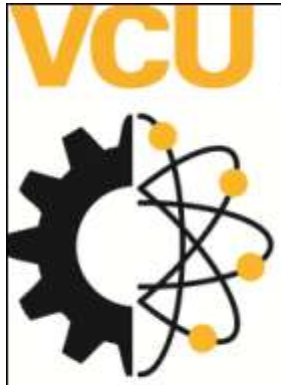


Virginia Commonwealth University

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

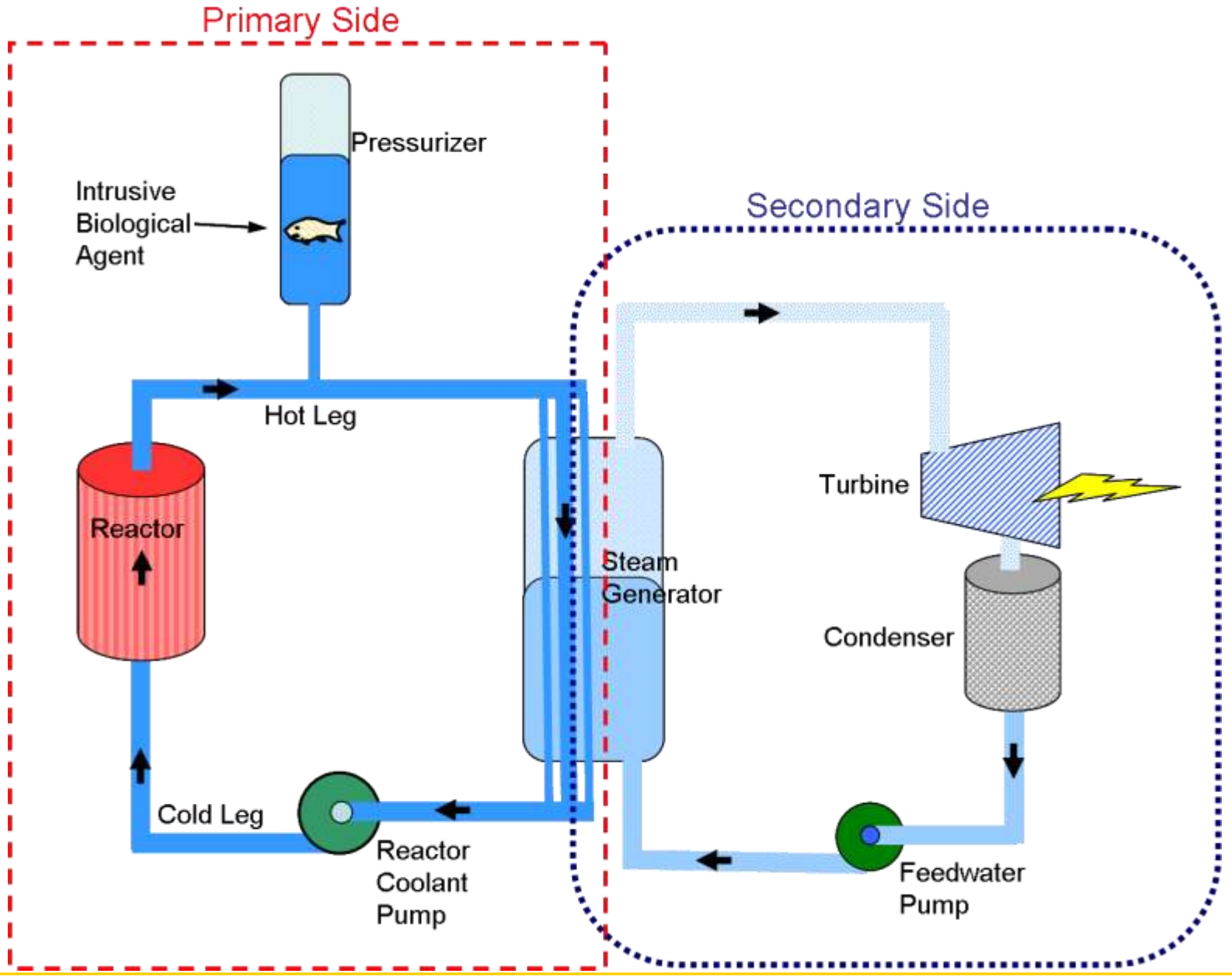
- **Dr. Sama Bilbao y Leon (Director of Nuclear Engineering)**
  - PhD, Nuclear Engineering, University of Wisconsin, Madison
- **Dr. Ross Anderson**
  - PhD, Nuclear Engineering, University of Virginia
- **Dr. Brian Hinderliter**
  - PhD, Engineering Physics, University of Virginia
- **Dr. Gokul Vasudevamurthy**
  - 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: •Nuclear medicine and other applications of nuclear science and technology •The future of nuclear power: fast breeder reactors, fusion technology, nuclear power and other power sources. •History of the US Nuclear Navy	TBD

Thanks to Keith Welch of Jefferson Lab for selected slides.

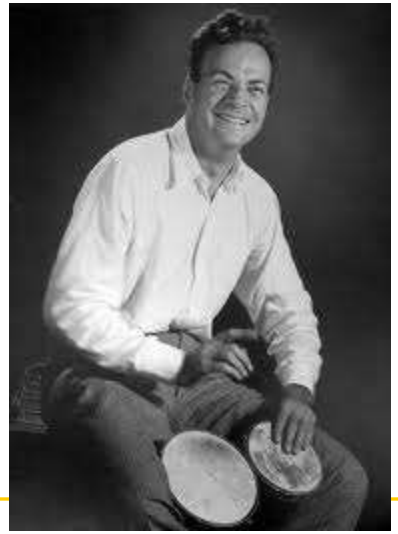
Nuclear Reactor

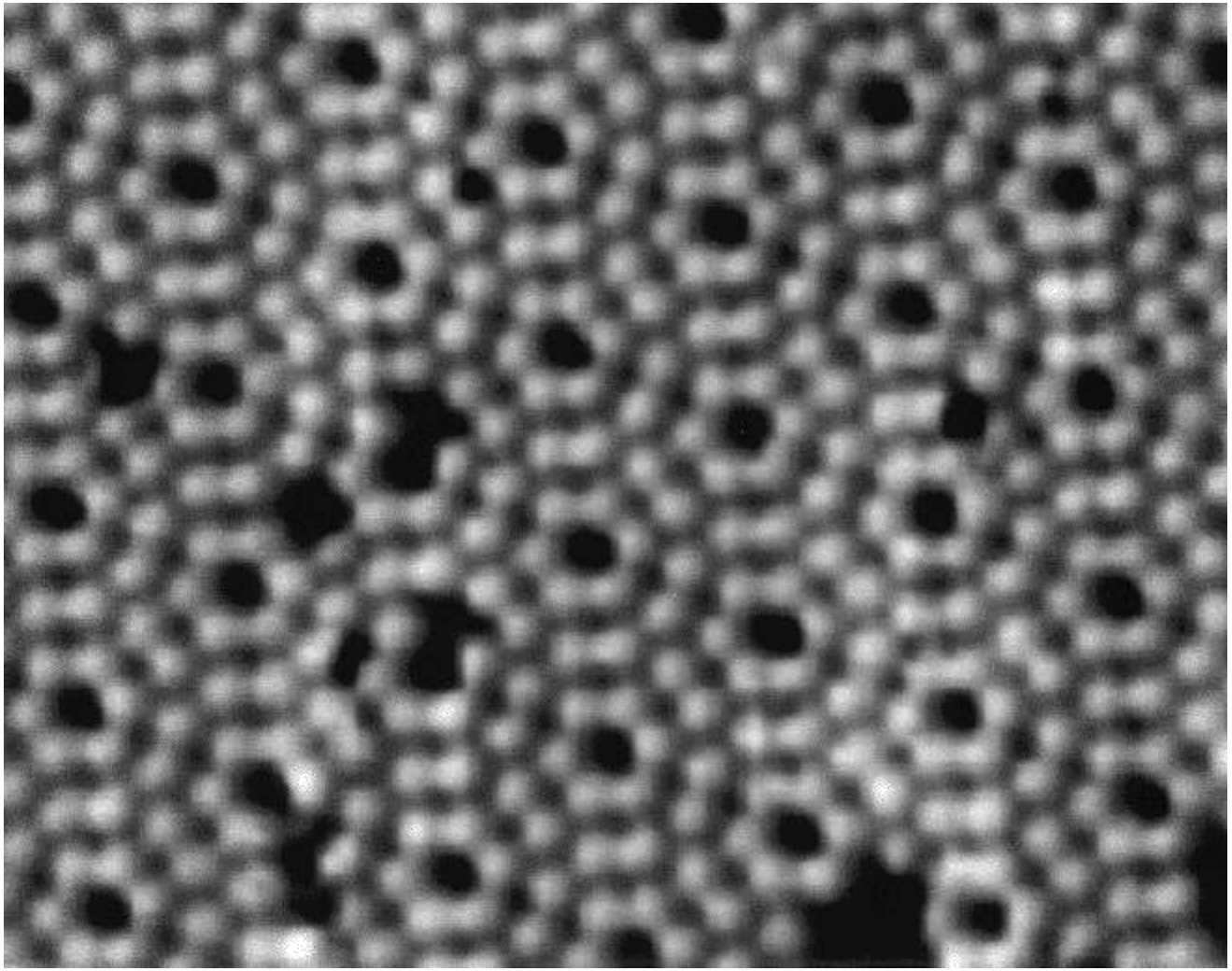


Atomic Hypothesis

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





VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

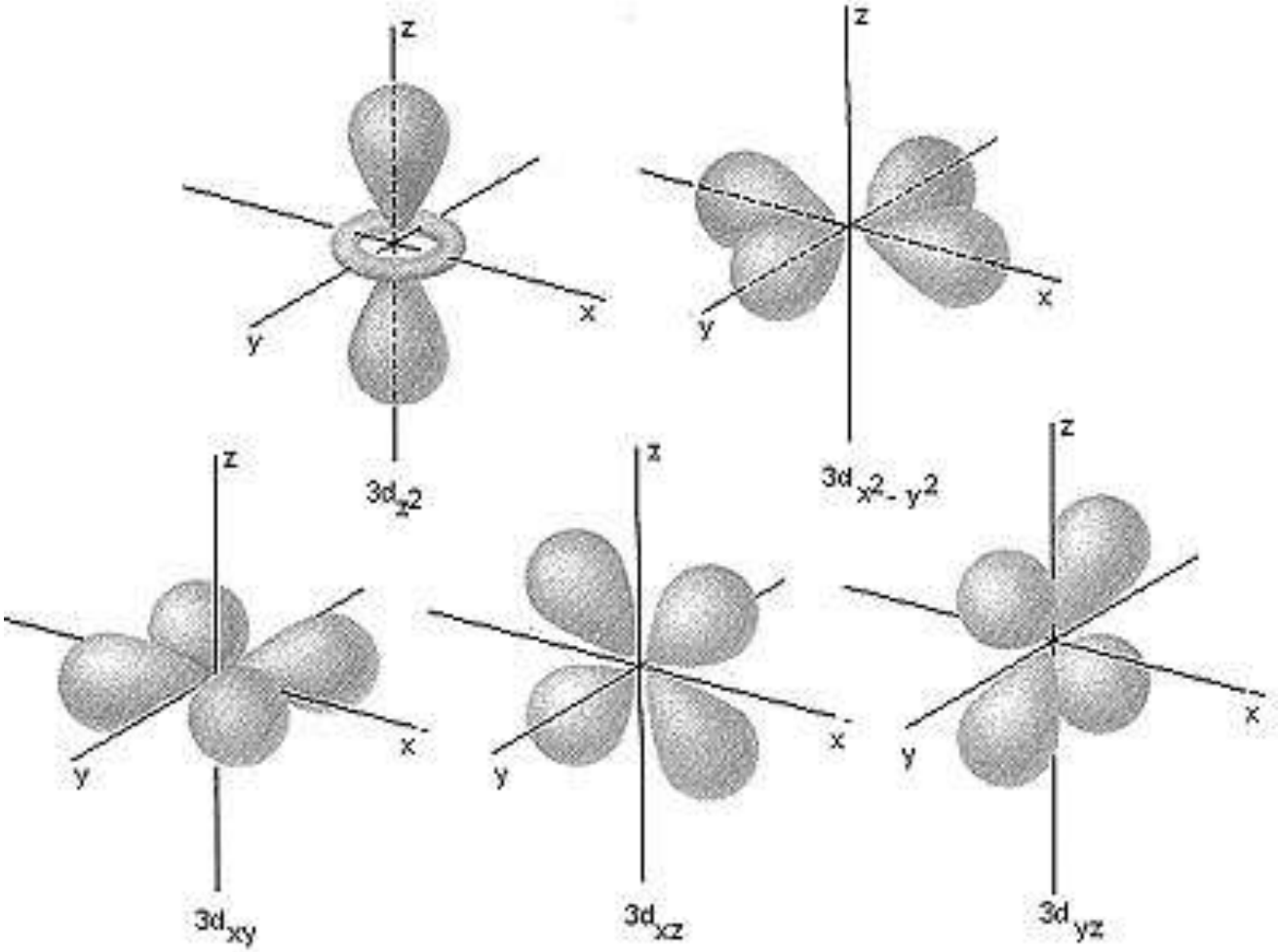
Elementary Particles

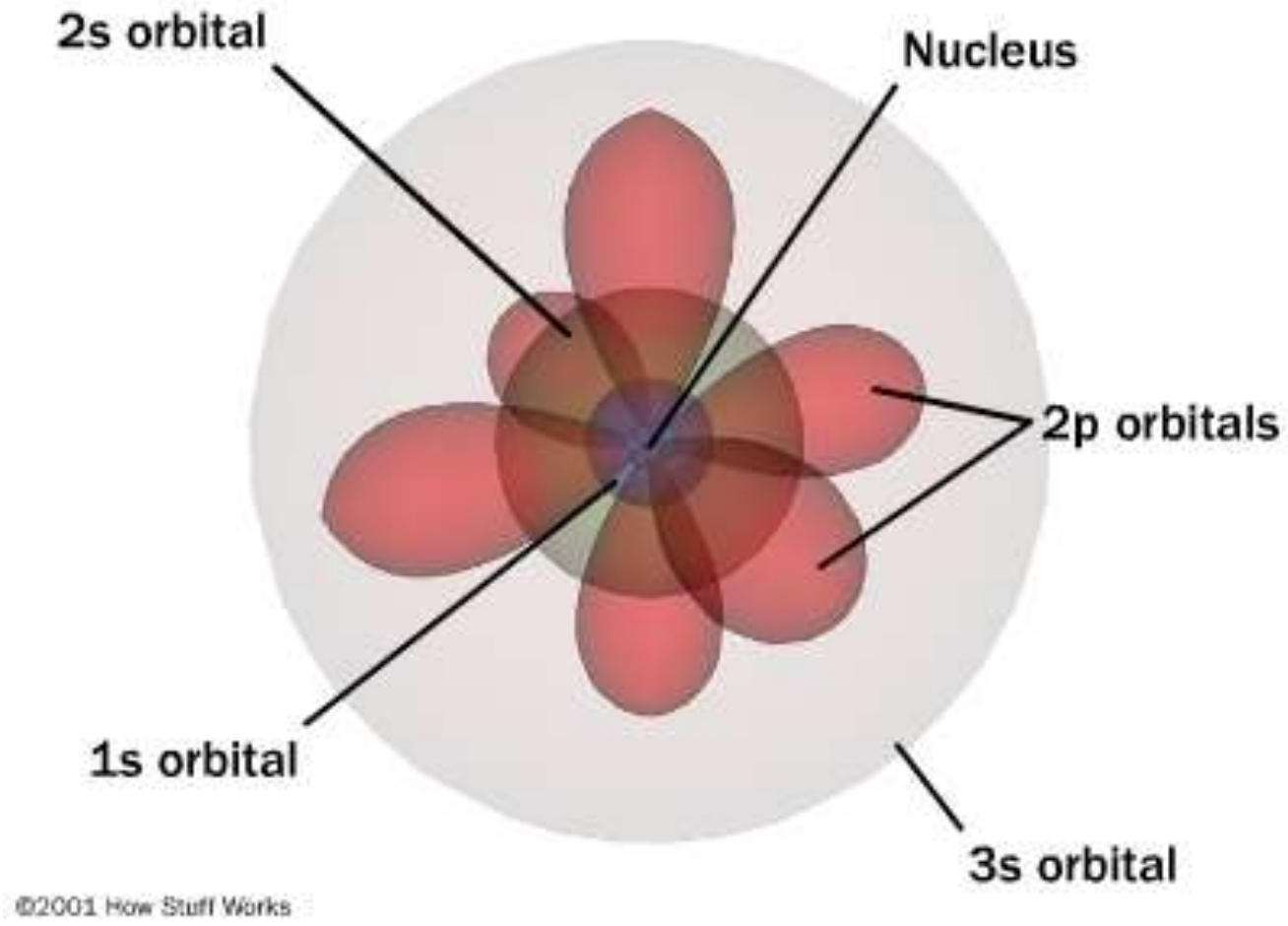
proton – positively charge nucleon 

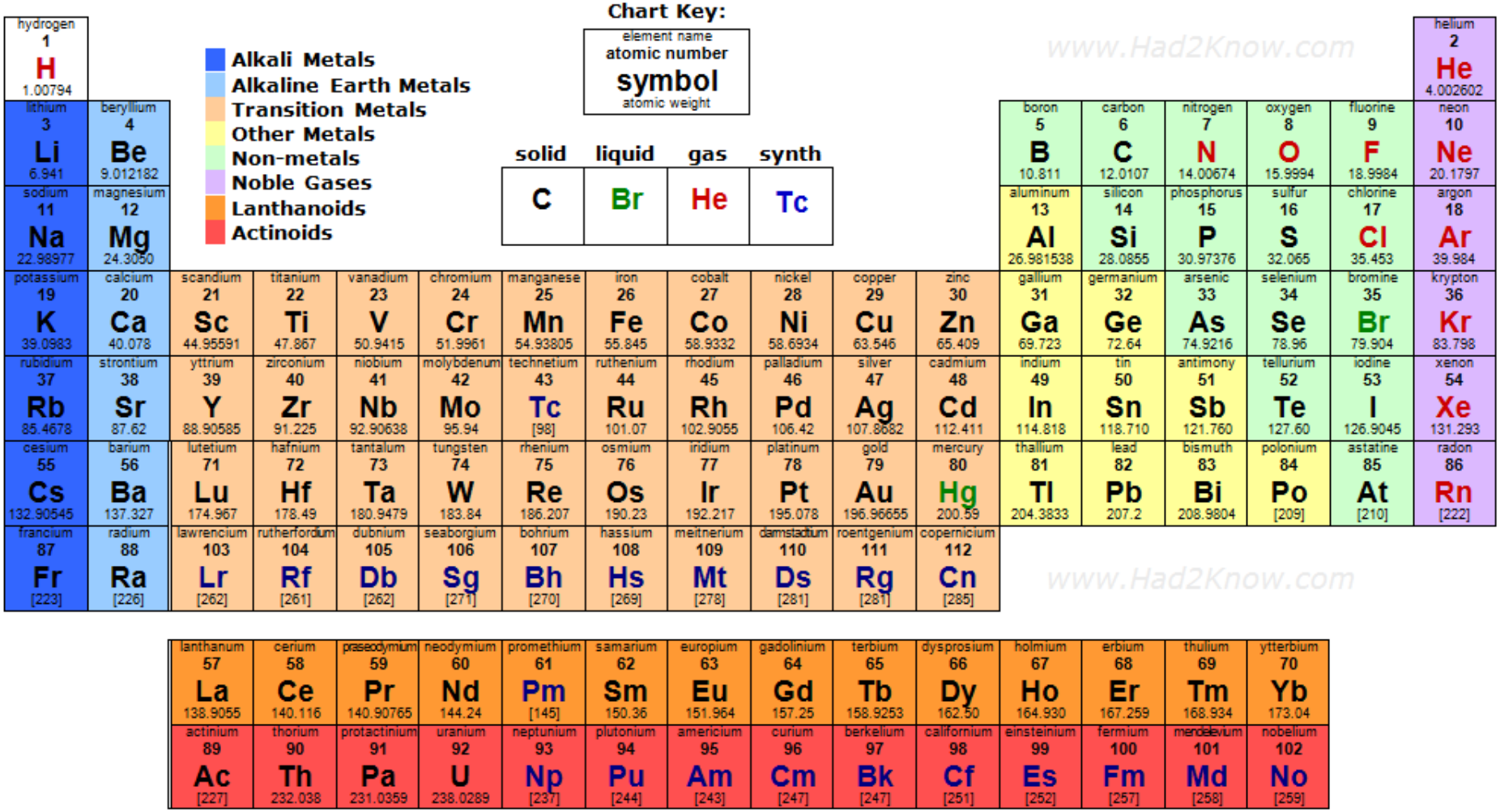
neutron – neutral nucleon 

electron – negatively charged 

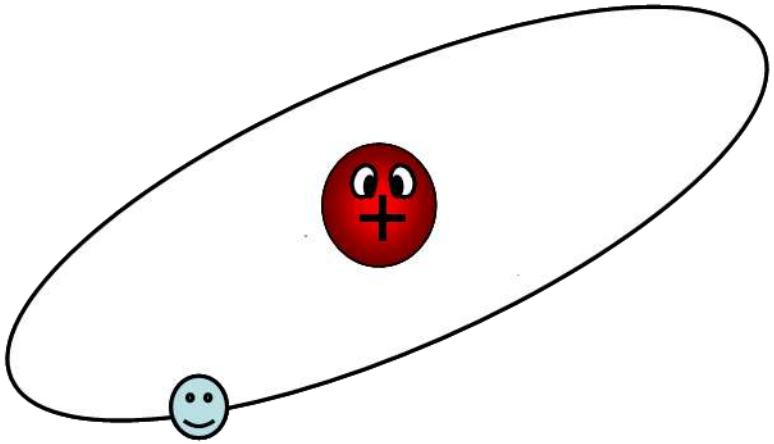
VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering




2s orbital
Nucleus
2p orbitals
1s orbital
3s orbital
©2001 How Stuff Works



VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

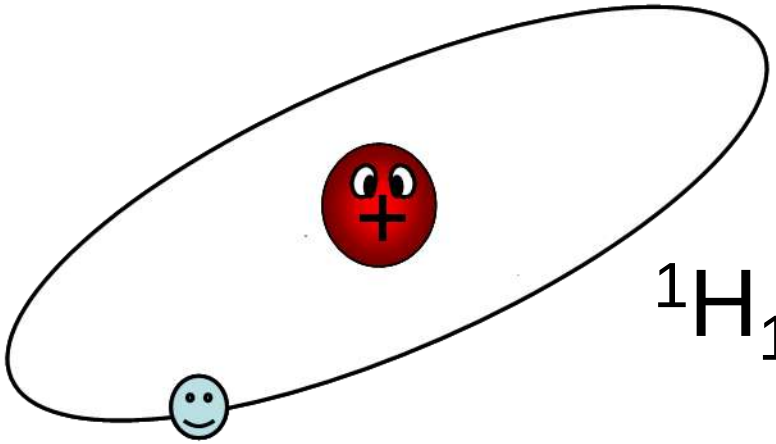


$^{1}H_{1}$

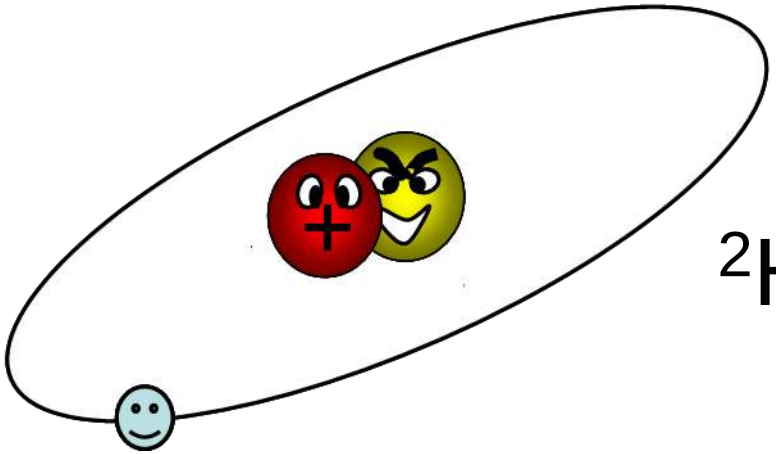
$^{A}X_{Z}$

A = total number of nucleons

Z = number of protons

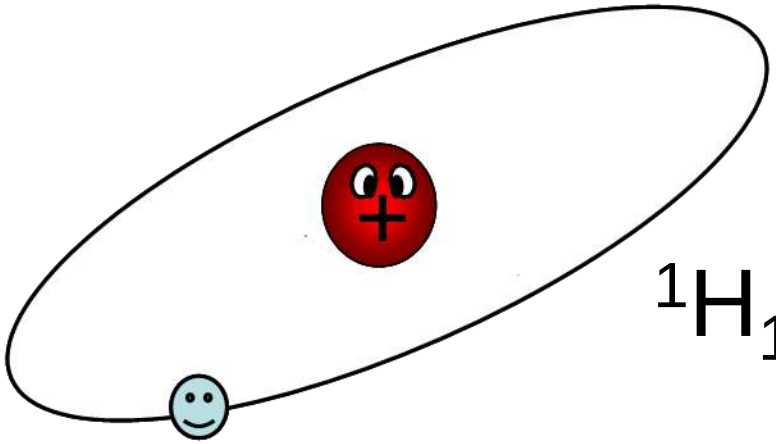


$^{1}H_{1}$

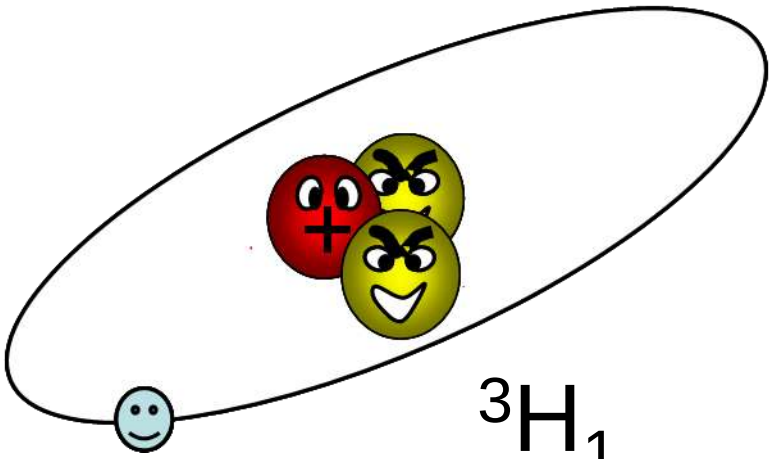


$^{2}H_{1}$

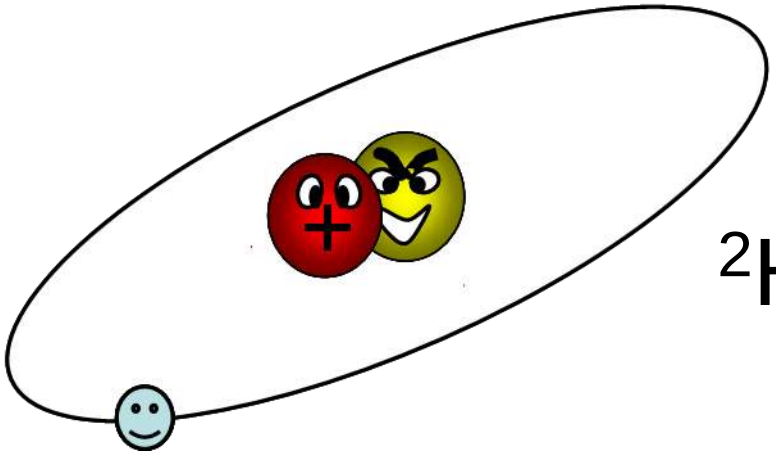
VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering



$^{1}H_{1}$

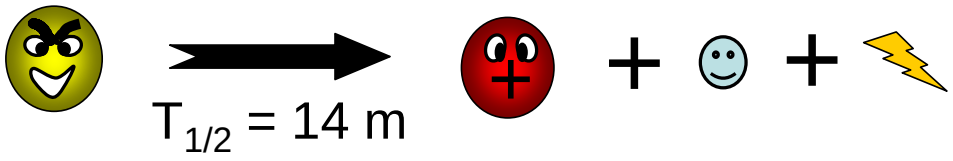


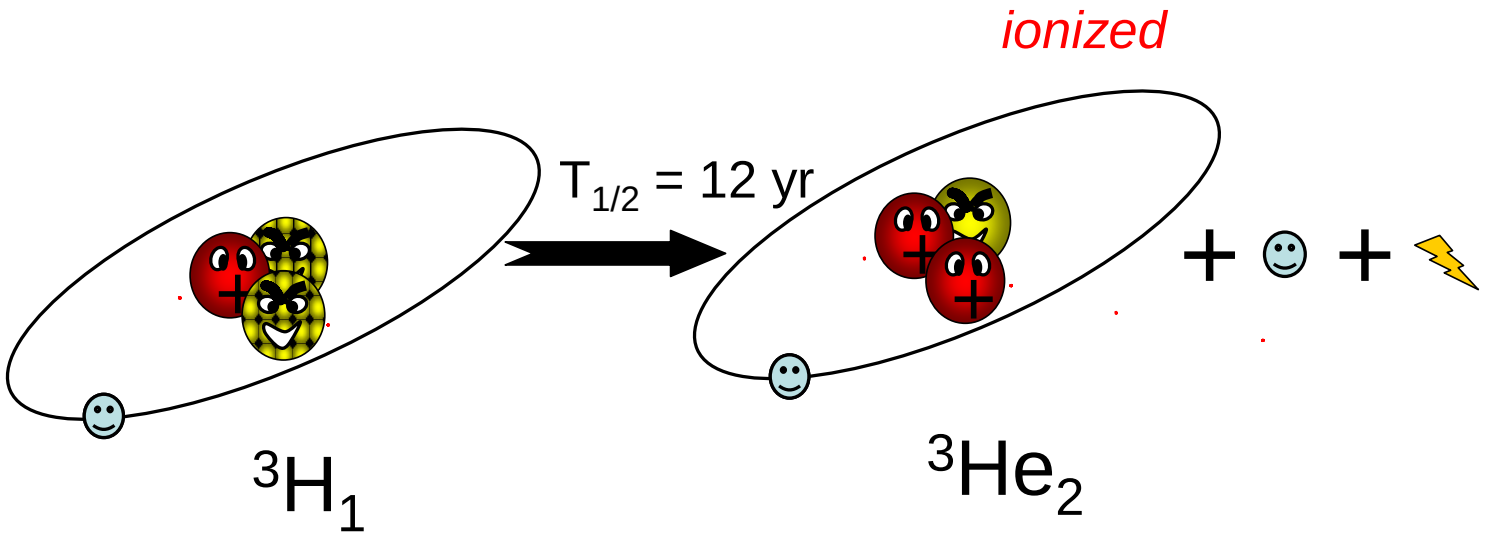
$^{3}H_{1}$

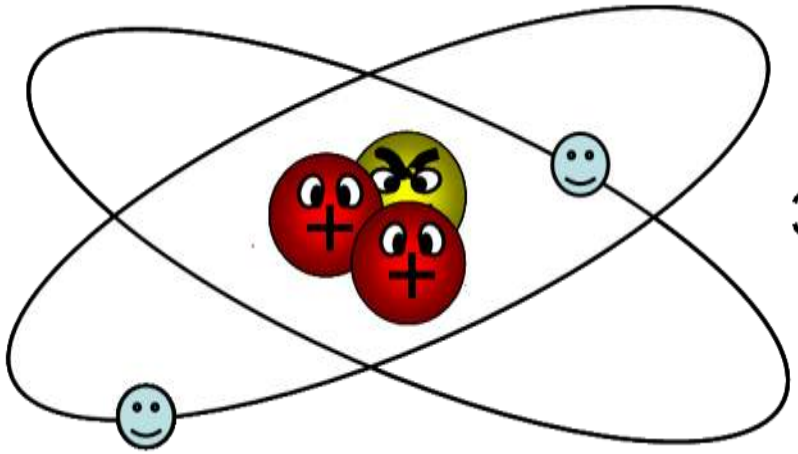


$^{2}H_{1}$

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

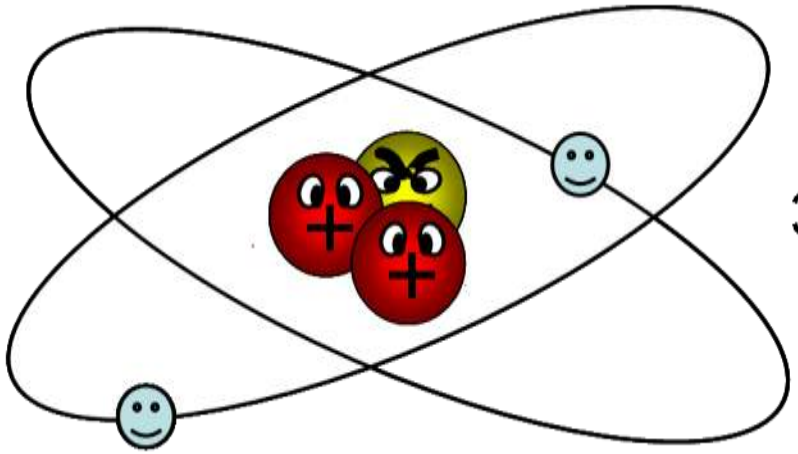






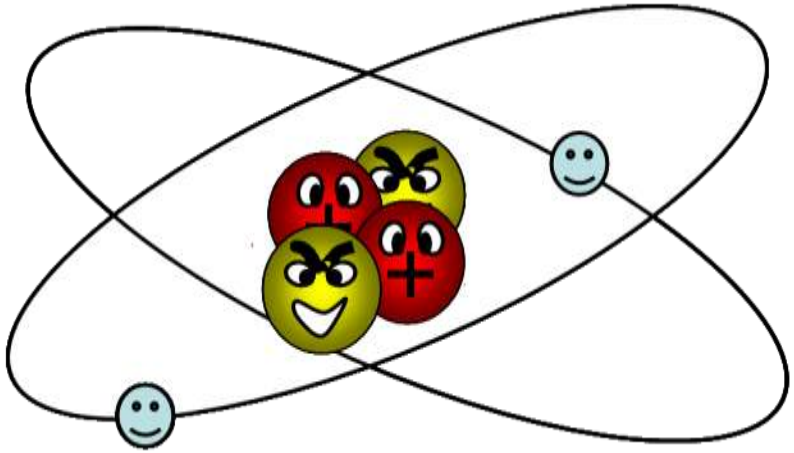
$^{3}He_{2}$

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering



$^{3}He_{2}$

$^{4}He_{2}$



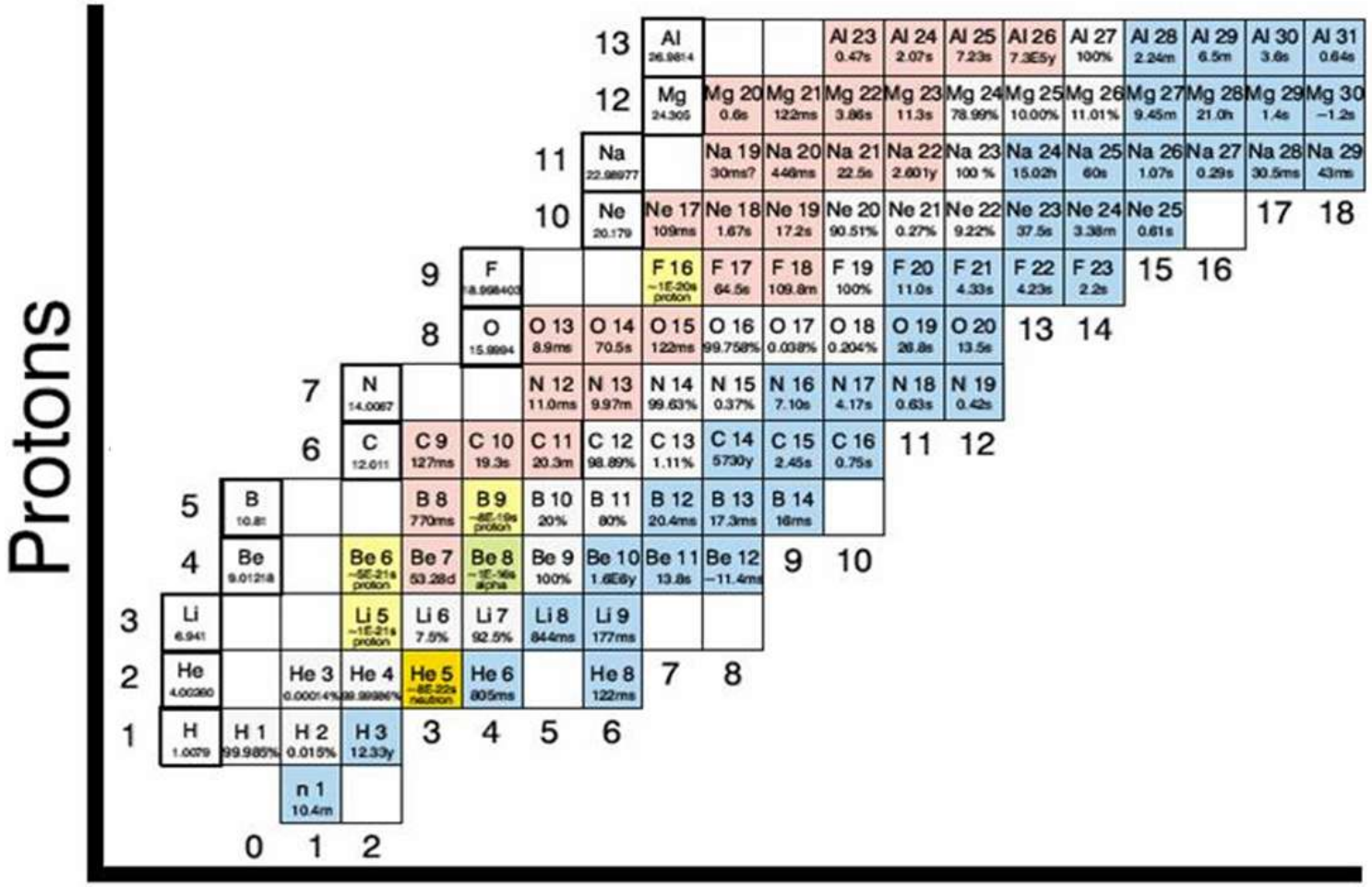
VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

NUCLIDE = ISOTOPE

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

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

CHART OF THE NUCLIDES

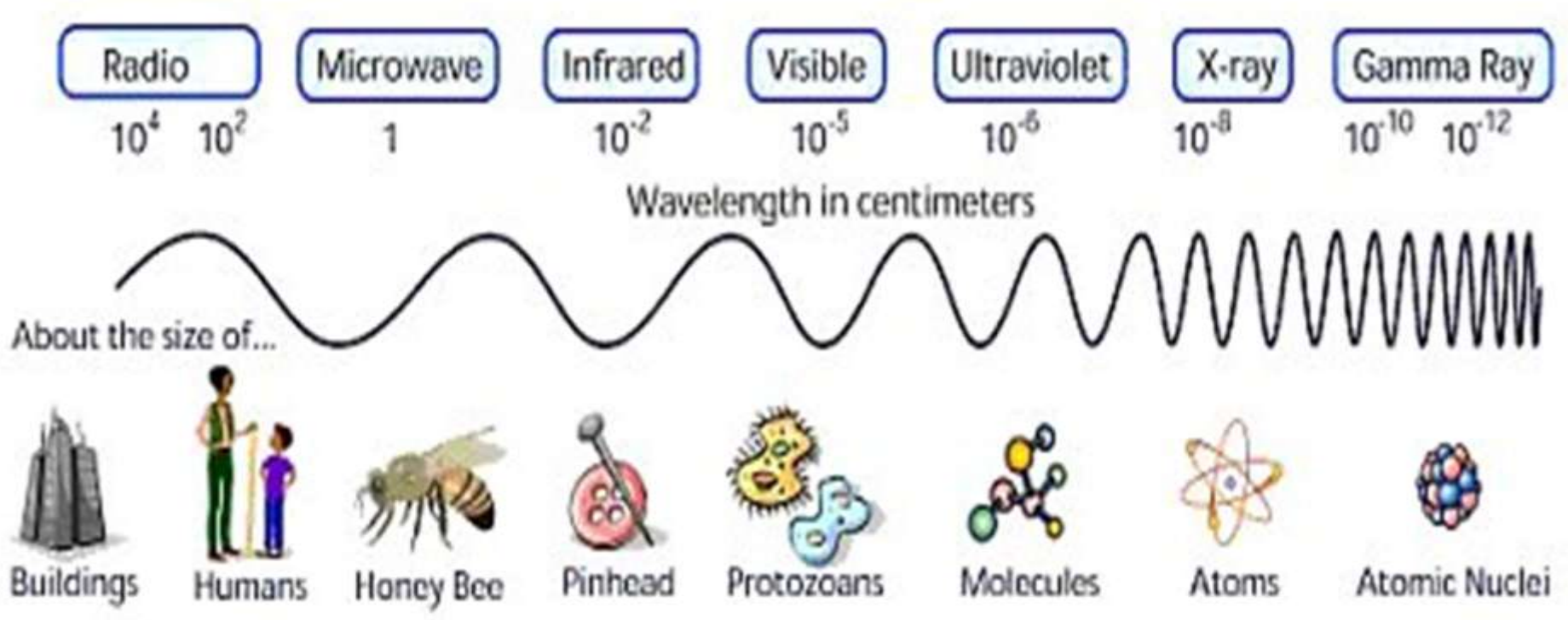


Forces of Nature

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

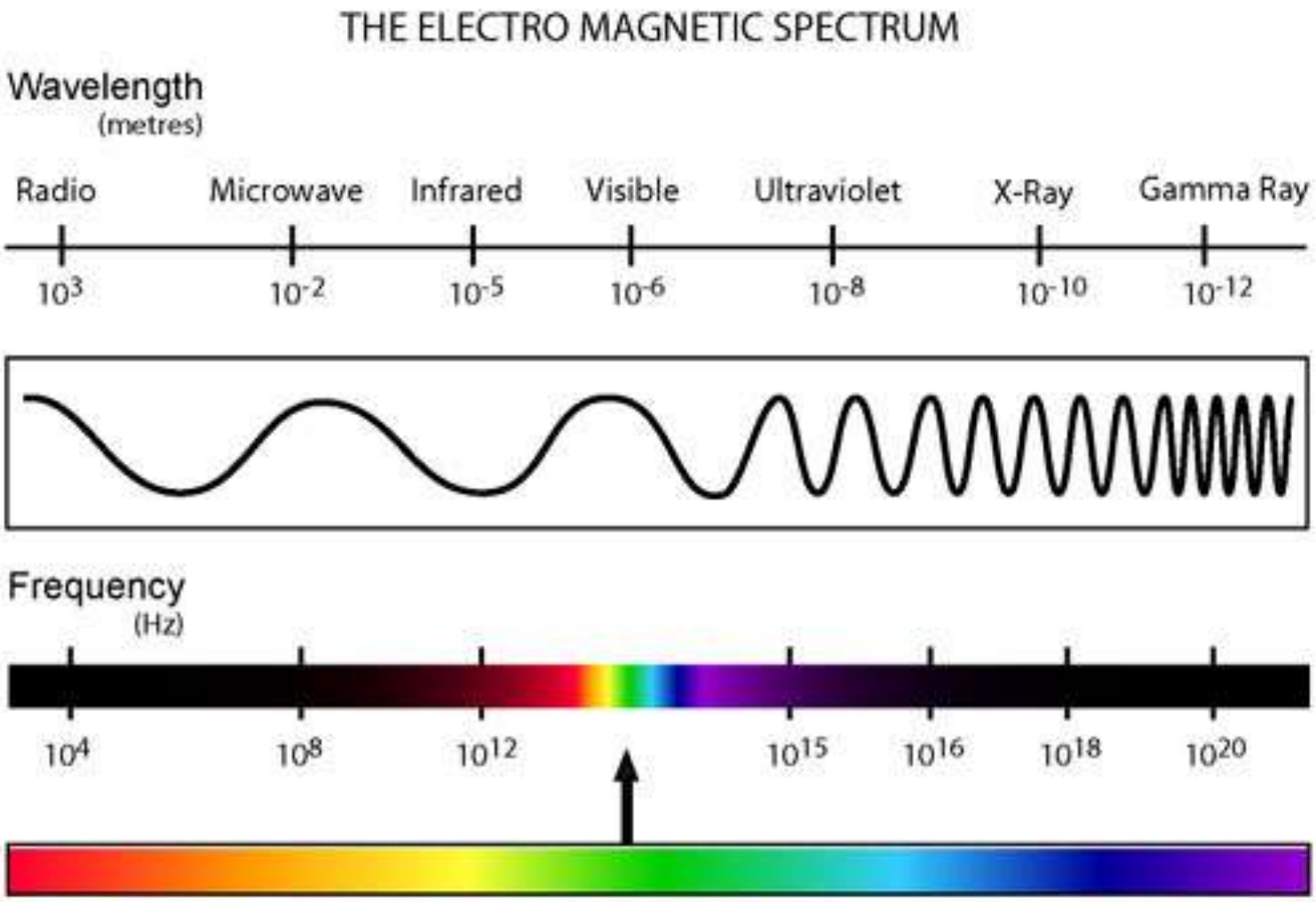
VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

Electromagnetic Spectrum



Particles can also be described by

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

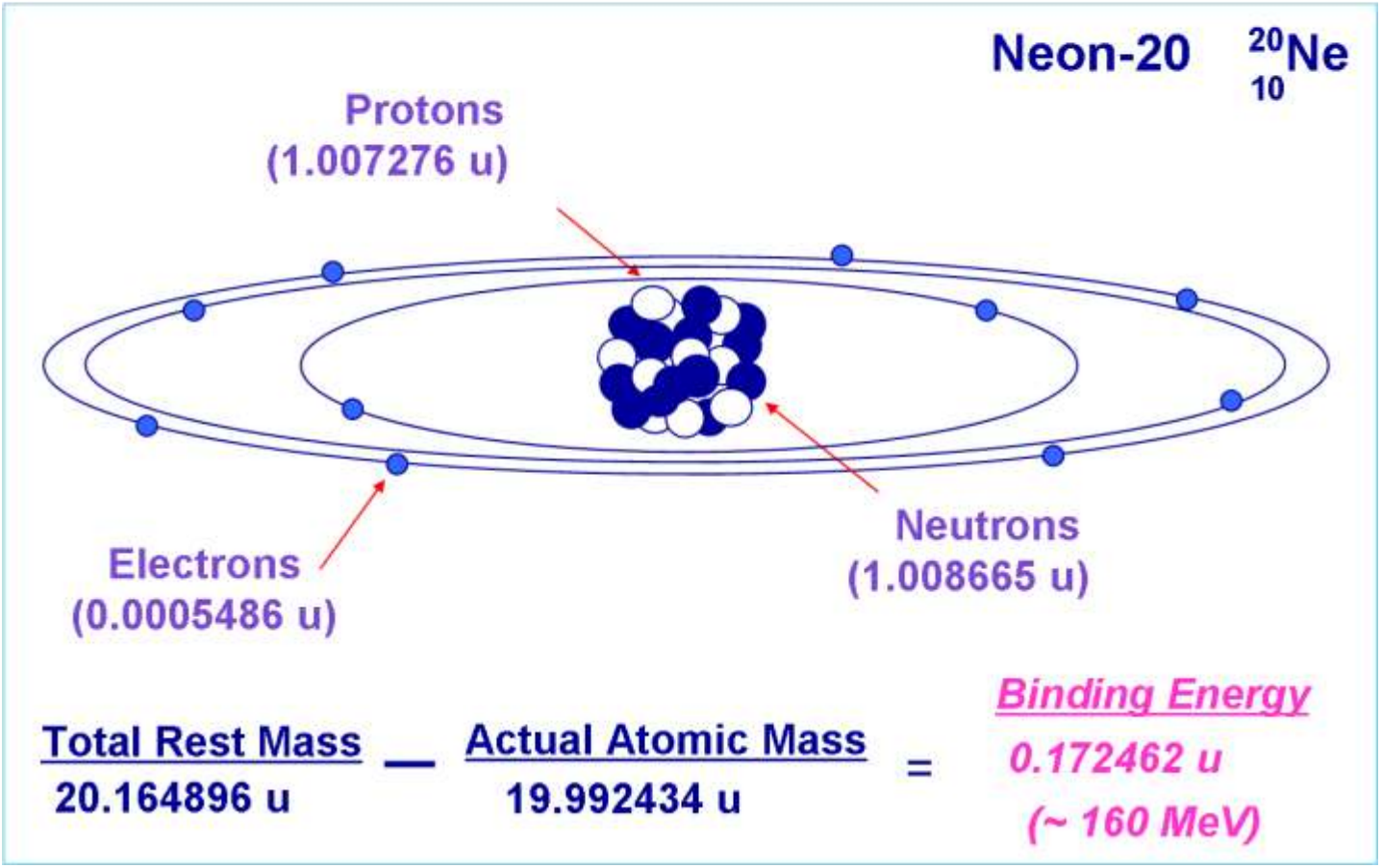

THE ELECTRO MAGNETIC SPECTRUM
Wavelength
(metres)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-Ray
Gamma Ray
10^{3}
10^{-2}
10^{-5}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
Frequency
(Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}

$E = mc^2$

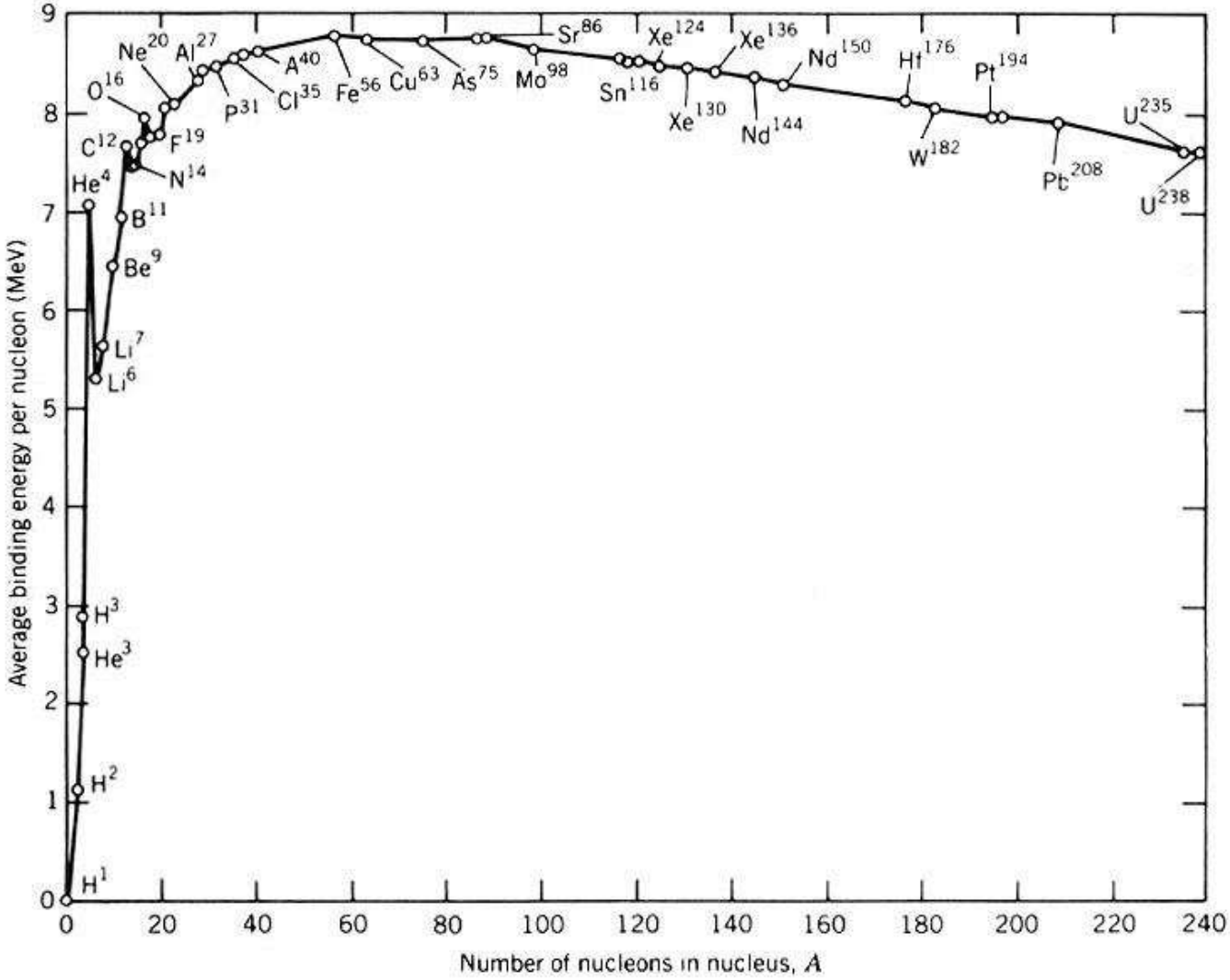
- Matter is “condensed” or "frozen" energy
- Combines classical physics laws of *conservation of mass* and *conservation of energy* into ***conservation of mass/energy***

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

Matter = Energy



VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering



Radiation

- Radiation = Energy in transit

  → the transfer of energy by waves or particles

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

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:

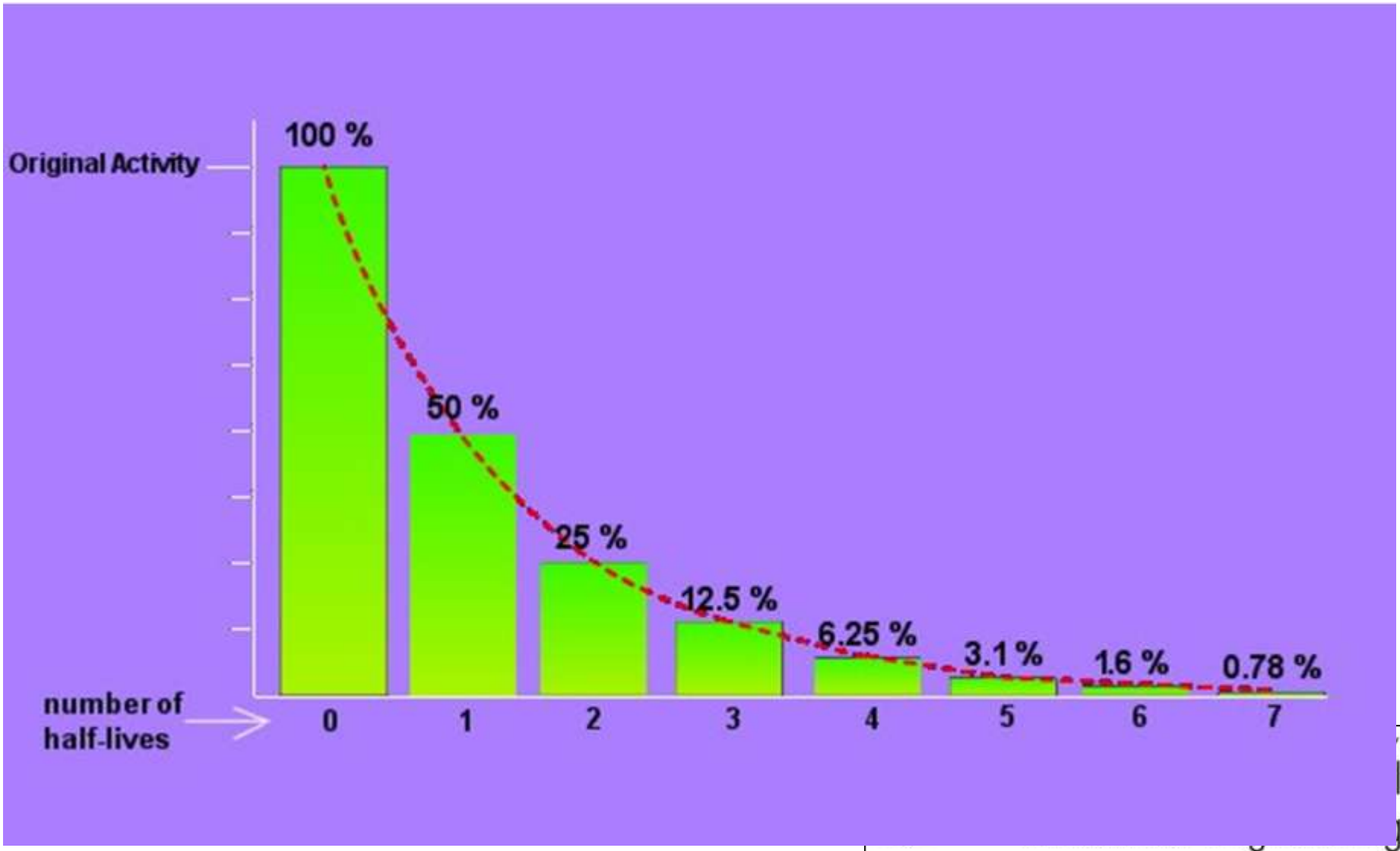
  radio, microwave, ultraviolet, infrared, visible

Sources of Radiation

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

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

Radioactive Half-life



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

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

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

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

Activity = # of disintegrations per sec

$A = \lambda N(t)$

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

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: α Decay

$$^{A}_{Z}X \longrightarrow ^{A-4}_{Z-2}Y + \alpha$$

Daughter Nucleus

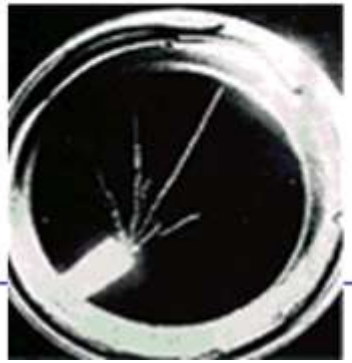
$^{222}_{86}Rn$

Parent Nucleus

$^{226}_{88}Ra$

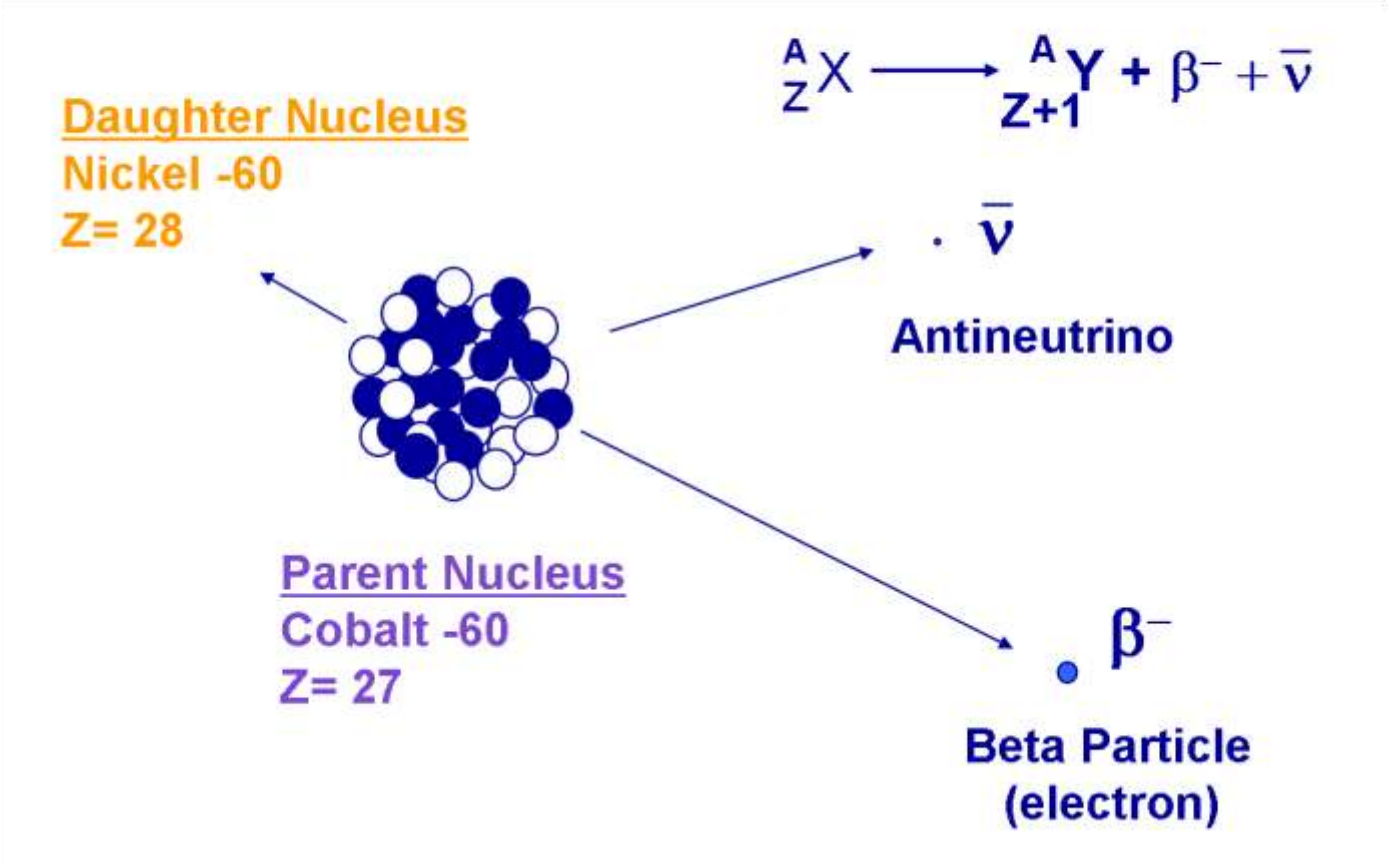
$^{4}_{2}\alpha^{++}$

Alpha Particle
(Helium Nucleus)



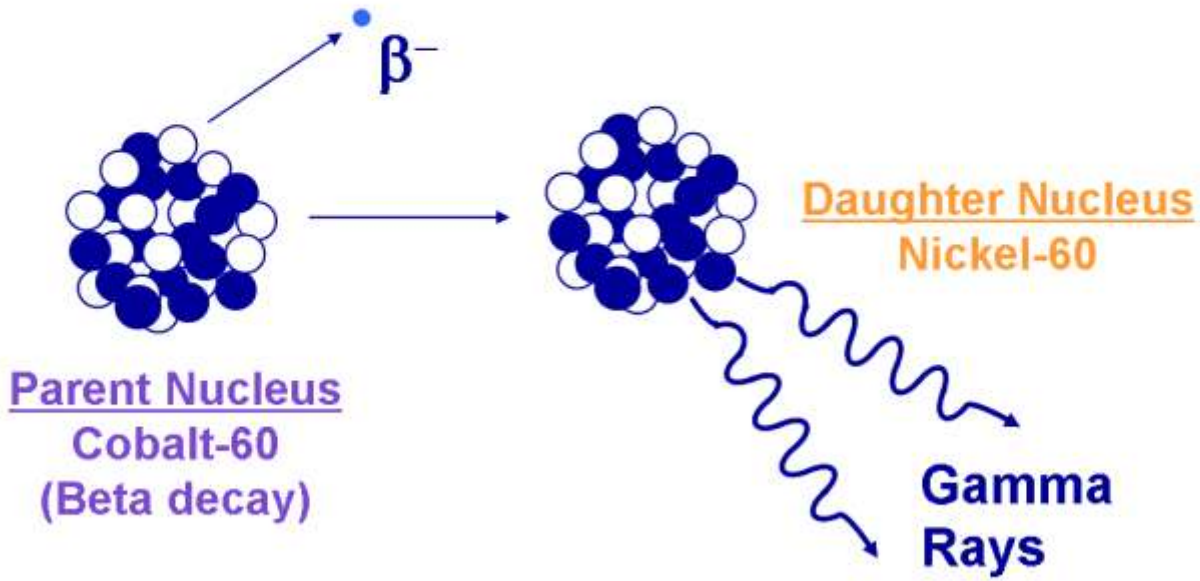
VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

Radioactivity: β^- Decay

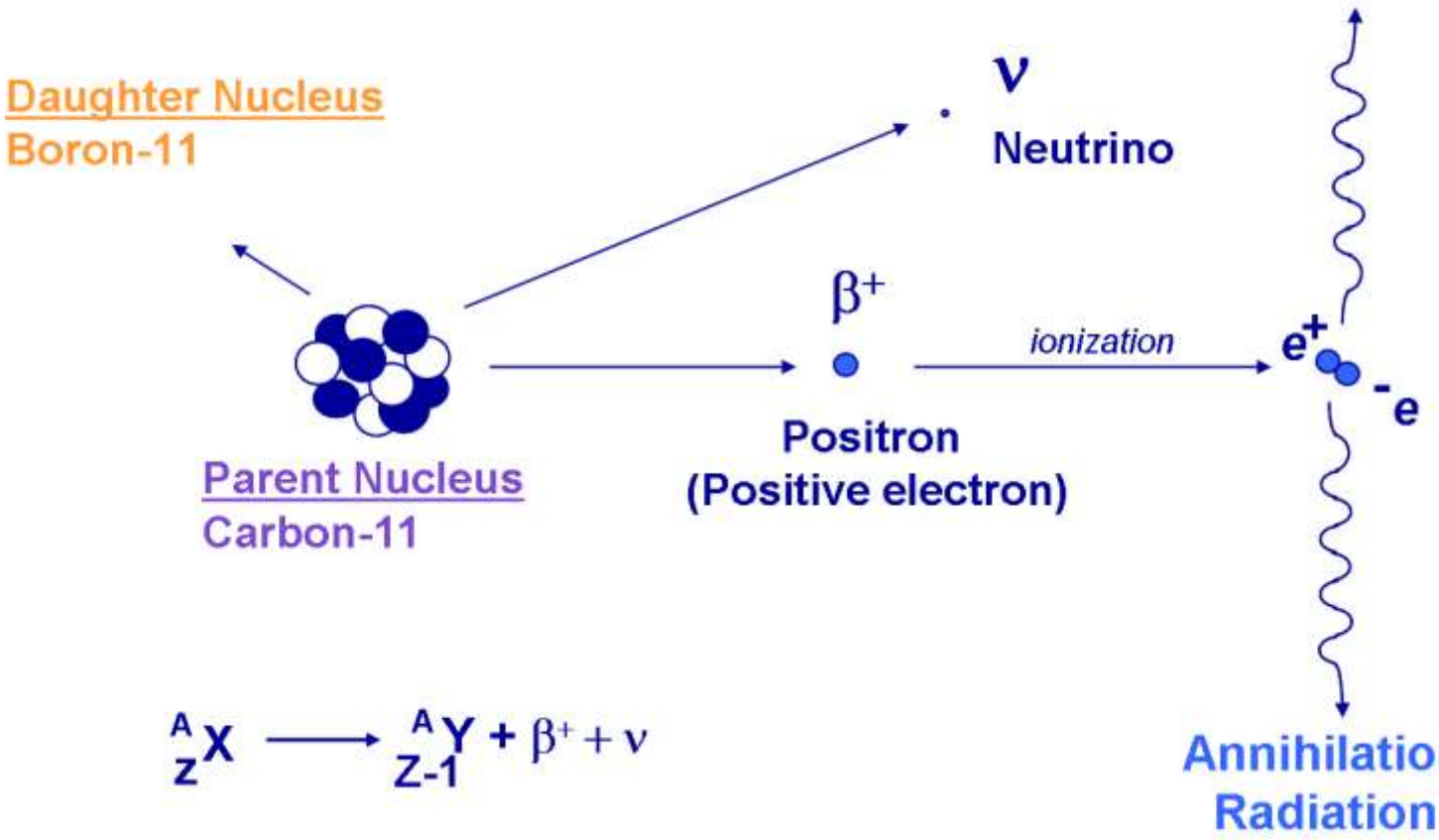


VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

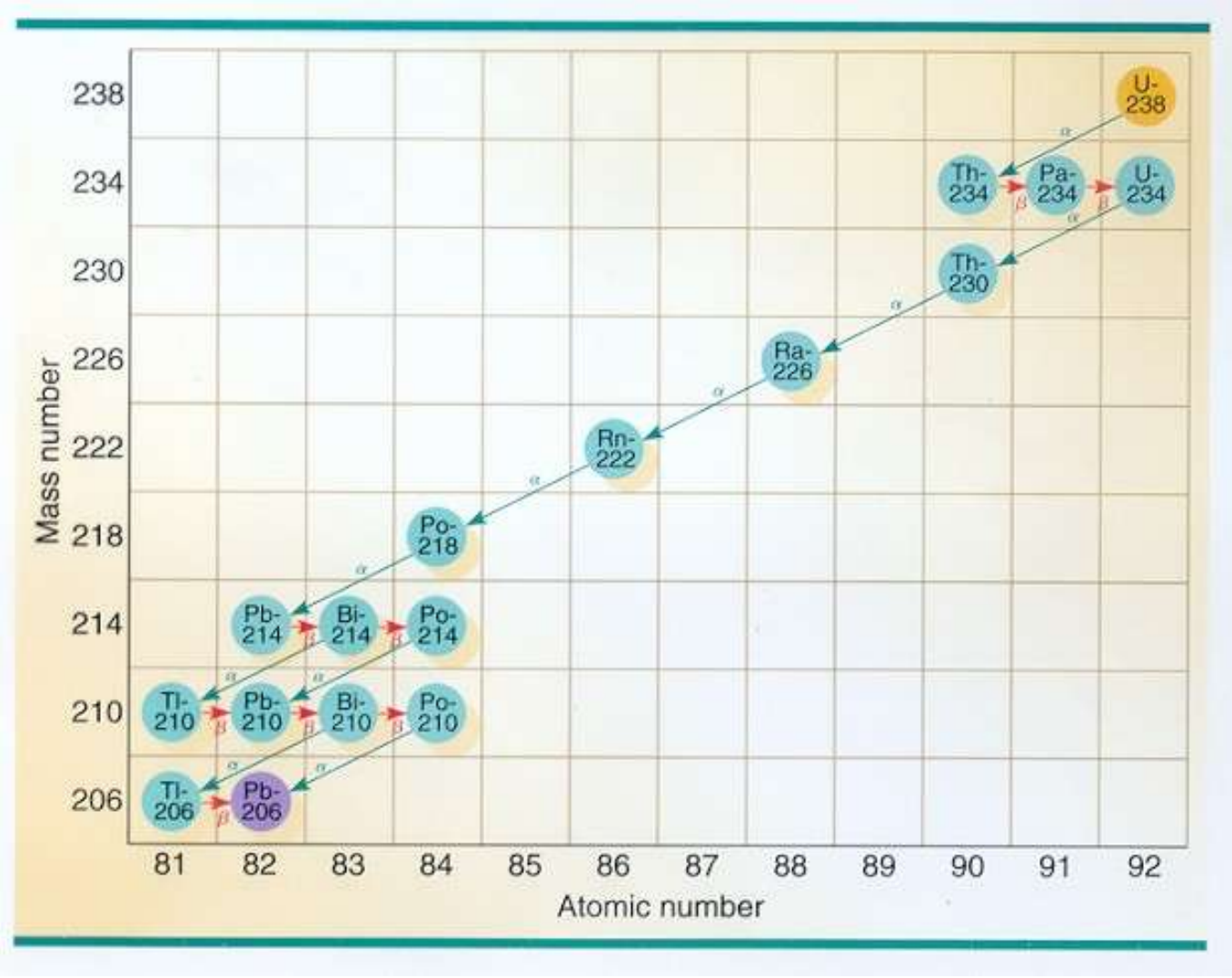
Gamma Emission

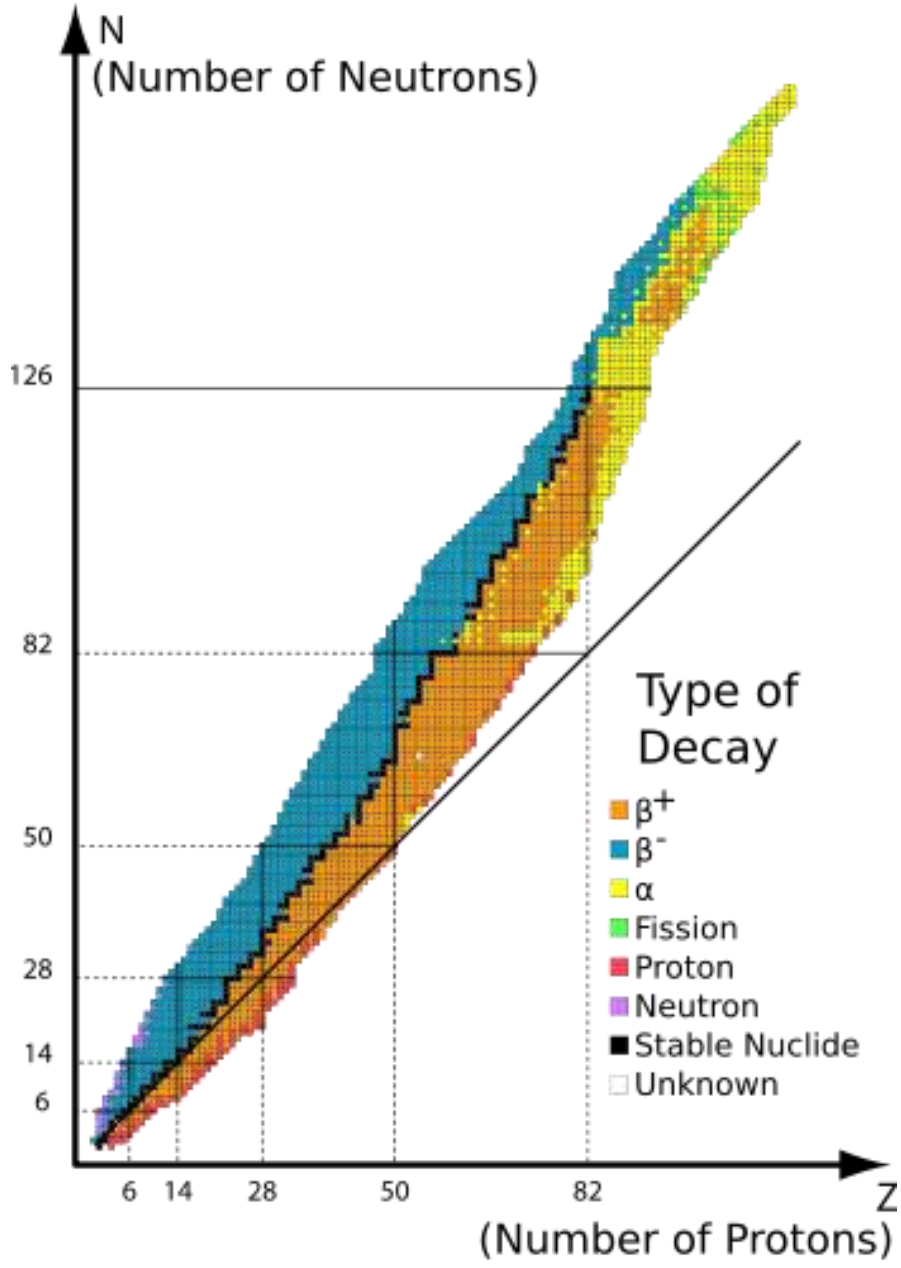


Radioactivity: β^+ Decay



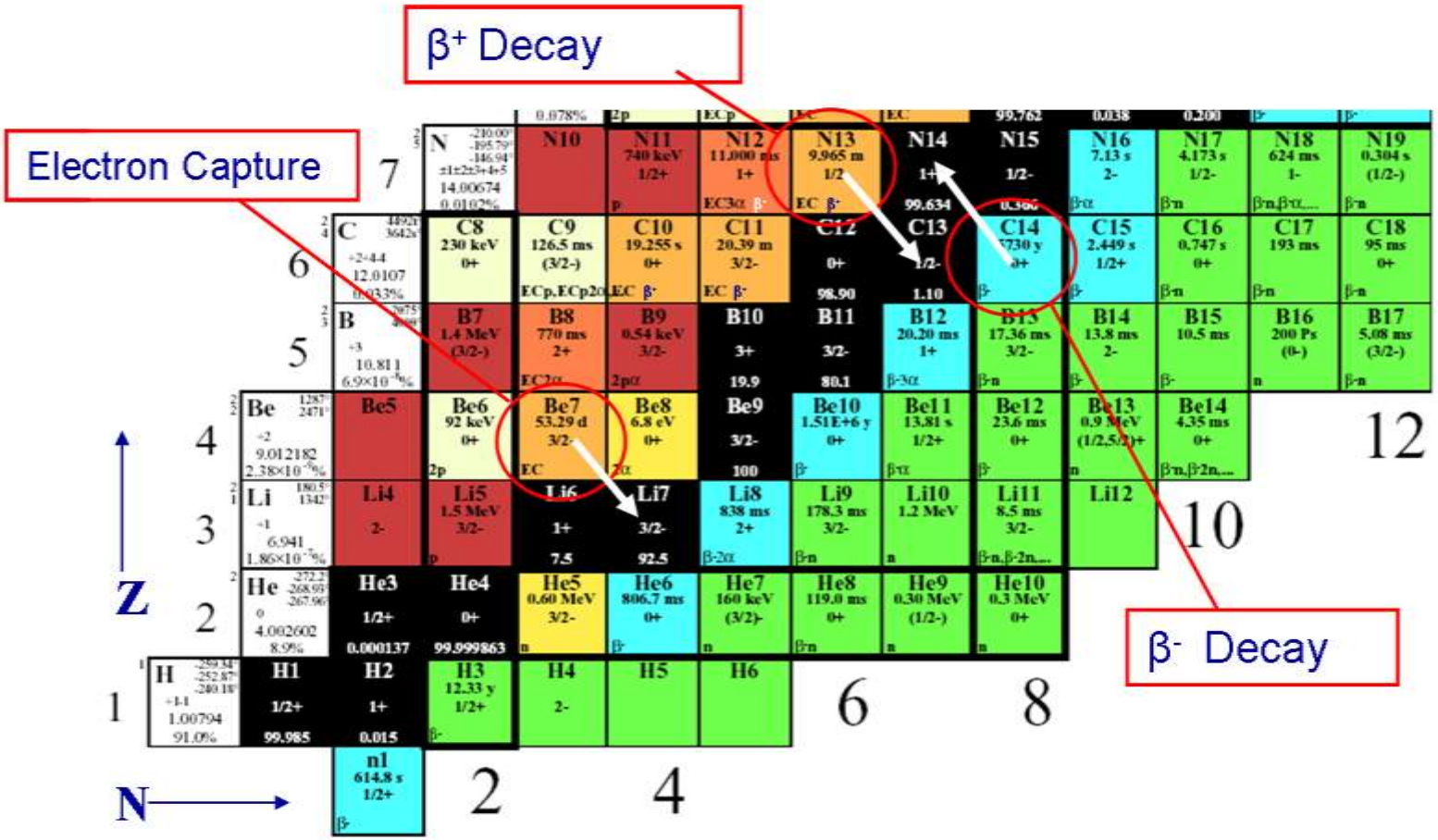
$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + \beta^+ + \nu $$





VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

Results of Decay Processes

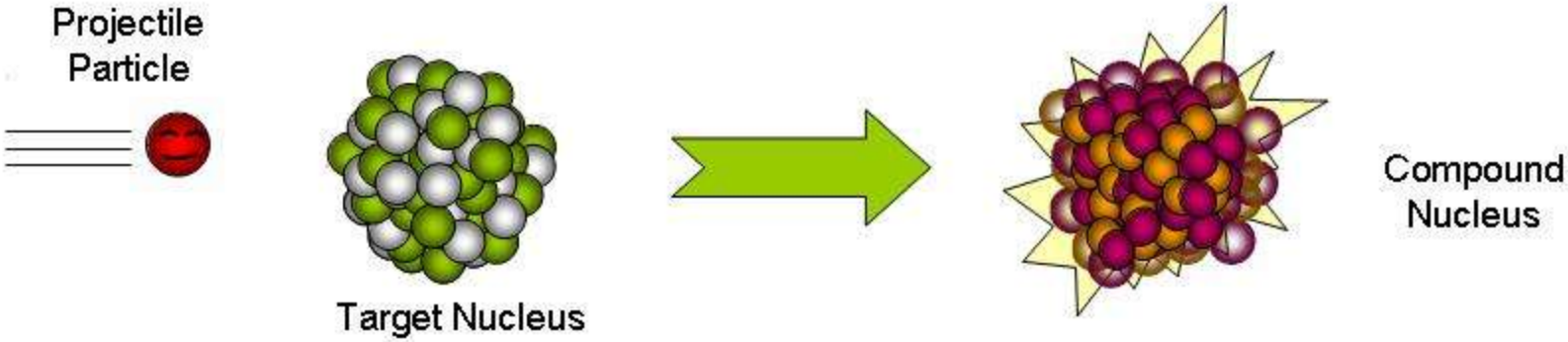


Sources of Radiation

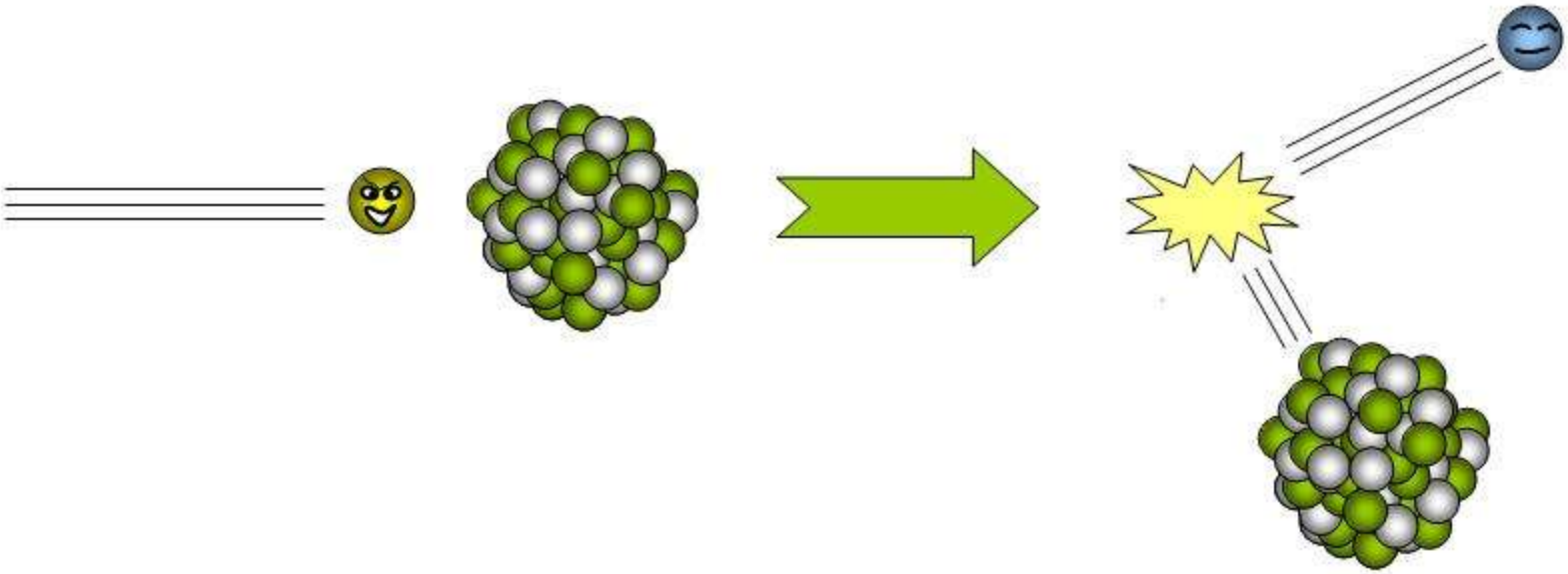
- Radioactive decay
- "Extra-nuclear" processes – X-rays
- Nuclear Reactions: fission, fusion, other

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

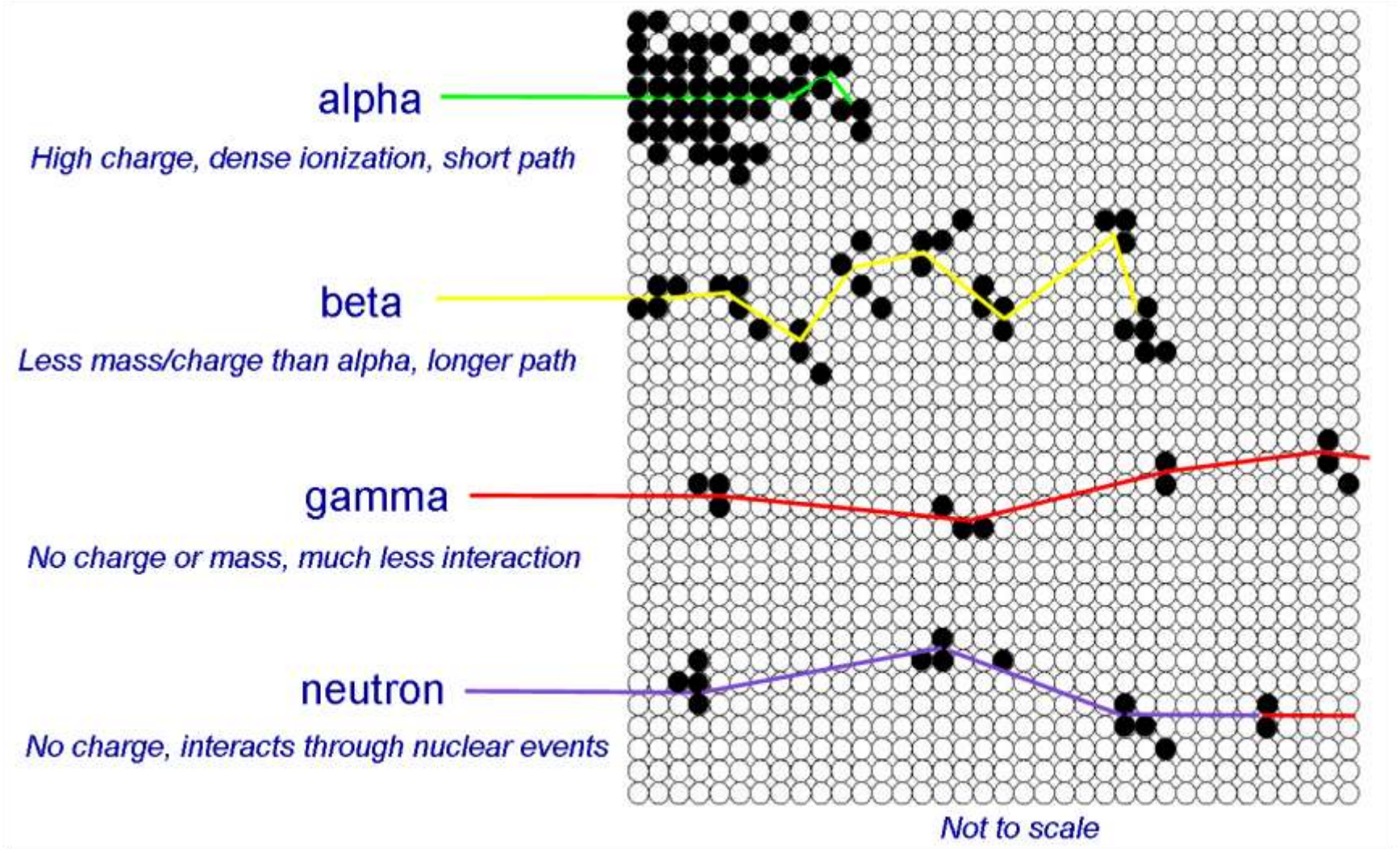
Absorption



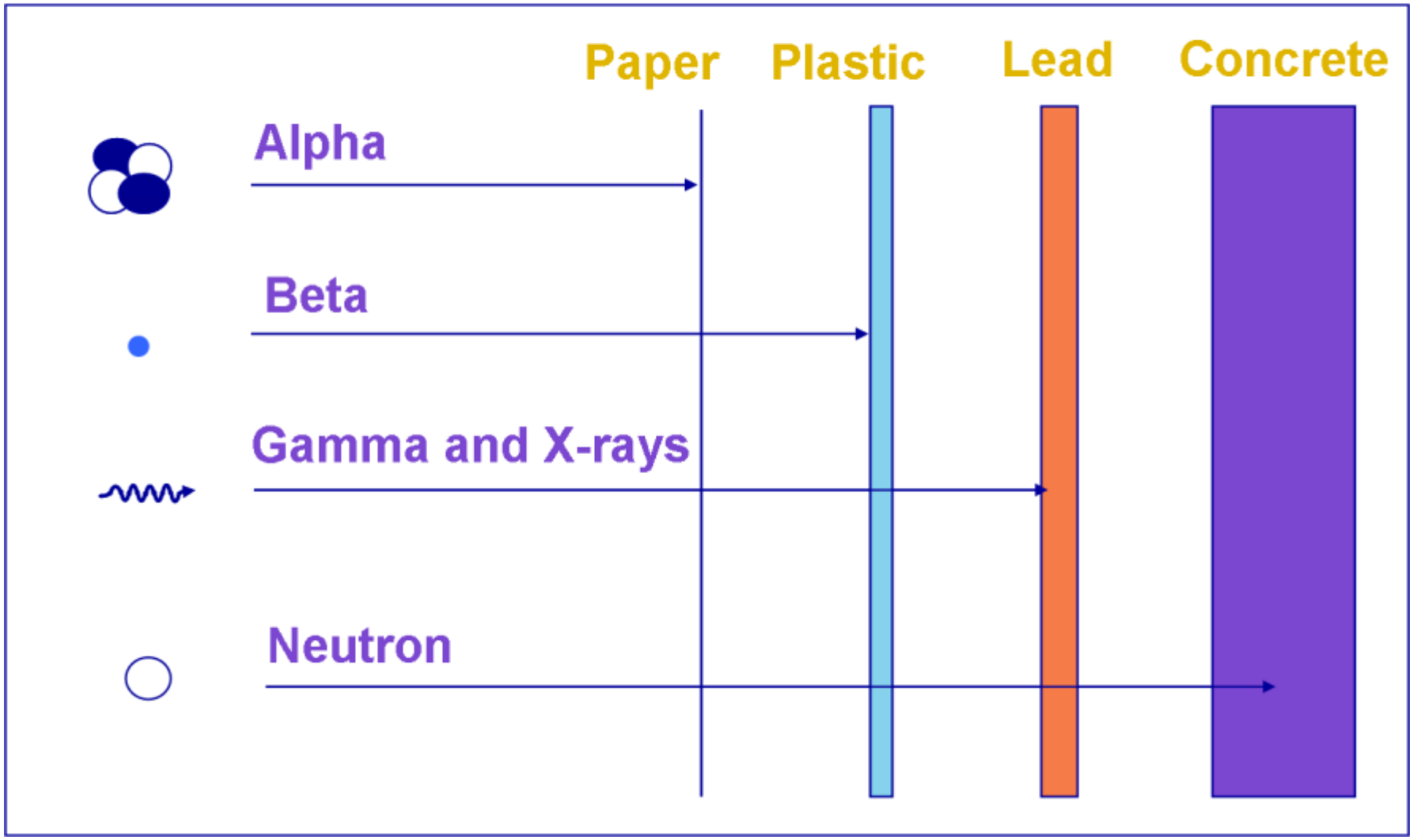
Scatter

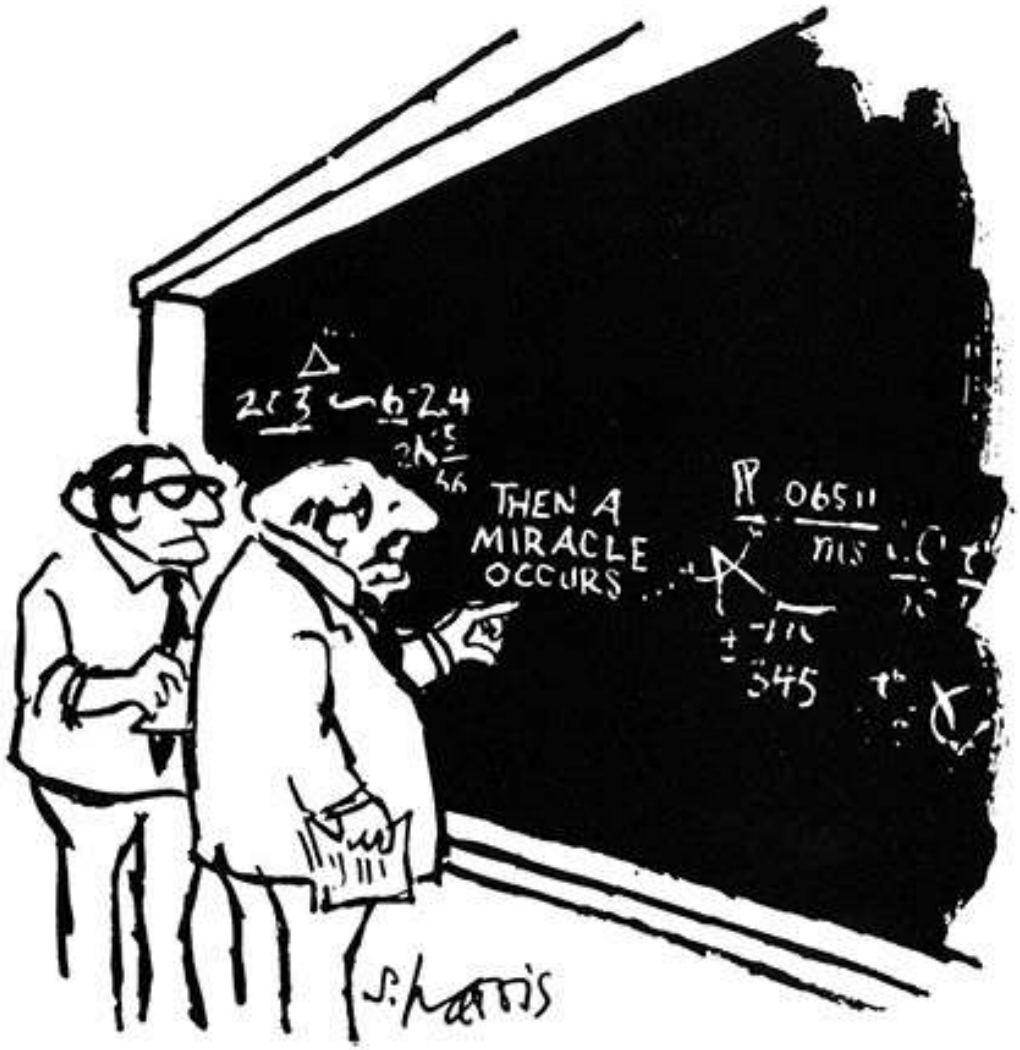


Radiation Interaction and Penetration Through Matter



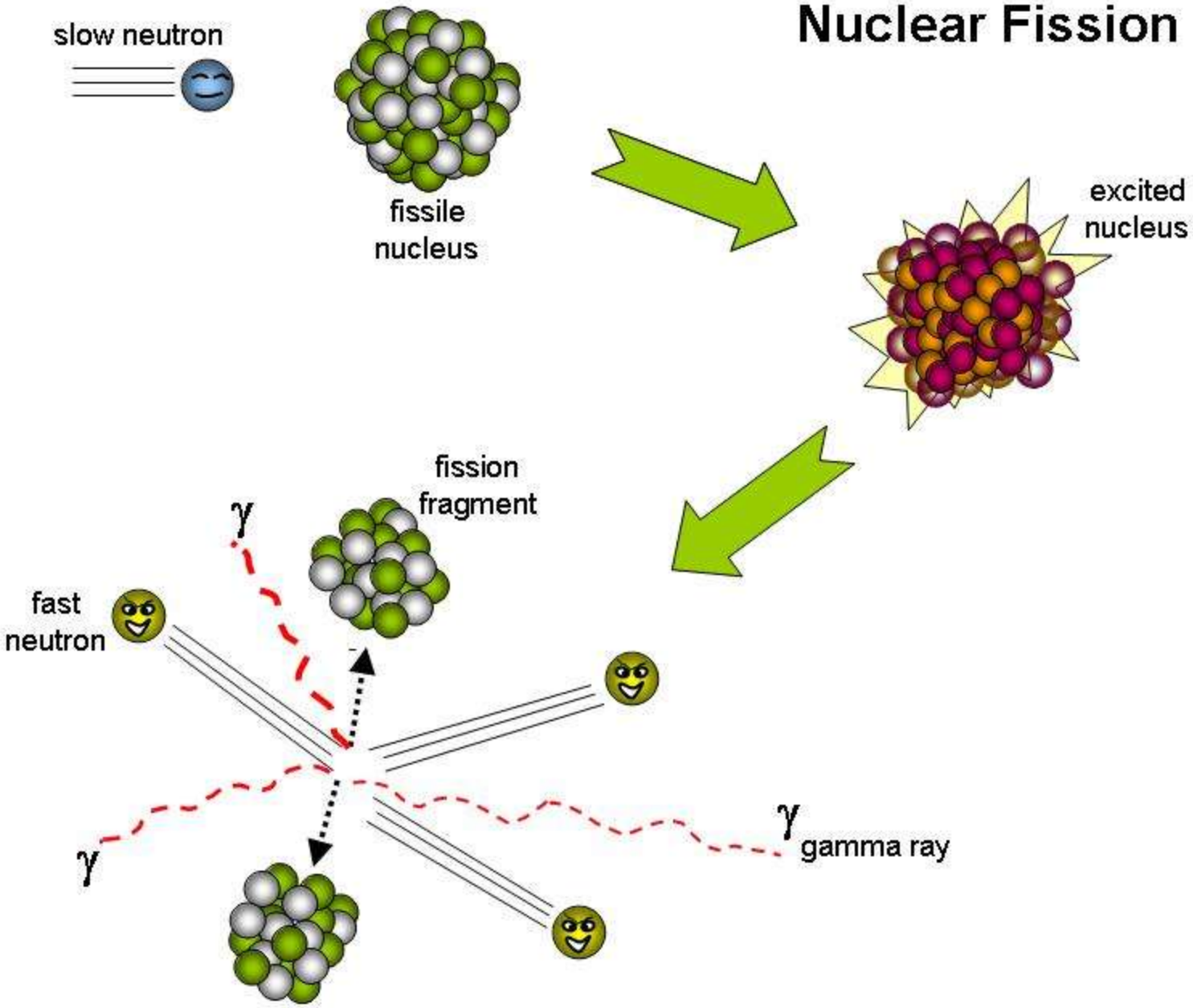
Shielding for Radiation





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

Wraith University
Department of Mechanical
& Nuclear Engineering


Nuclear Fission
slow neutron
fissile nucleus
excited nucleus
fission fragment
γ
fast neutron
γ
γ
gamma ray

Nuclear Fission

- Combustion of one carbon atom releases about 4 eV (electron volts) of energy

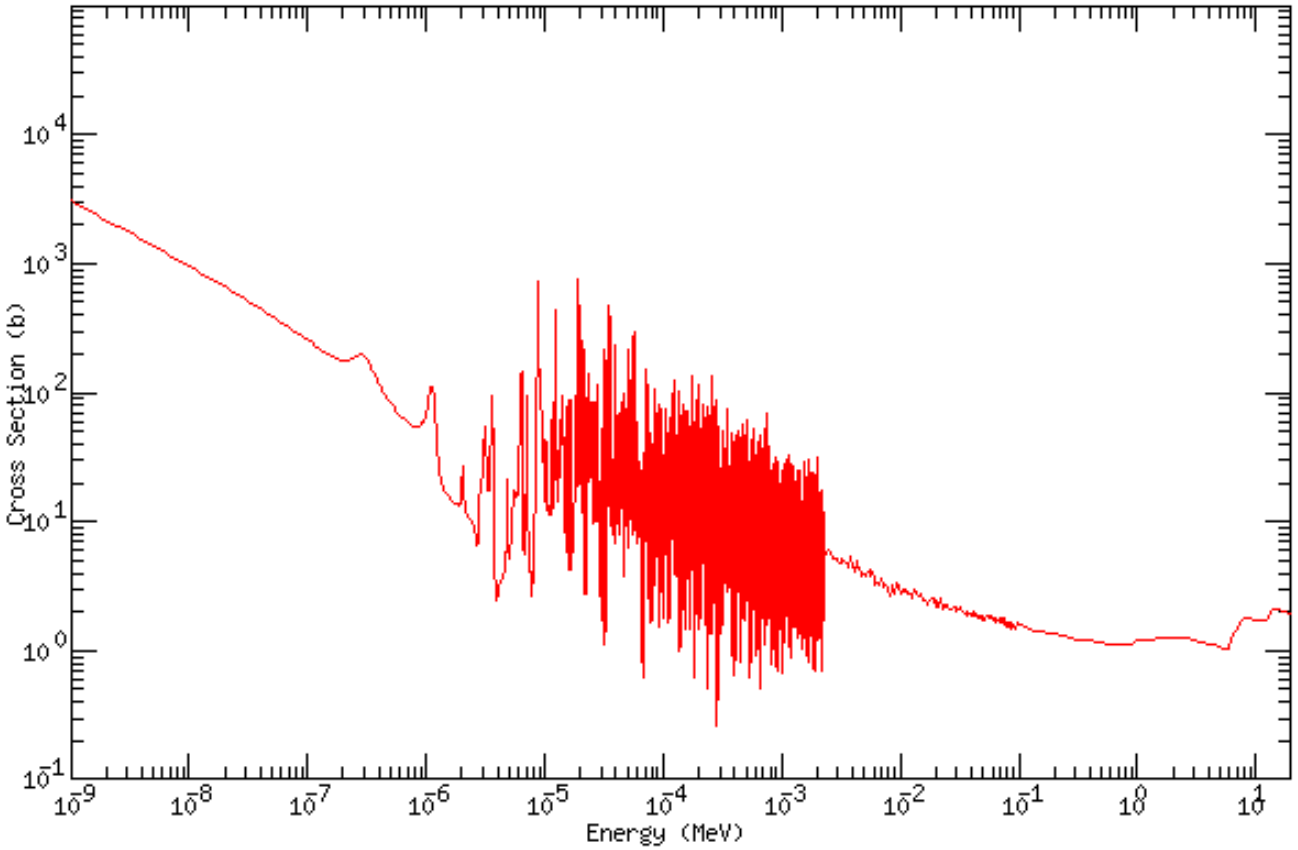
- Fission of one $^{235}U_{92}$ nucleus releases about 200,000,000 eV of energy

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

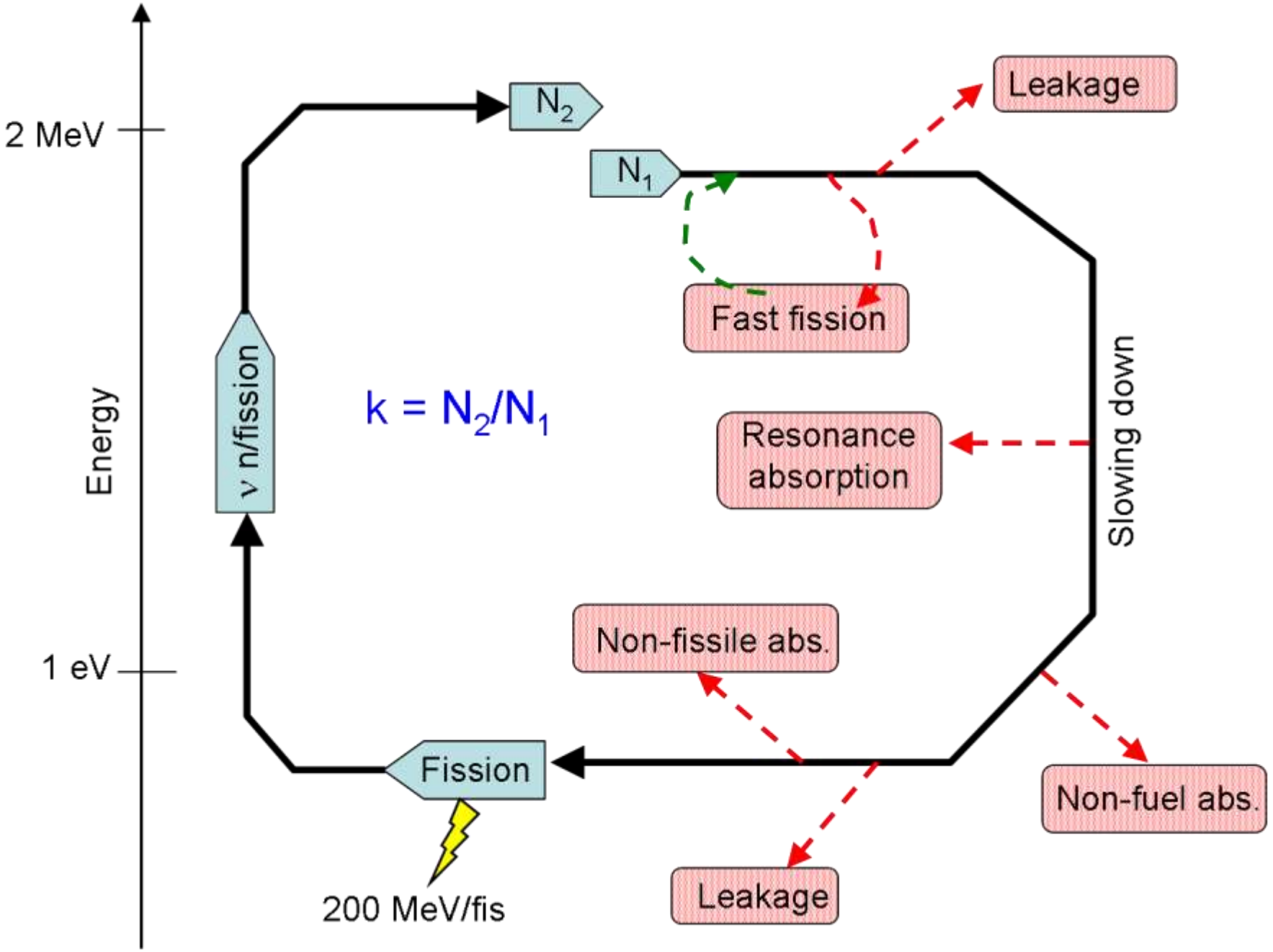
Oklo Reactor – Gabon, Africa

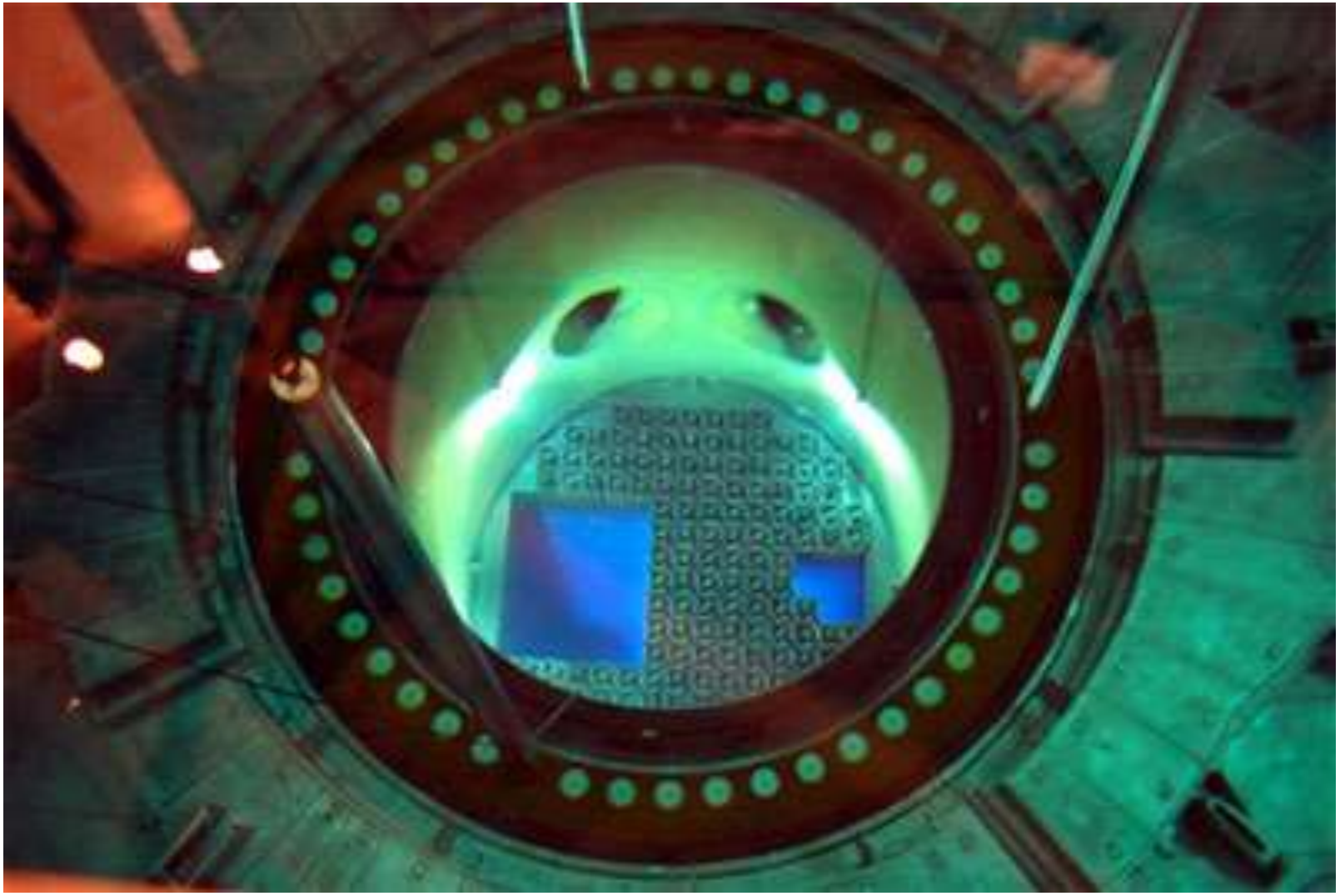
VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

^{235}U Fission Cross Section



VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering


2 MeV
1 eV
Energy
N_2
N_1
Leakage
Fast fission
Slowing down
Resonance absorption
Non-fissile abs.
Non-fuel abs.
Leakage
Fission
200 MeV/fis
ν n/fission
$k = N_2/N_1$



VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

VCU Virginia Commonwealth University
Department of Mechanical & Nuclear Engineering

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