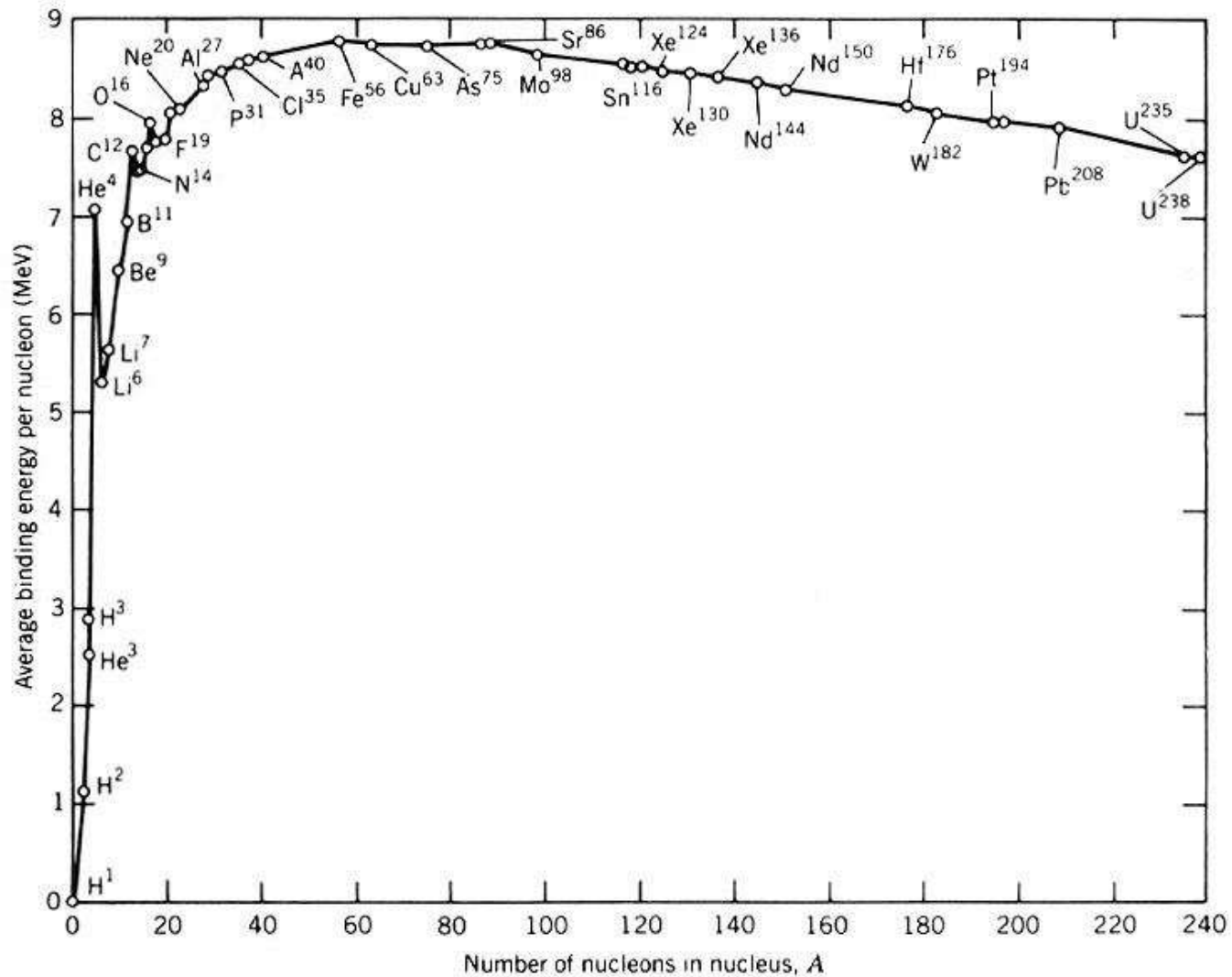


$$E = mc^2$$

- Matter is “condensed” or “frozen” energy
- Combines classical physics laws of *conservation of mass* and *conservation of energy* into ***conservation of mass/energy***

# Matter = Energy





# Radiation

- **Radiation** = Energy in transit  
→ the transfer of energy by waves or particles

# Radiation

- Radiation = Energy in transit  
→ the transfer of energy by waves or particles
- **Ionizing Radiation**: Alpha and beta particles, gamma and x-rays, neutrons

# Radiation

- Radiation = Energy in transit  
→ the transfer of energy by waves or particles
- Ionizing Radiation: Alpha and beta particles, gamma and x-rays, neutrons
- "dose" is caused by the absorption of the kinetic energy of the resulting charged particles

# Radiation

- Radiation = Energy in transit  
→ the transfer of energy by waves or particles
- Ionizing Radiation: Alpha and beta particles, gamma and x-rays, neutrons
- "dose" is caused by the absorption of the kinetic energy of the resulting charged particles
- **Non-ionizing radiation**: does not produce energetic ions:  
radio, microwave, ultraviolet, infrared, visible

# Sources of Radiation

- Radioactive decay
- "Extra-nuclear" processes – X-rays
- Nuclear Reactions: fission, fusion, other



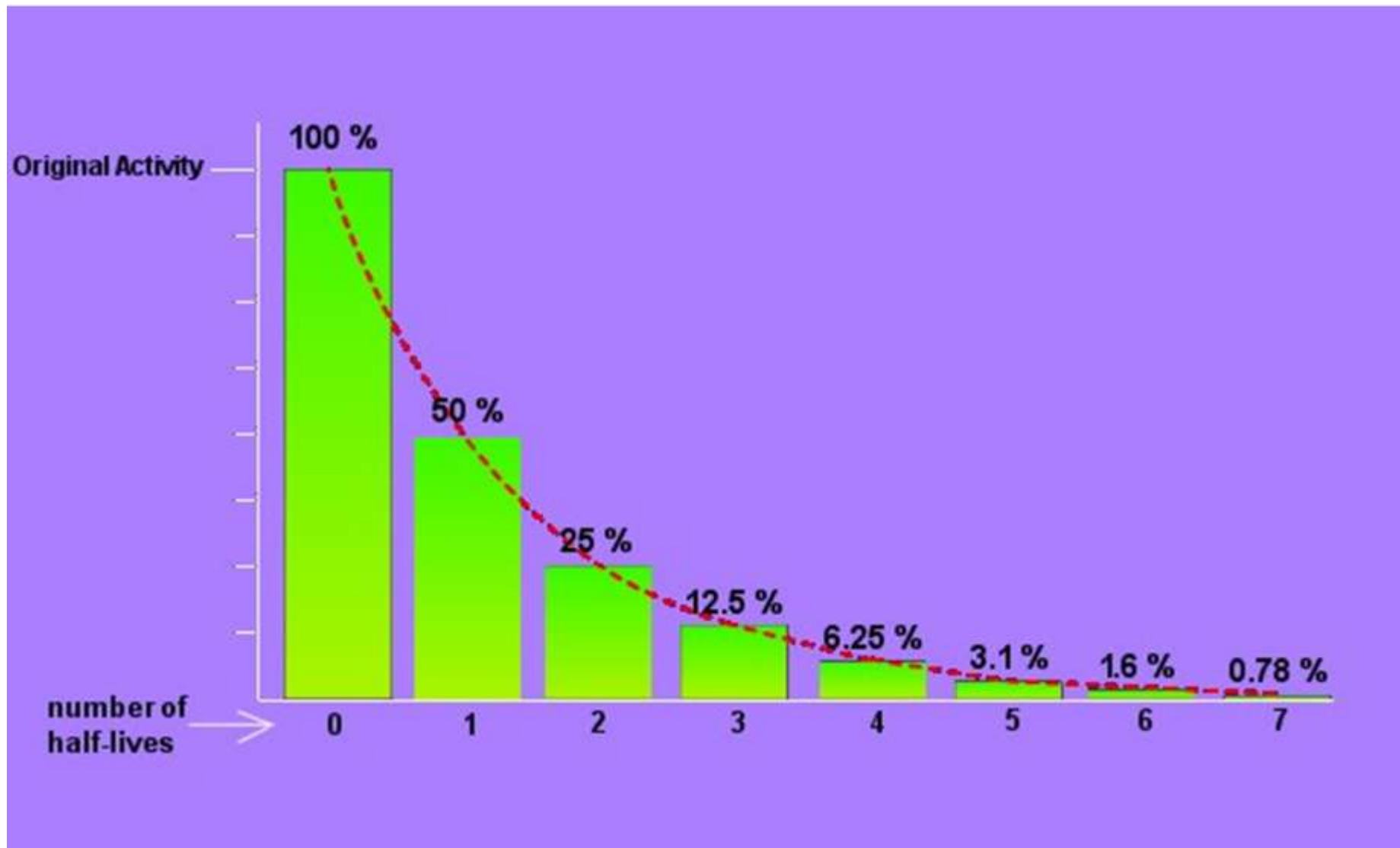


Virginia Commonwealth University

Department of Mechanical  
& Nuclear Engineering



# Radioactive Half-life



# "Golly, gee, Mr. Wizard, what does it all mean?"



$$N(t) = N_0 e^{-\lambda t}$$

where the decay constant  $\lambda = 0.693/T_{1/2}$

Activity = # of disintegrations per sec

$$A = \lambda N(t)$$

# Radioactive Decay

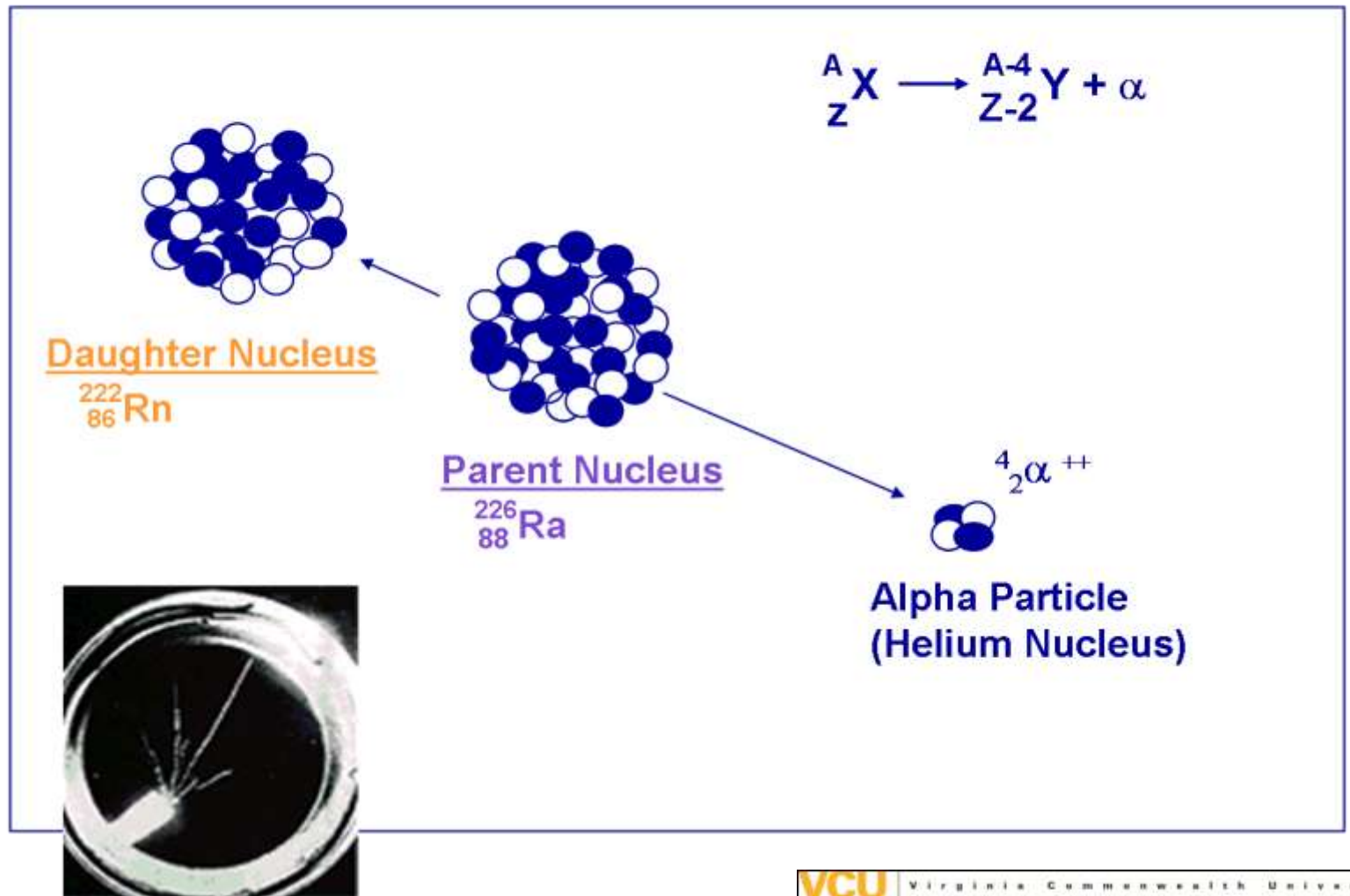
- All radioactive decay processes result in a nucleus with less mass-energy, and a more stable configuration, than the original, unstable nucleus.

# Radioactive Decay

- All radioactive decay processes result in a nucleus with less mass-energy, and a more stable configuration, than the original, unstable nucleus.
- Several modes of transition are available, and the nucleus will decay via one or more of these modes, depending on which ones are energetically “preferable” to move towards stability.



# Radioactivity: $\alpha$ Decay





# Radioactivity: $\beta^-$ Decay

Daughter Nucleus

Nickel -60

Z= 28



Parent Nucleus

Cobalt -60

Z= 27



$\bar{\nu}$

Antineutrino

$\beta^-$

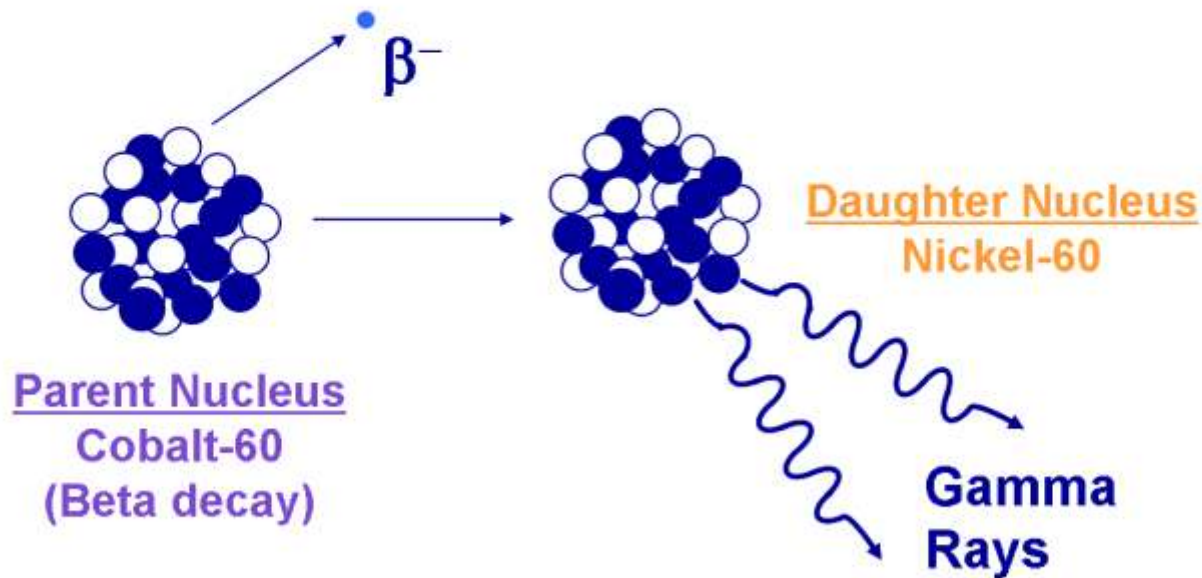
Beta Particle  
(electron)



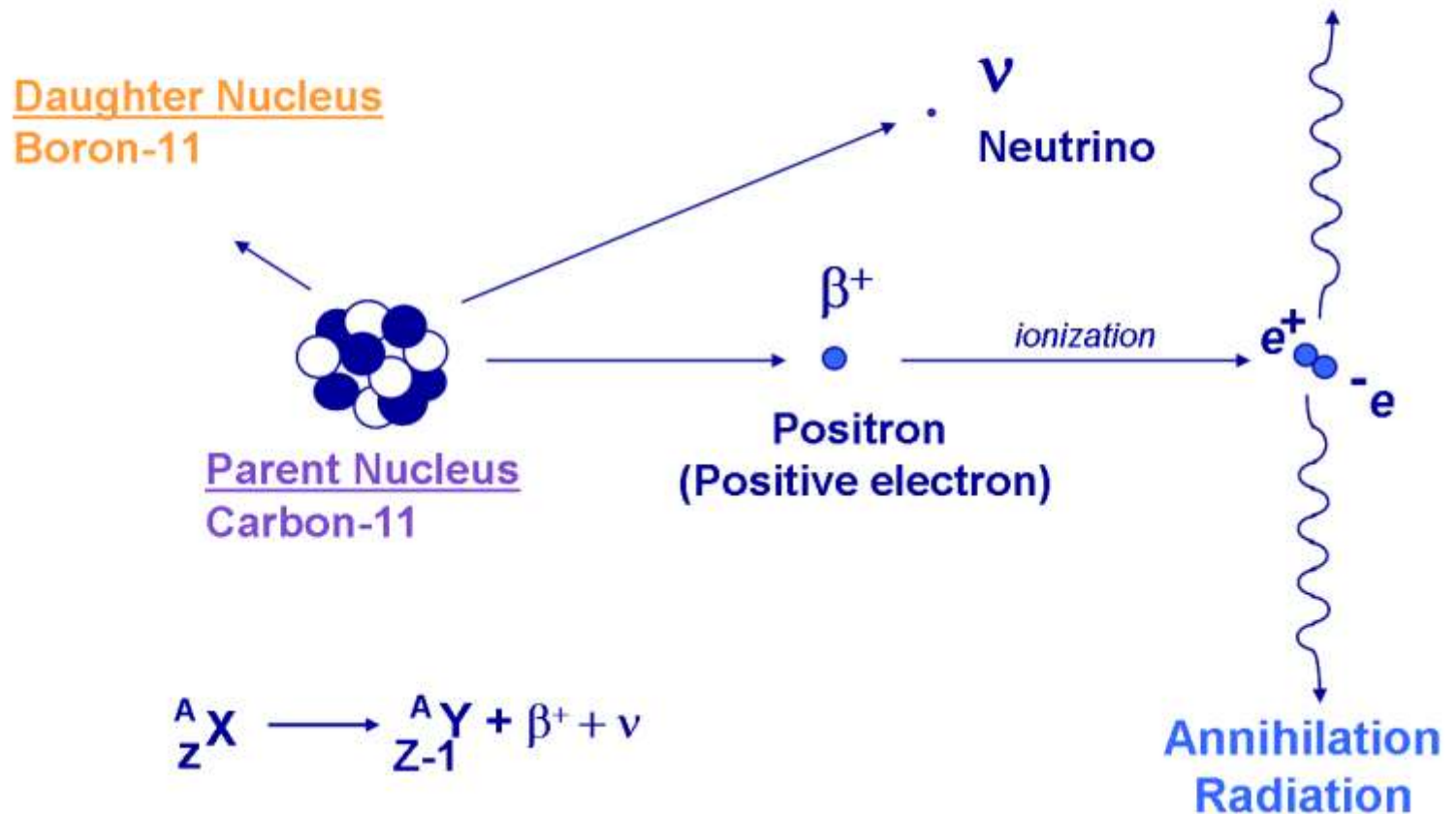
Virginia Commonwealth University

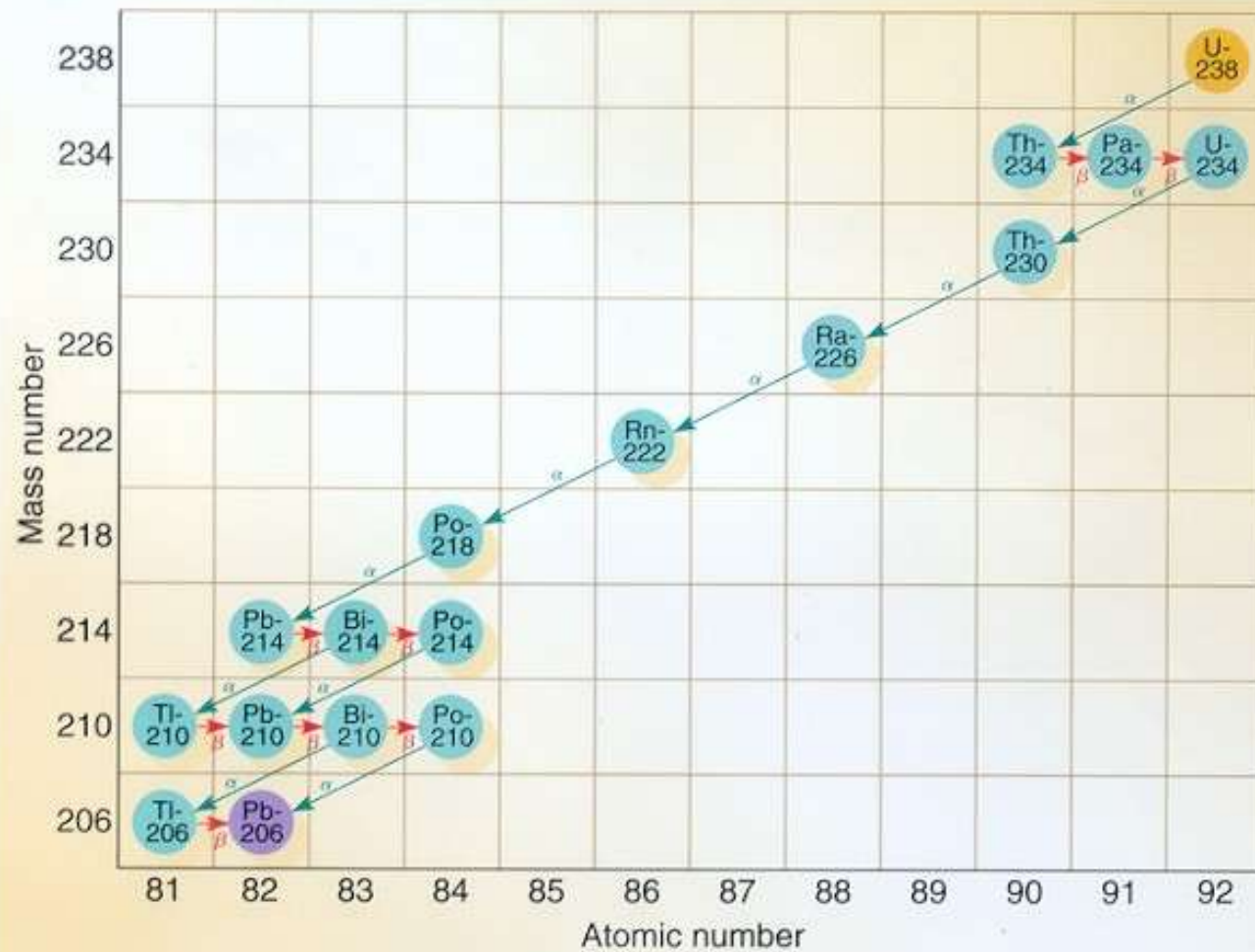
Department of Mechanical  
& Nuclear Engineering

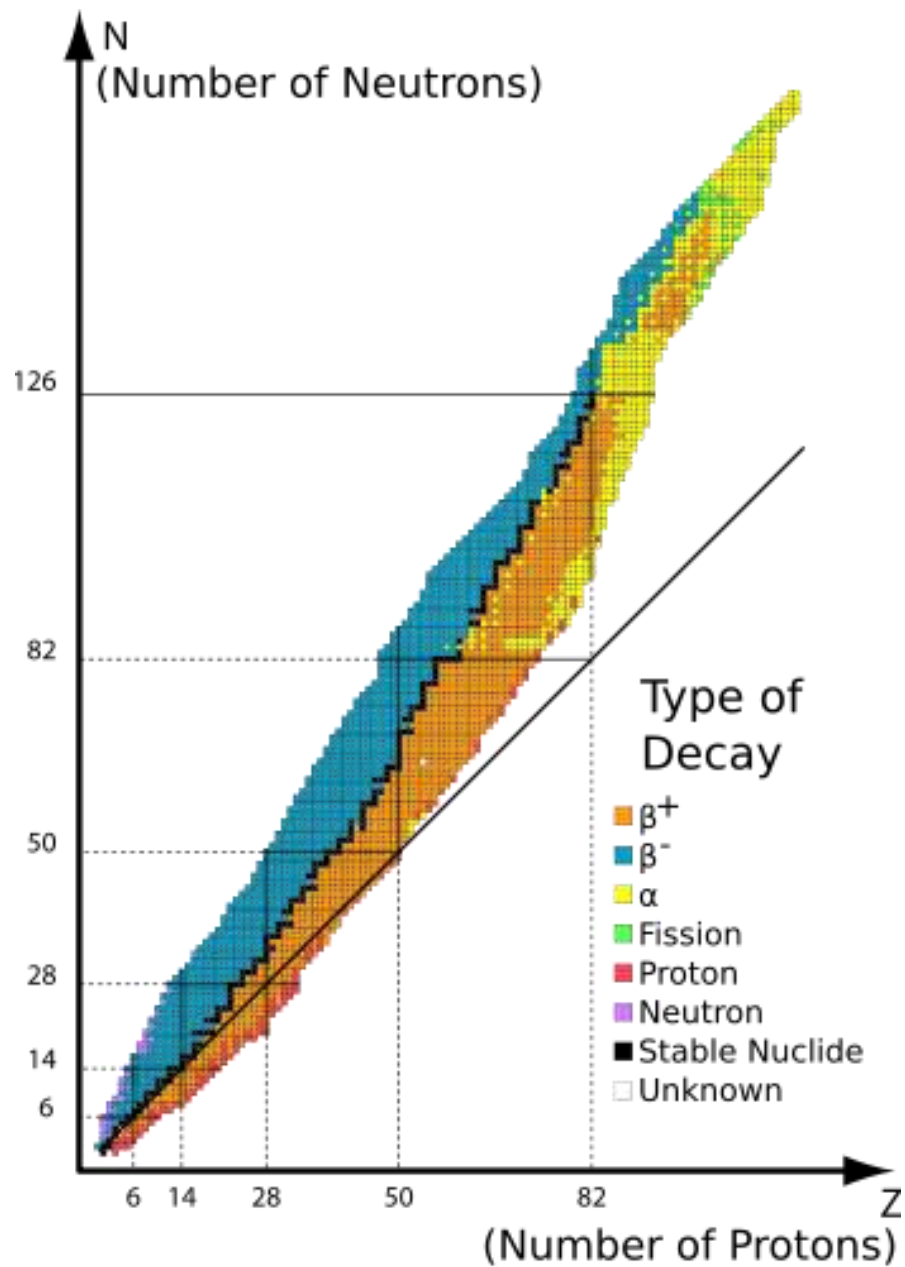
# Gamma Emission



# Radioactivity: $\beta^+$ Decay

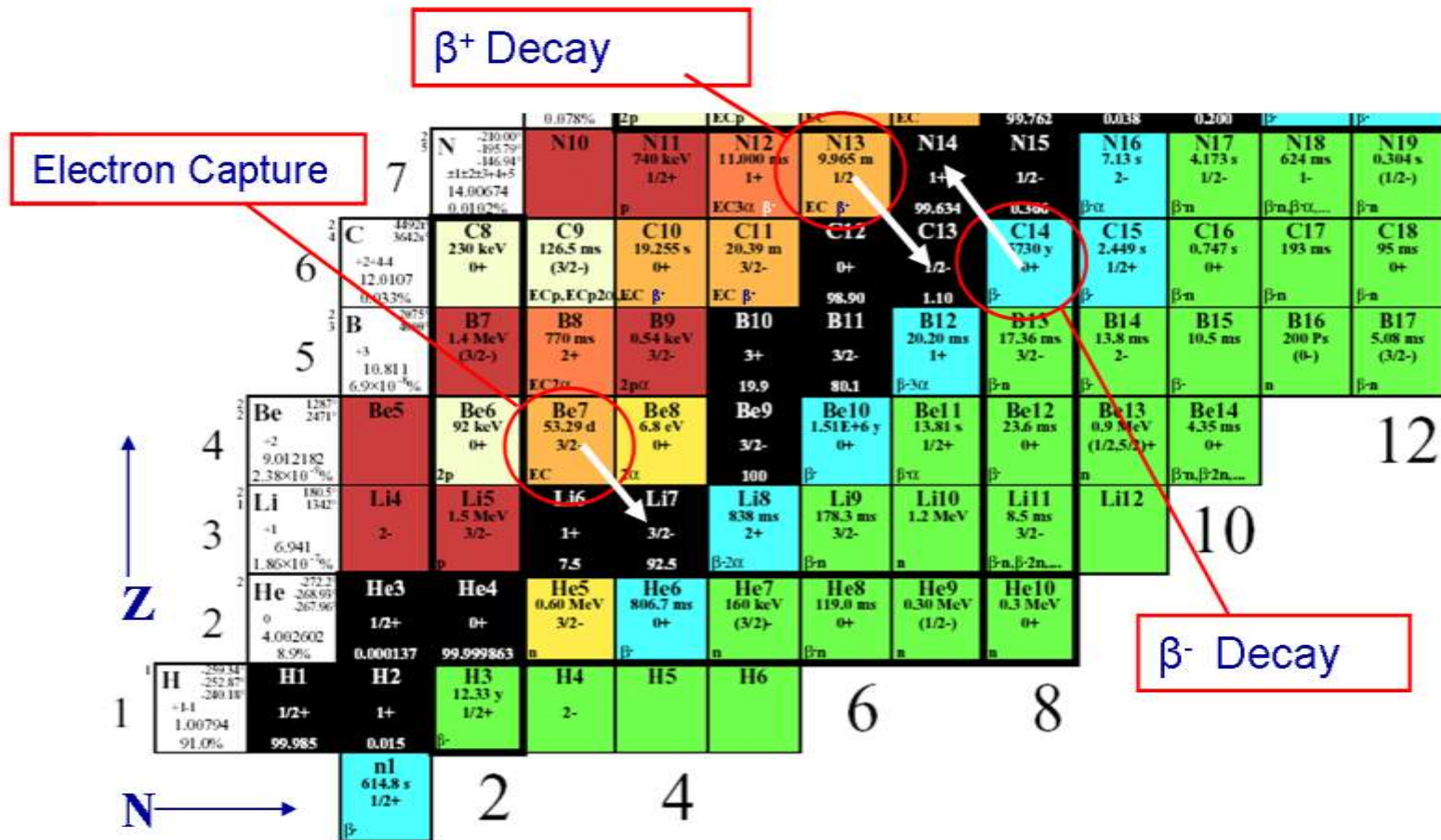








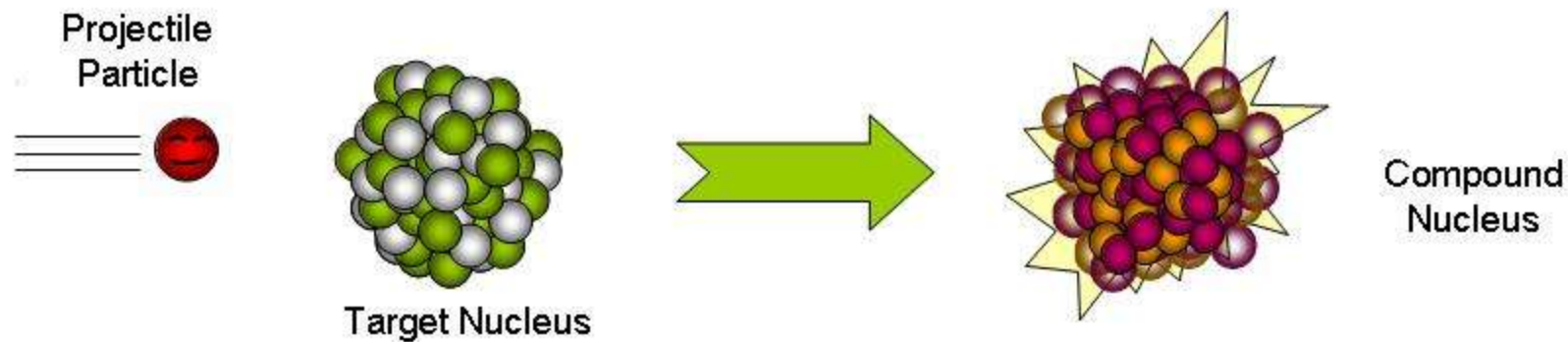
# Results of Decay Processes



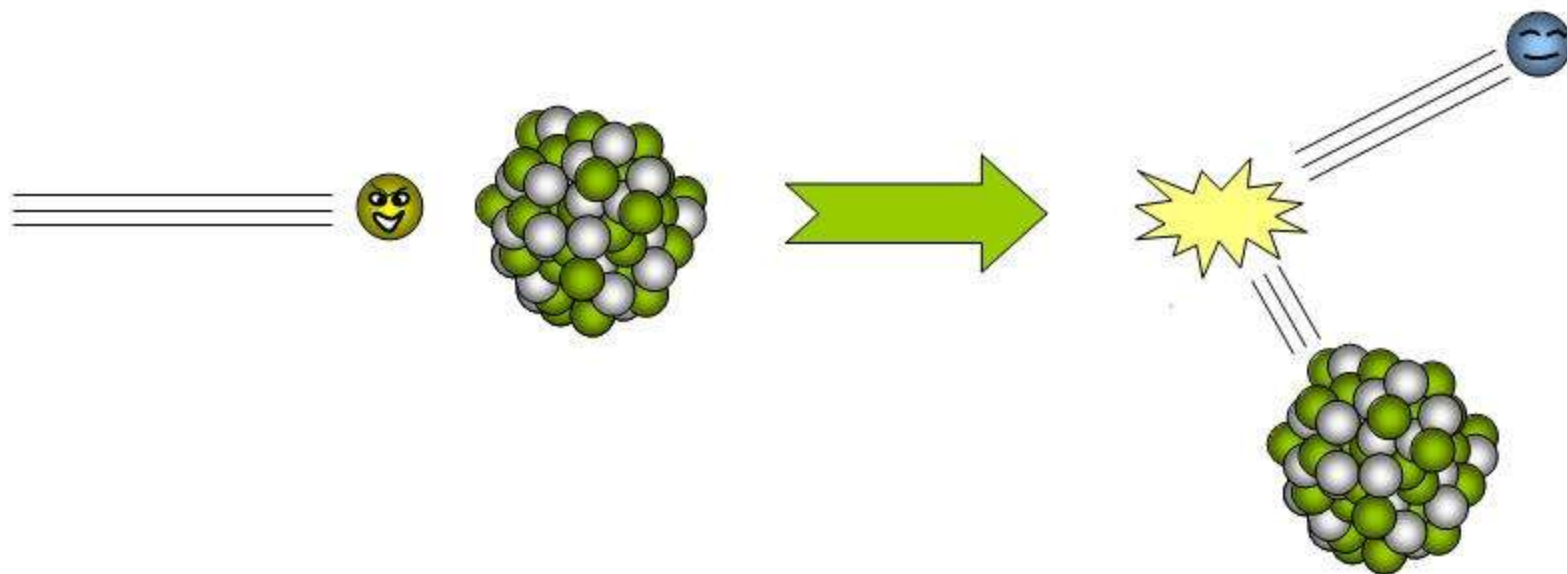
# Sources of Radiation

- Radioactive decay
- "Extra-nuclear" processes – X-rays
- Nuclear Reactions: fission, fusion, other

## Absorption

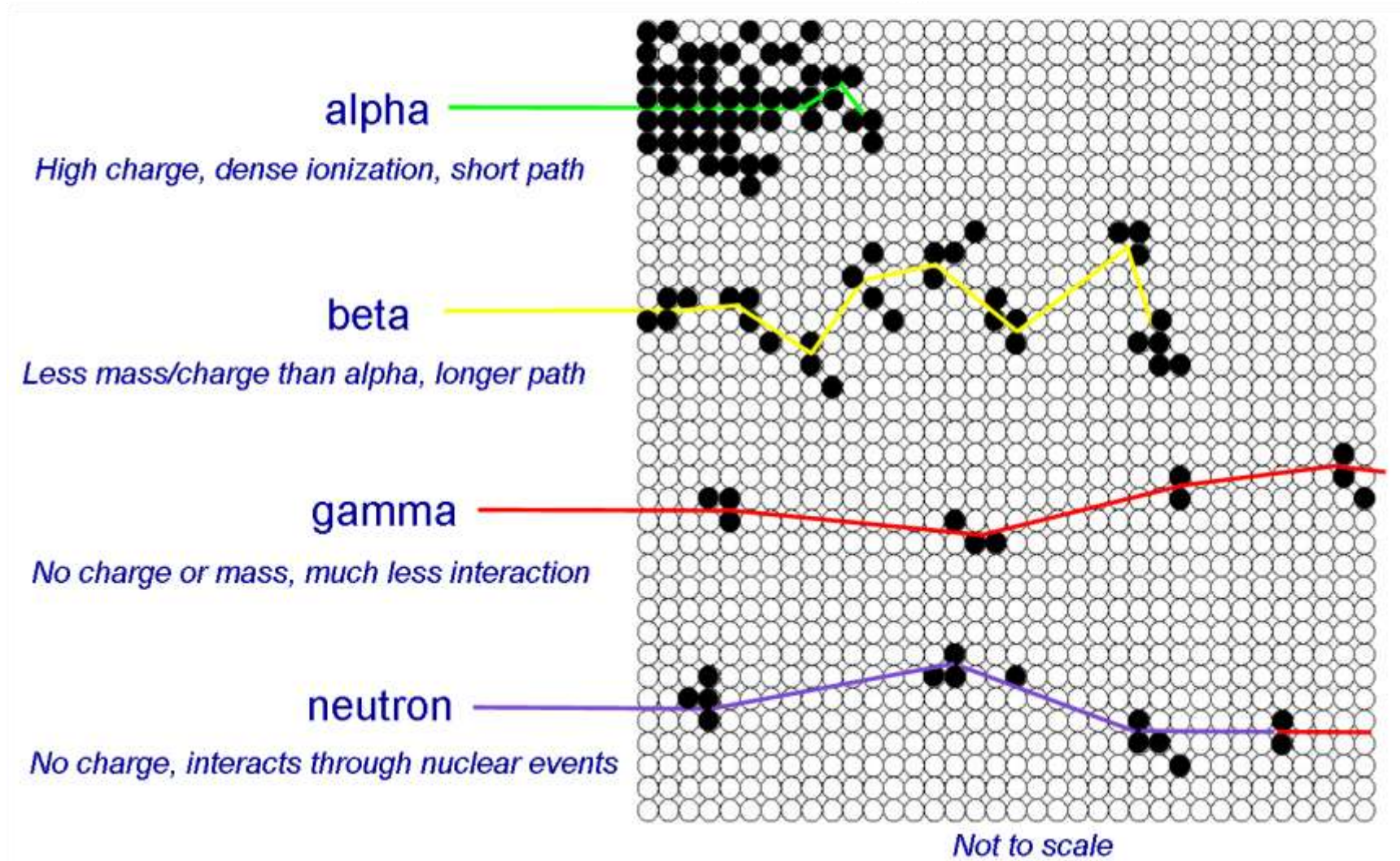


## Scatter

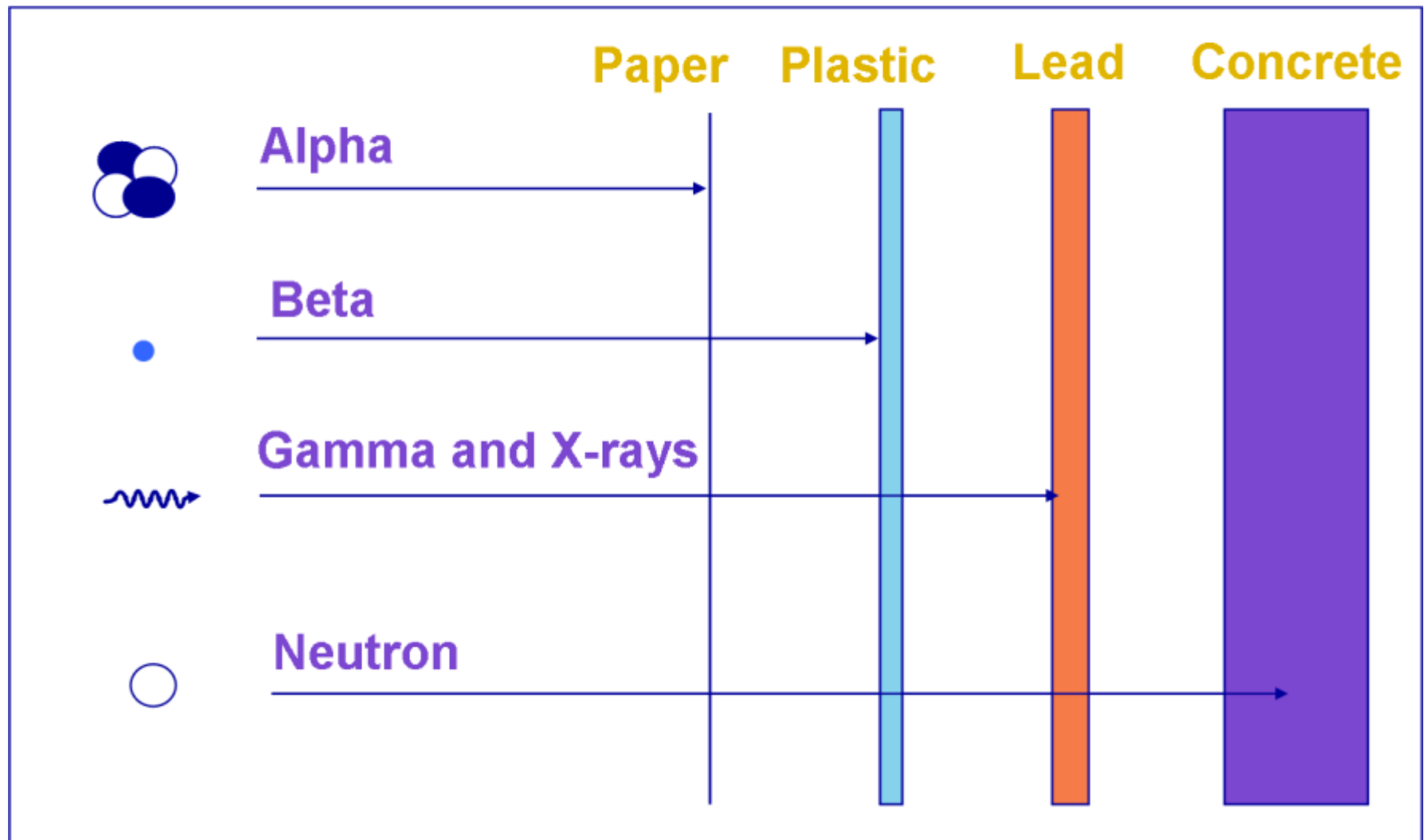


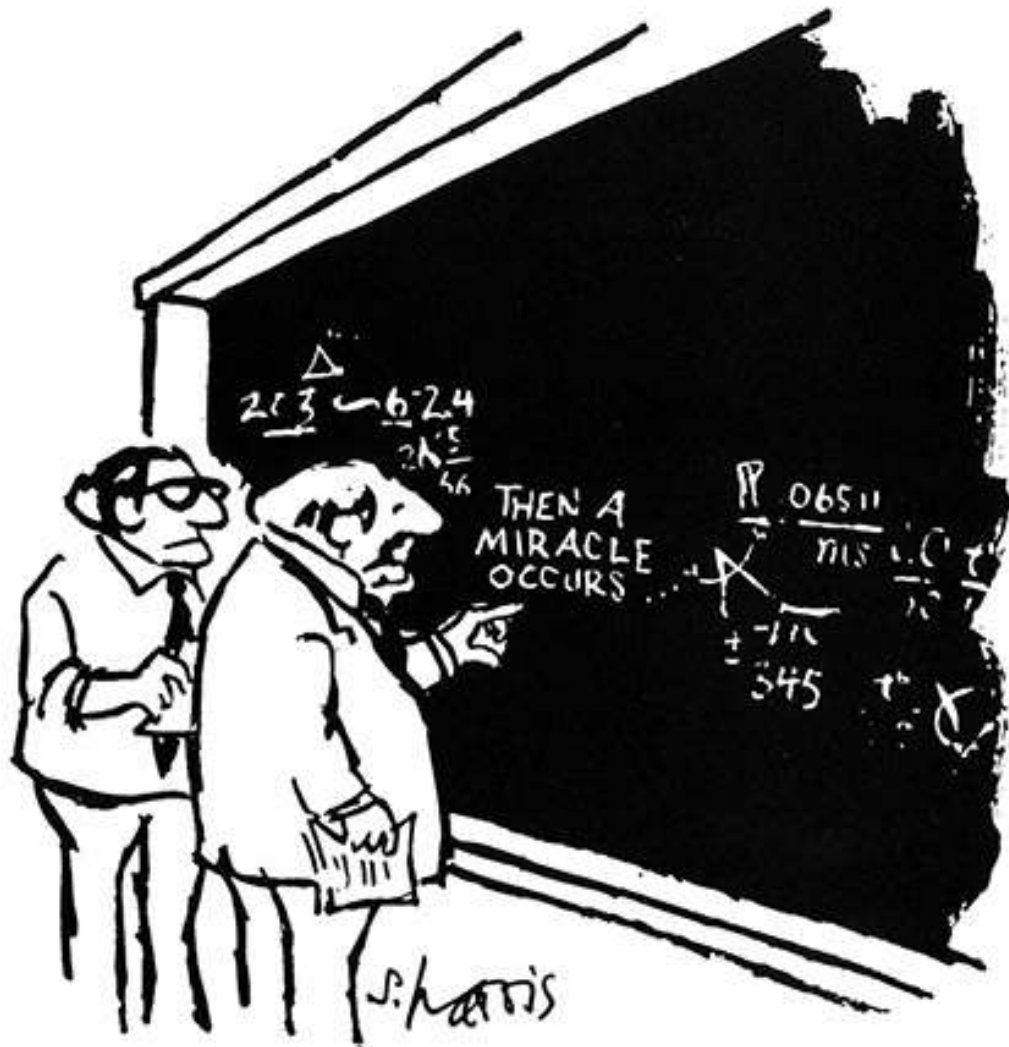


# Radiation Interaction and Penetration Through Matter



# Shielding for Radiation





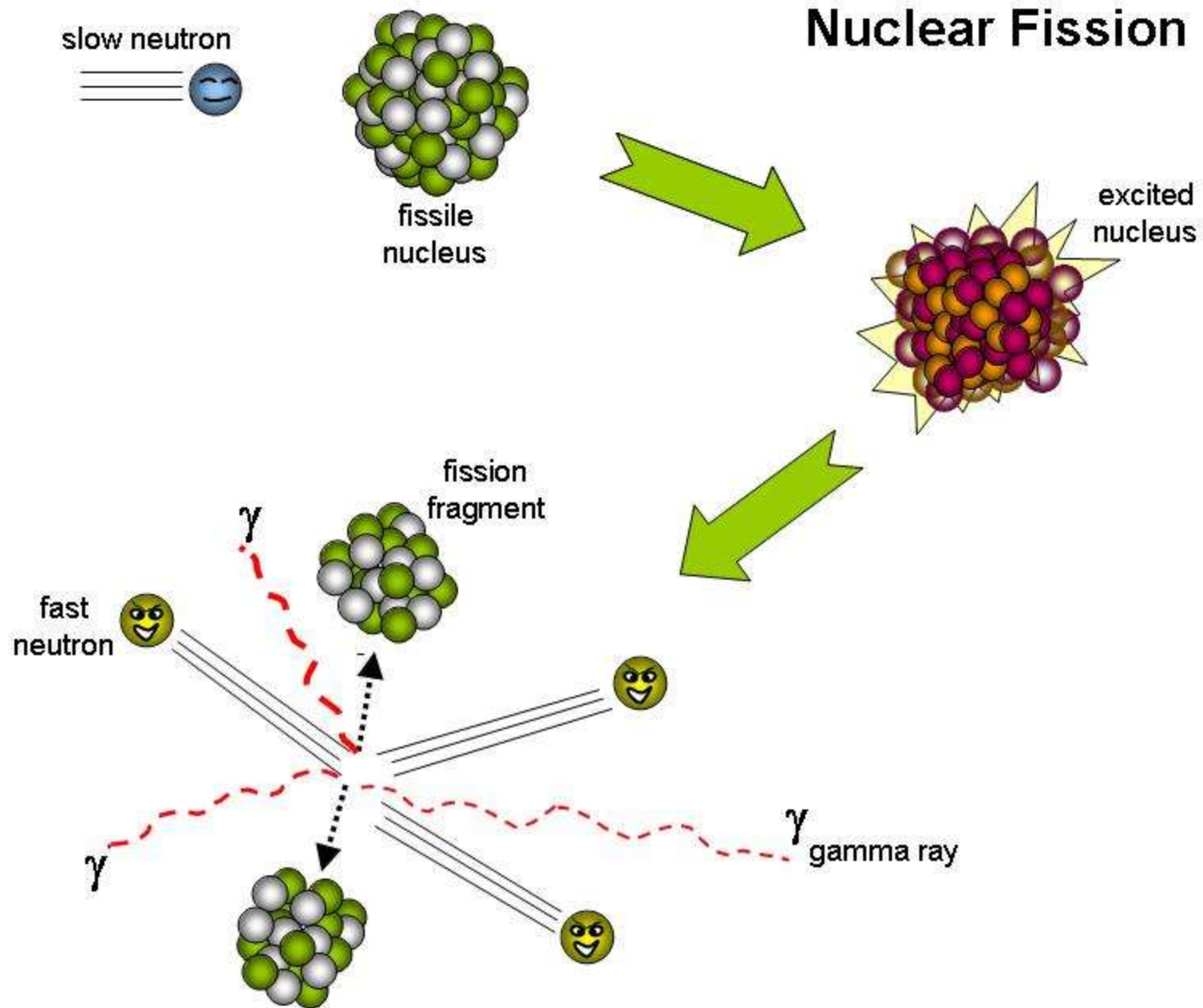
"I think you should be more explicit here in step two."

wealrh University



Department of Mechanical  
& Nuclear Engineering

# Nuclear Fission



# Nuclear Fission

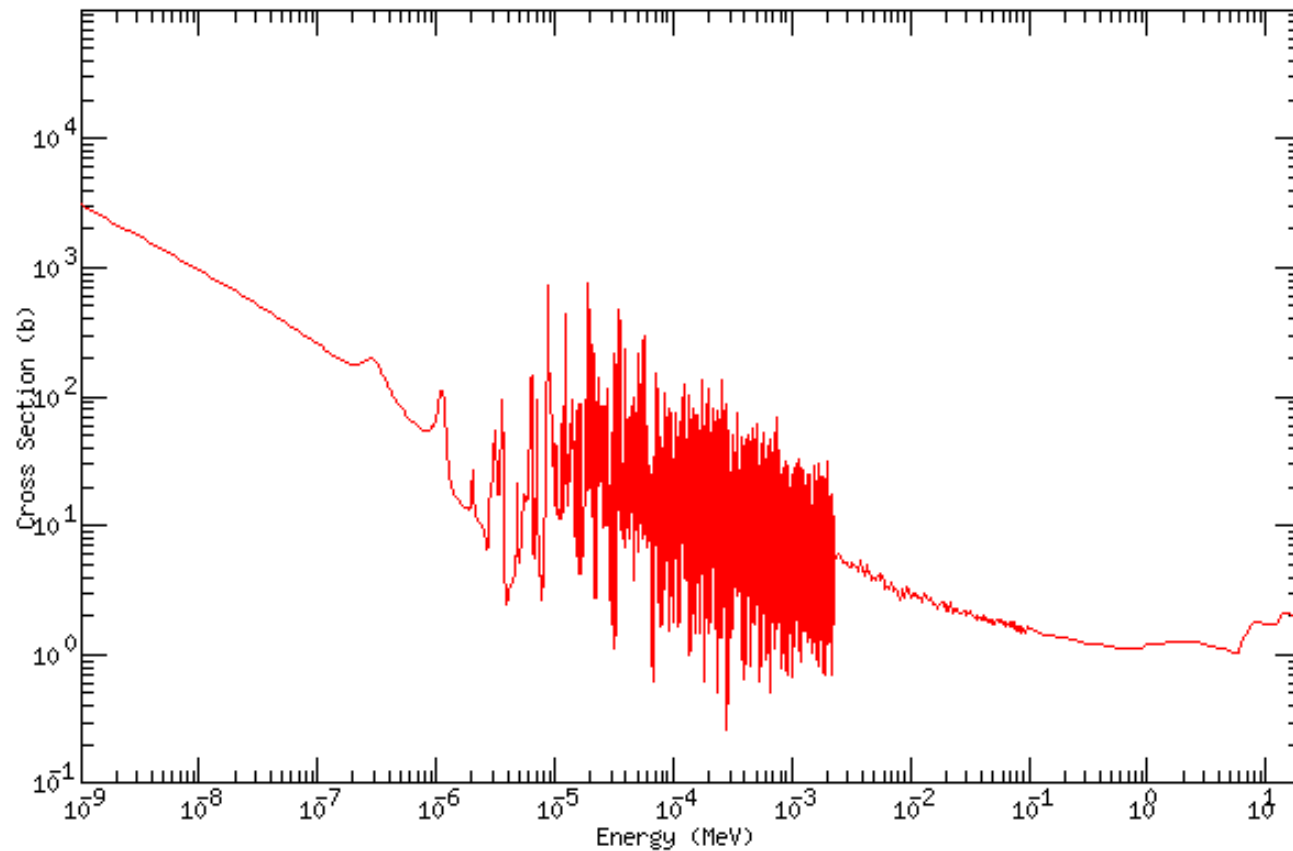
- Combustion of one carbon atom releases about 4 eV (electron volts) of energy
- Fission of one  $^{235}\text{U}_{92}$  nucleus releases about **200,000,000 eV** of energy

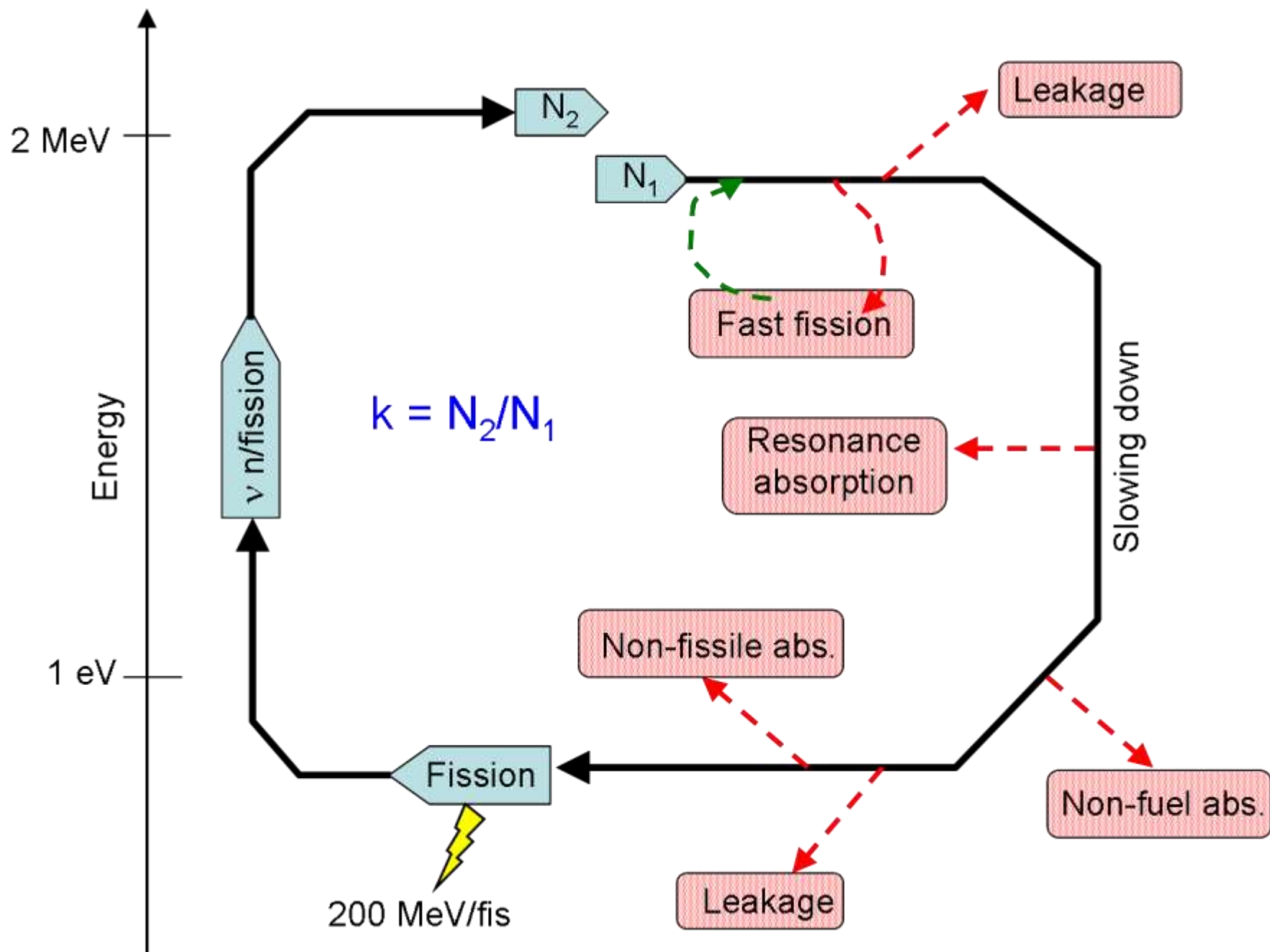


# Oklo Reactor – Gabon, Africa



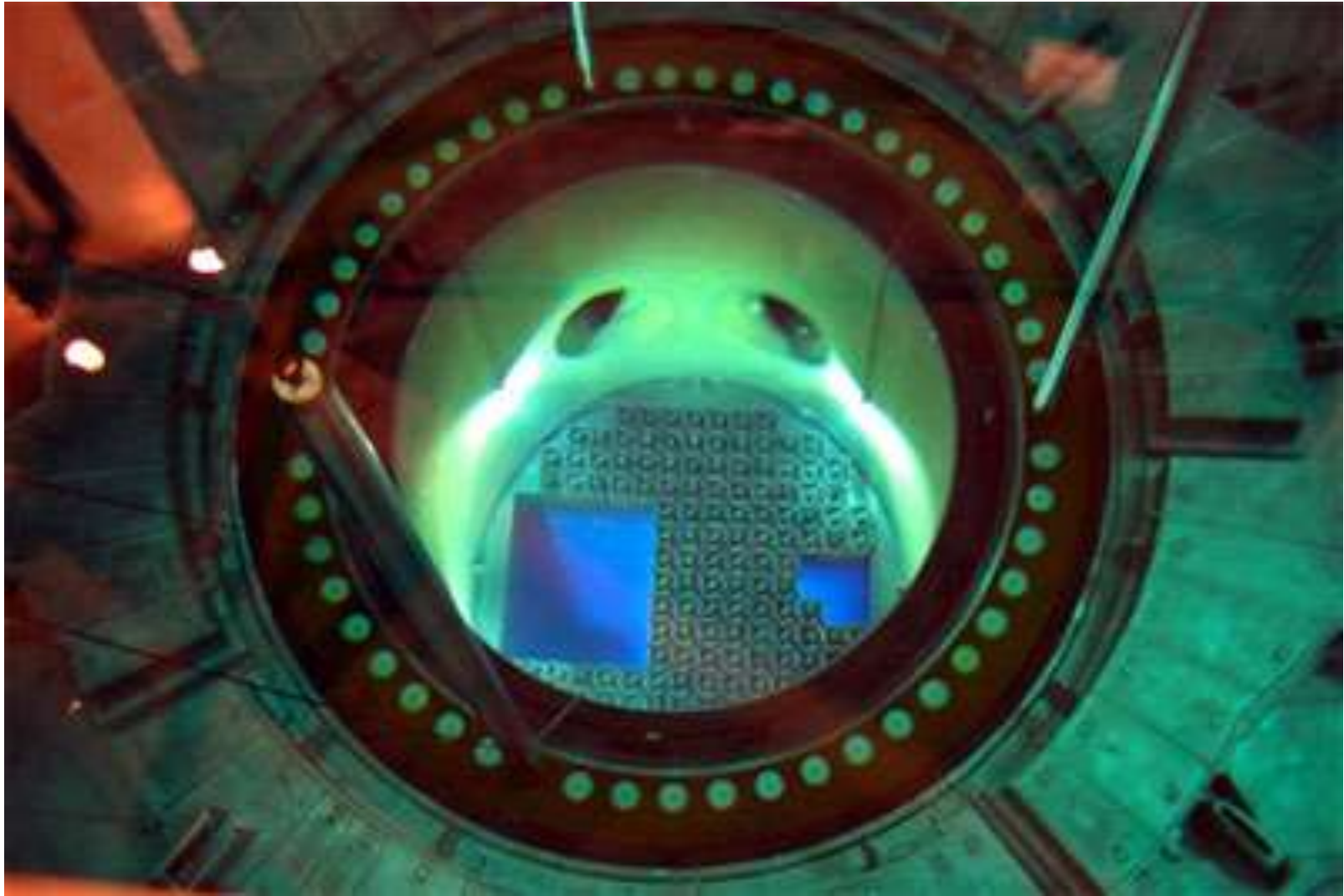
# $^{235}\text{U}$ Fission Cross Section















For a copy of this presentation, email James Miller at [jgmiller@vcu.edu](mailto:jgmiller@vcu.edu) and request either PowerPoint format or *pdf* format.