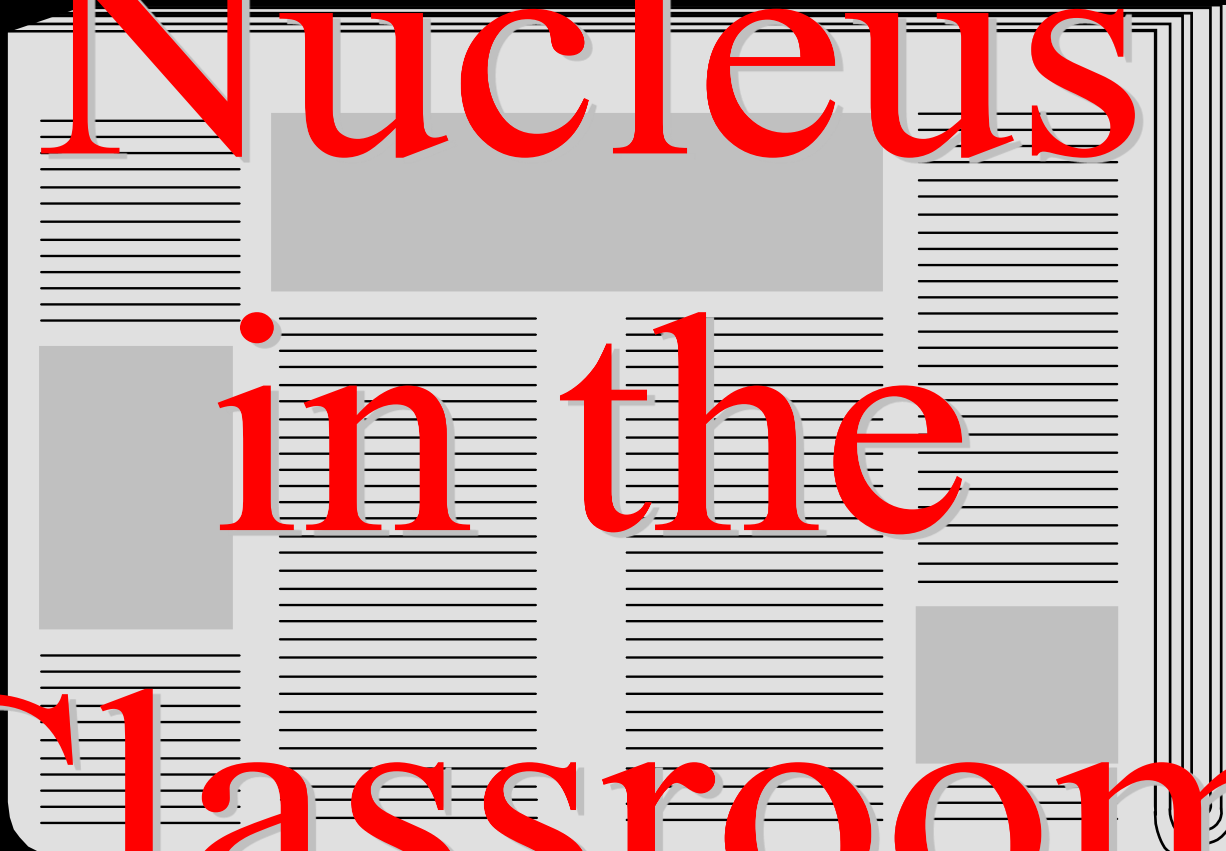
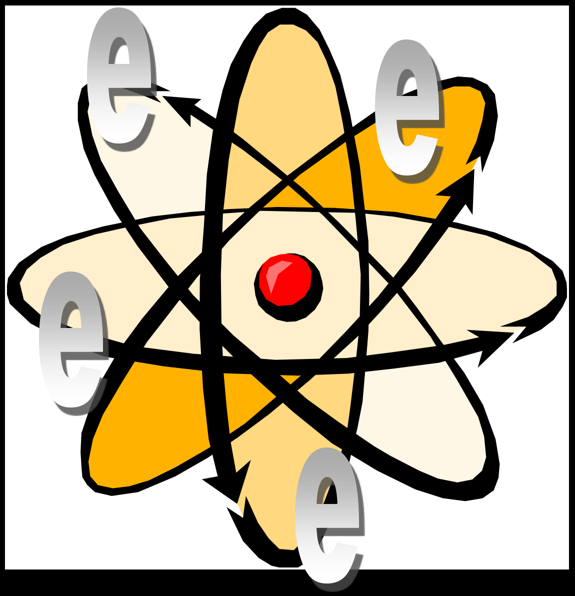
Nuclear Energy

Physical Science

Nucleus in the Classroom



Chemistry focuses on the <u>ELECTRON</u> of the atom …

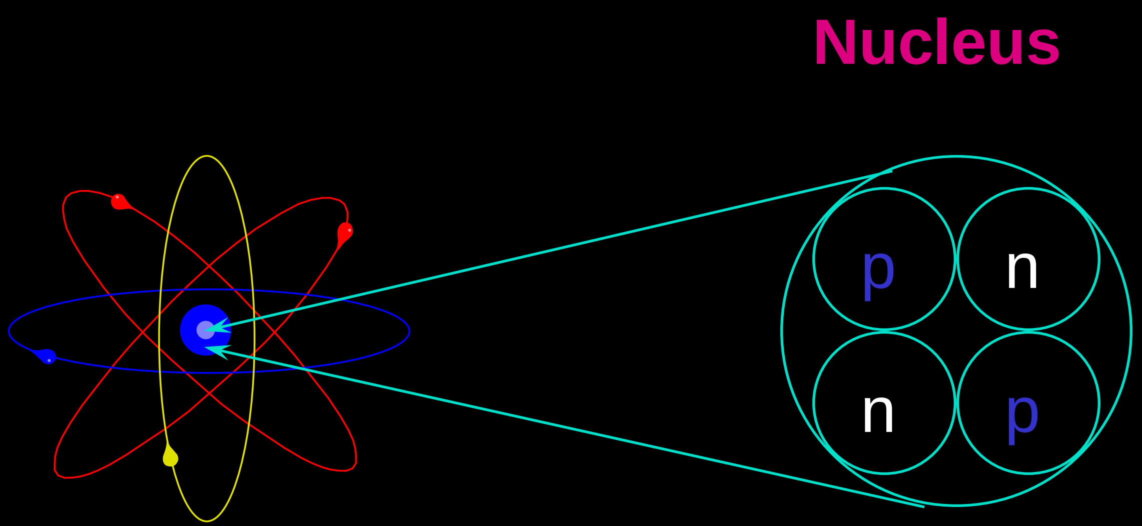


Electrons determine an atom’s chemical properties and behaviors

Nuclear Scientists focus on the nucleus of the atom

(They study nuclear particles and their potential energy)

Structure of the Atom



n = neutrons

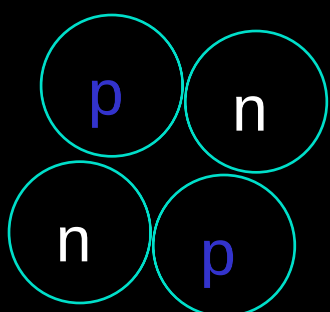
p = protons

Electrons exist in energy orbitals around the nucleus

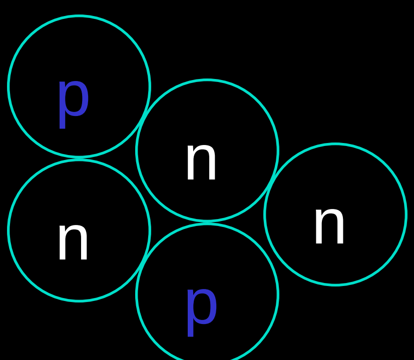
Isotopes → ISO "same" TOPE "type"

possess the same # of protons but a different # of neutrons

${}_{2}He^{4}$



${}_{2}He^{5}$

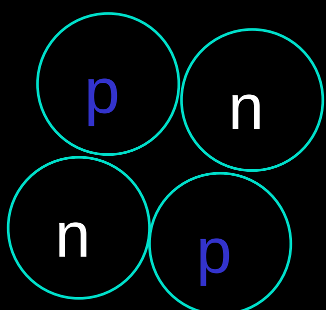


Isotopes of Helium

Atomic Number = 2 (protons)

Atomic Mass = 4

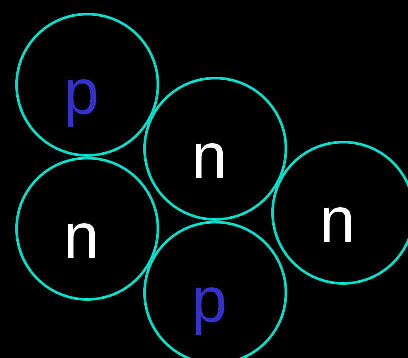
$^{4}_{2}He$



Atomic Number = 2 (protons)

Atomic Mass = 5

$^{5}_{2}He$



Isotopes of Helium

Isotope Properties

- Isotopes of the same element have exactly the same chemical behavior because they possess the same # of electrons
- Isotopes of the same element have different mass
- Some isotopes are unstable (radioactive) and others are not
- For example, ${}_6C^{12}$ is stable (6 protons & 6 neutrons), but ${}_6C^{14}$ is not (6 protons & 8 neutrons)

We Are All Made of Isotopes

- Most of the carbon in our cells is ${}_{6}C^{12}$,
- but all living things have enough ${}_{6}C^{14}$ in them to produce
- 15.3 beta emissions per minute per gram of carbon.
- Nothing is more "natural" than being radioactive!

Dating Past Events –

Archeology and Geology

Archeology

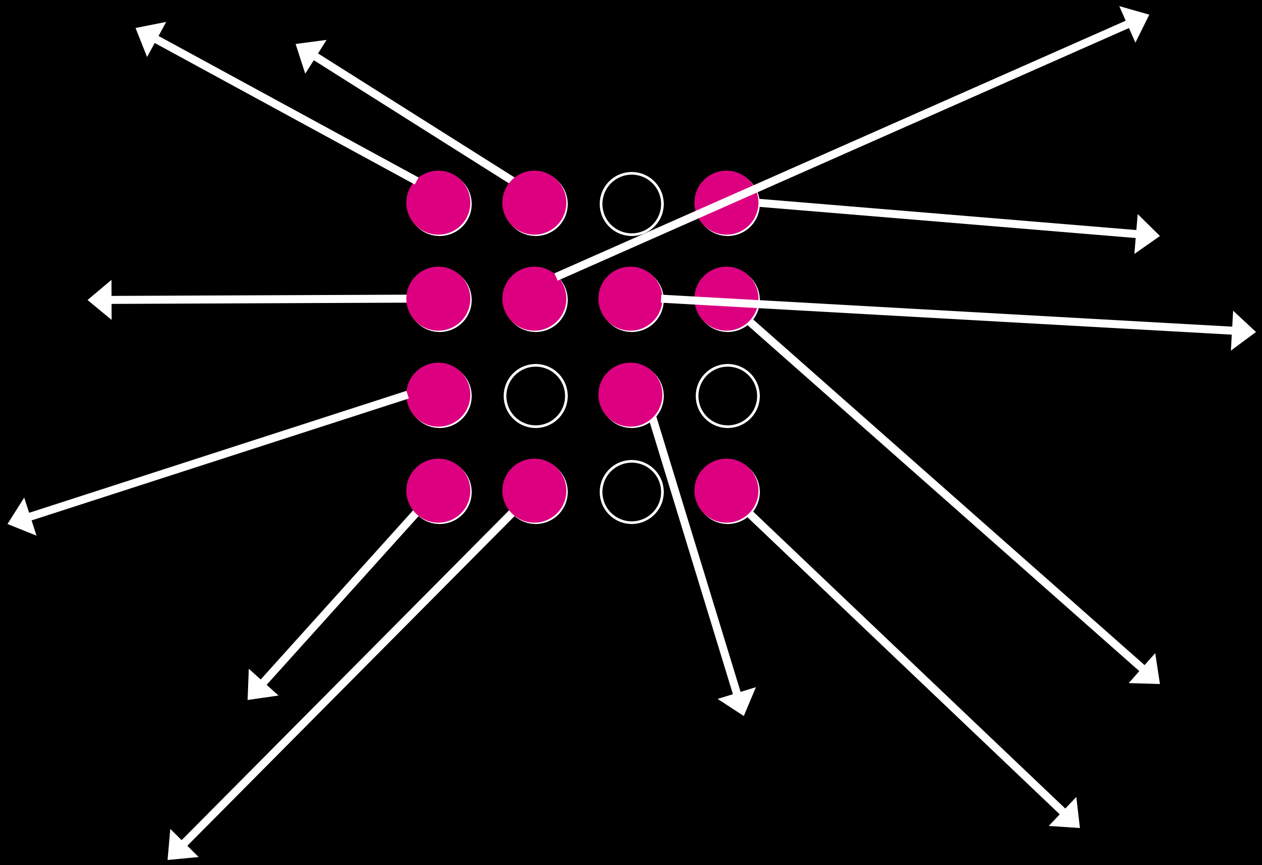
- C^{14} is produced from C^{13} in the upper atmosphere by cosmic rays
- Some of the carbon in carbon dioxide (CO_2) is C^{14}
- Living things like trees and plants incorporate the C^{14} in wood and fiber while they are alive

Archeology

- C^{14} has a half-life of 5730 years
- We can date old wooden objects by how much **less** radioactive they are than when the wood was alive!
- The longer some organism has been dead, the less radioactivity it will have

- After one half-life of 5730 years, C^{14} has ½ its original amount.
- After two half-lives of 5730 years, C^{14} has 1/4 its original amount. (11,460 years)
- After three half-lives of 5730 years, C^{14} has 1/8 its original amount. (17,190 years)

Half Life



- If our body contains 400 grams of Carbon 14, how many years would it take to only have 25 grams?

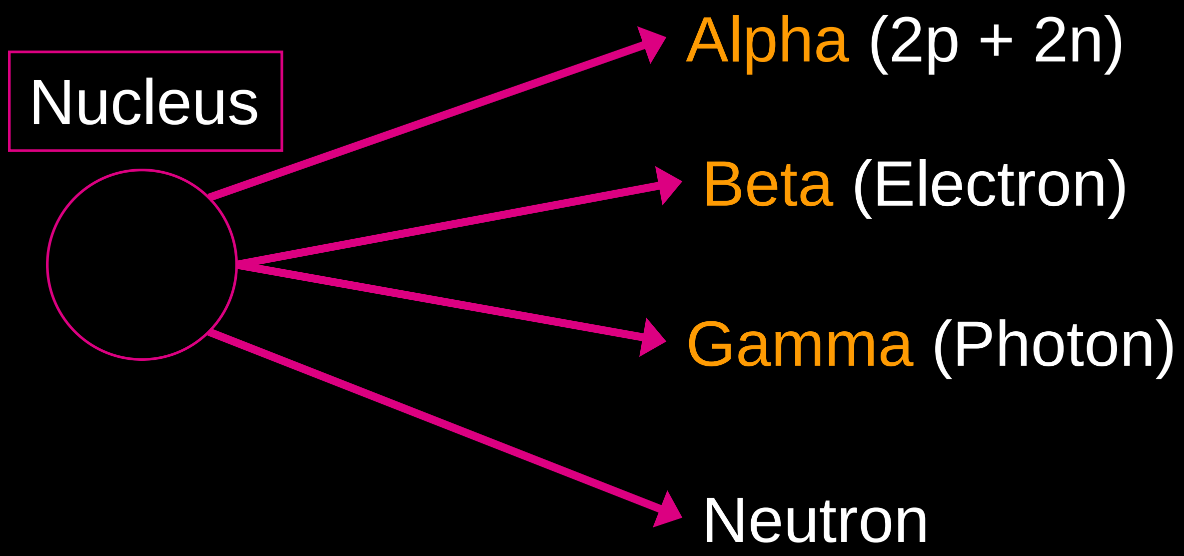
400 grams → 200 grams → 100 grams → 50 grams → 25 grams =

4 half-lives

5730 years/half-life x 4 half-lives =

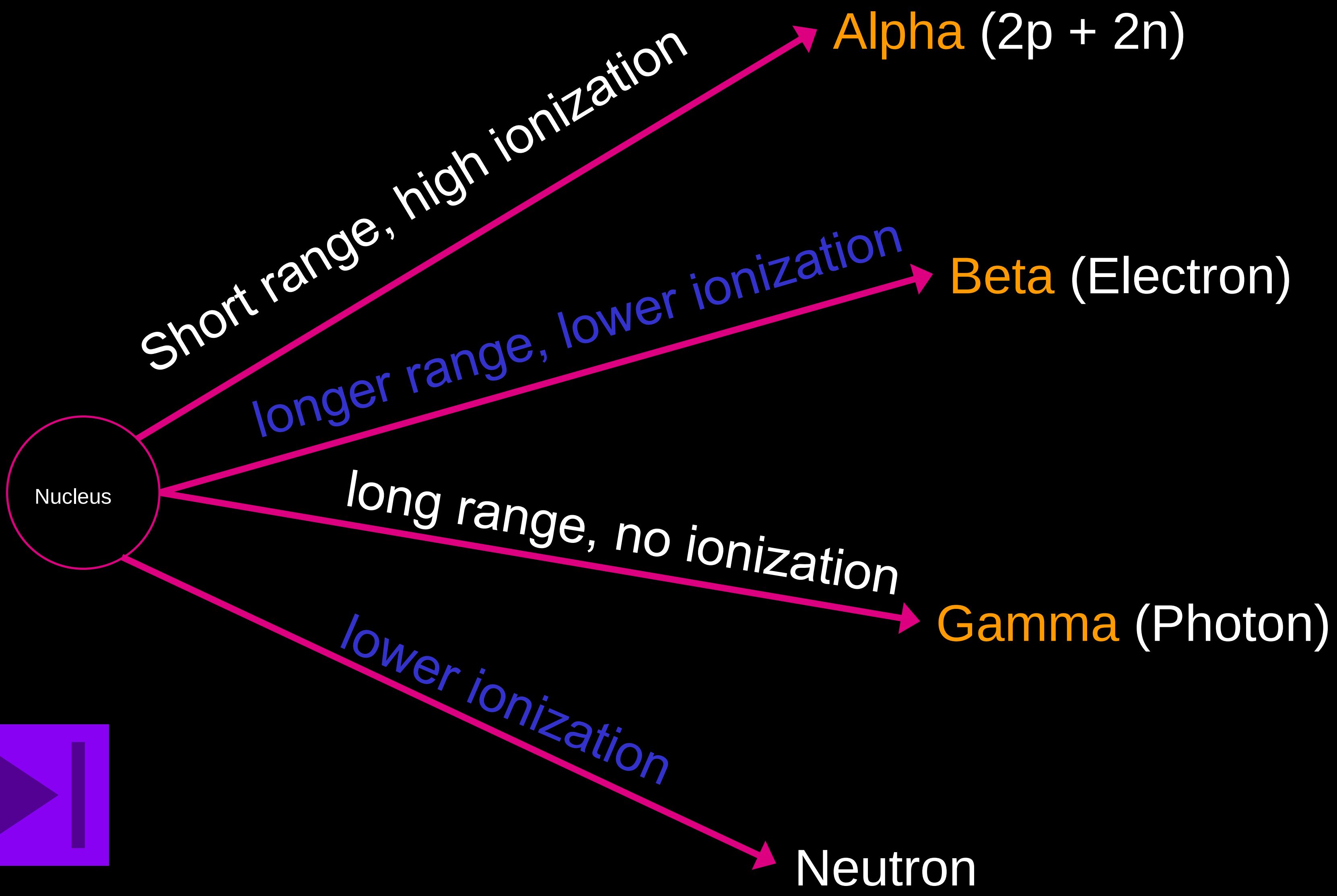
22,920 years

Types of Nuclear Radiation

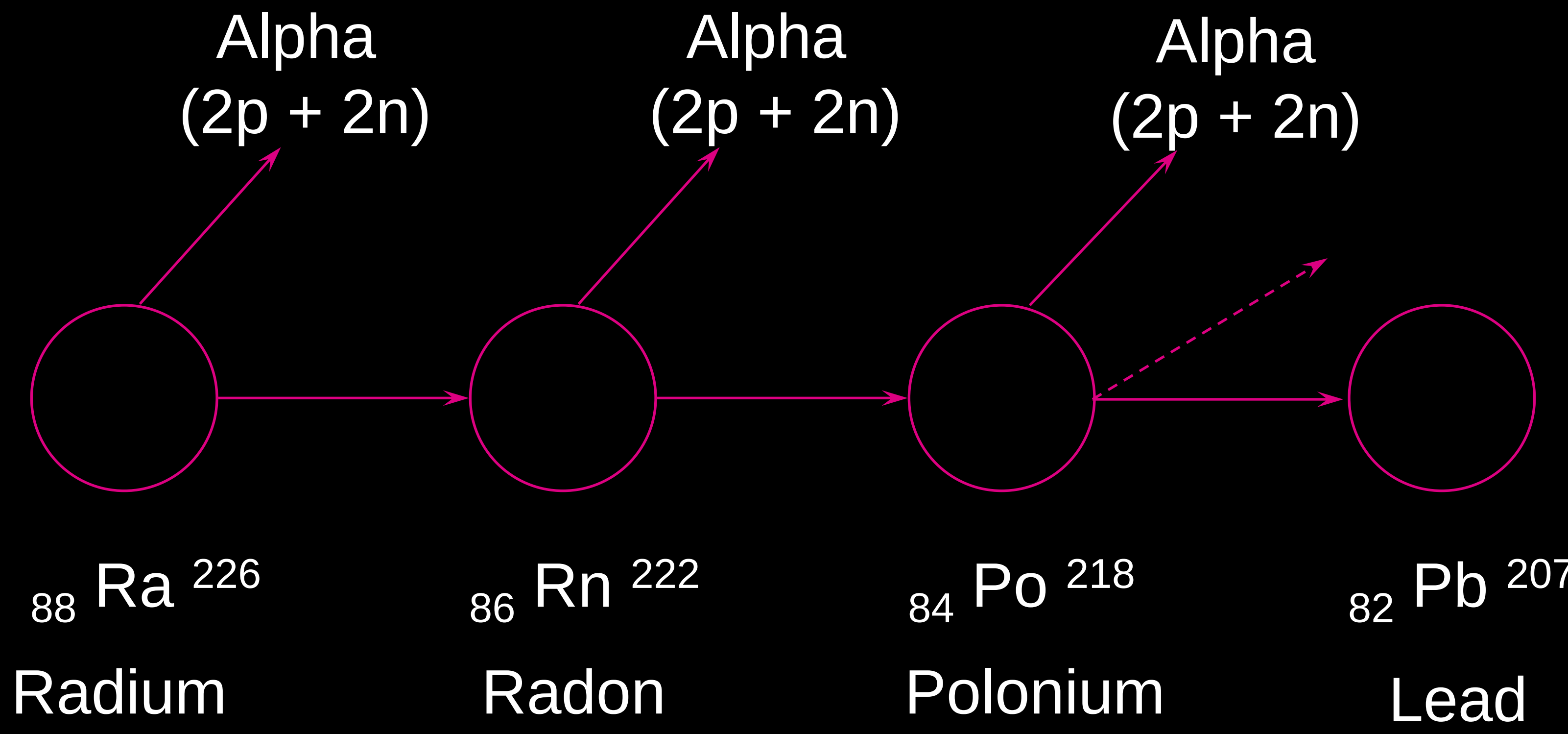


- How far can each type of nuclear radiation travel?

- How do outside forces of electricity and magnetism effect each particle?


Nucleus
Short range, high ionization
Alpha (2p + 2n)
longer range, lower ionization
Beta (Electron)
long range, no ionization
Gamma (Photon)
lower ionization
Neutron

Radioactive Isotopes Transmutate into Stable Isotopes



Radium

- Radium was discovered by Madame Marie Curie … for which she was awarded the Noble Peace Prize in Physics
- The radioactive atom, Radium, is found in rocks and turns into Radon and eventually into Lead
- Rocks that contain Radium can be dated by determining the amount of Helium and Lead in them (*the more He & Pb, the older the rock*).

- Alpha radiation (an Alpha particle) is a Helium nucleus or Helium nuclide
- Since the nucleus contains protons which are positively charged, the alpha particles will repel other positive charges

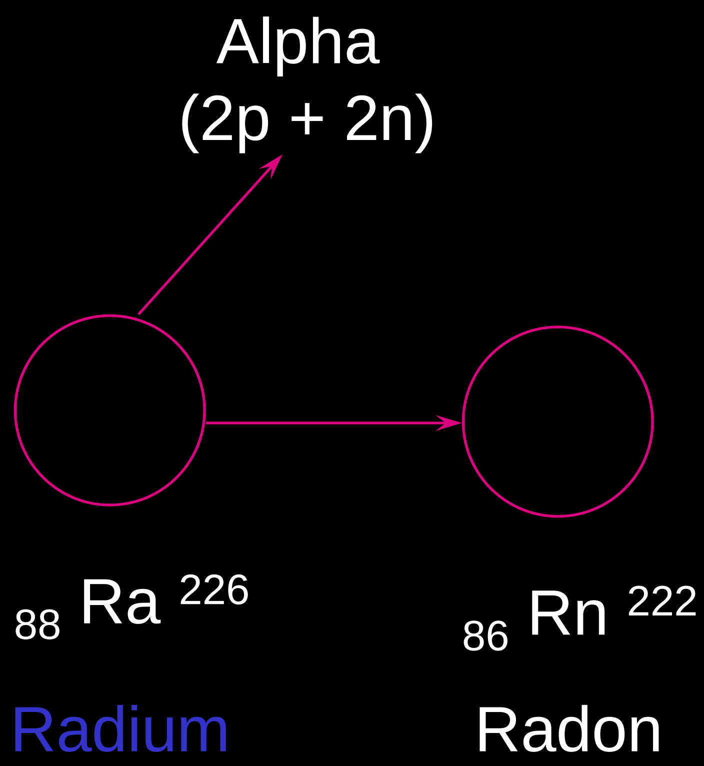
+ +

- and be attracted to negative particles

+ −

- When the alpha particle stops moving so fast, it acquires two electrons and becomes Helium gas which is "inert" or unreactive

Radium exists in small amounts in most igneous rocks

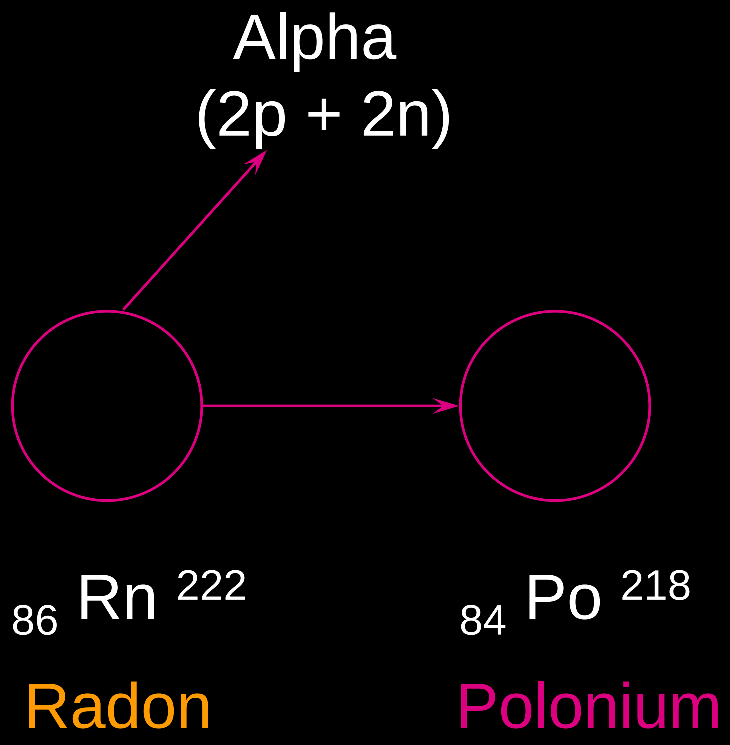


It decays into <u>radon</u> which is a gas that can escape through cracks in the rock and leak into basements

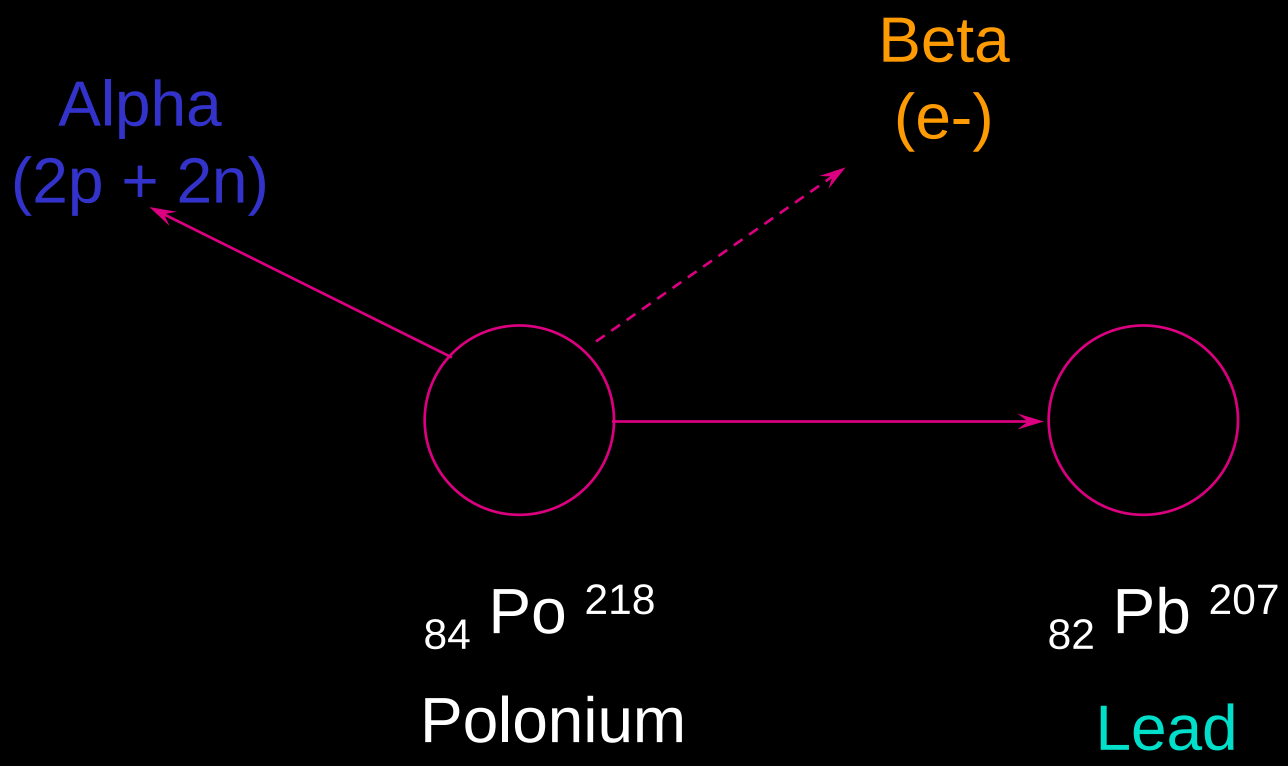
Radon

- Radon is a heavy gas that will accumulate in low areas unless ventilated
- Radon damages internal organs and tissues if inhaled
- It is recommended to use Radon detectors or monitors in basements as well as to circulate air to remove build-ups

- If Radon is inhaled it can emit an alpha particle and turn into Polonium which is a solid that stays in the lung



The particle will continue to emit alpha and beta particles until it decays into a stable isotope of Lead



Nuclides

- Nuclear Energy focuses on the nucleus and nuclear particles
- A "Nuclide" is the nucleus of an atom without consideration of the electrons outside the nucleus

Table of Nuclides

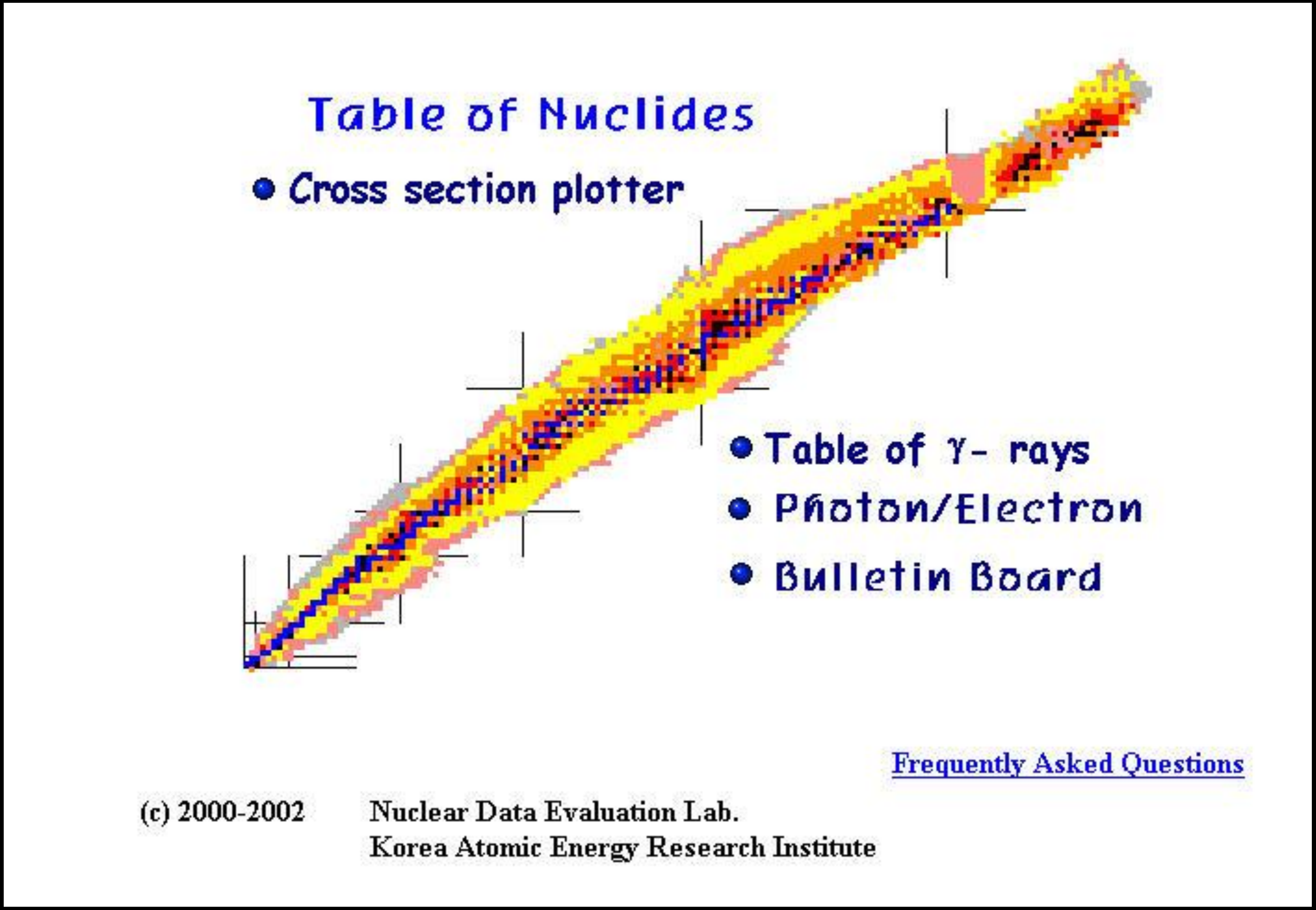


Chart Details

Nuclide : C-14 Nuclide Table

6-C-14
basic
XS graphs

element

6-carbon-14

Carbon-14 helps in research to ensure that potential new drugs are metabolized without forming harmful by-products.

- Atomic Mass: 14.0032420 +- 0.0000000 amu
- Excess Mass: 3019.892 +- 0.004 keV
- Binding Energy: 105284.507 +- 0.019 keV
- Beta Decay Energy: B- 156.475 +- 0.004 keV

"The 1995 update to the atomic mass evaluation" by G.Audi and A.H.Wapstra, Nuclear Physics A595 vol. 4 p.409-480, December 25, 1995.

- Spin: 0+
- Half life: 5730 years
- Mode of decay: Beta to N-14
  - Decay energy: 0.156 MeV
- Possible parent nuclides:
  Beta from B-14
  Beta + Alpha from N-18

R.R.Kinsey, et al.,*The NUDAT/PCNUDAT Program for Nuclear Data* paper submitted to the 9 th International Symposium of Capture-Gamma_ray Spectroscopy and Related Top
1996.Data extracted from NUDAT database (Jan. 14/1999)

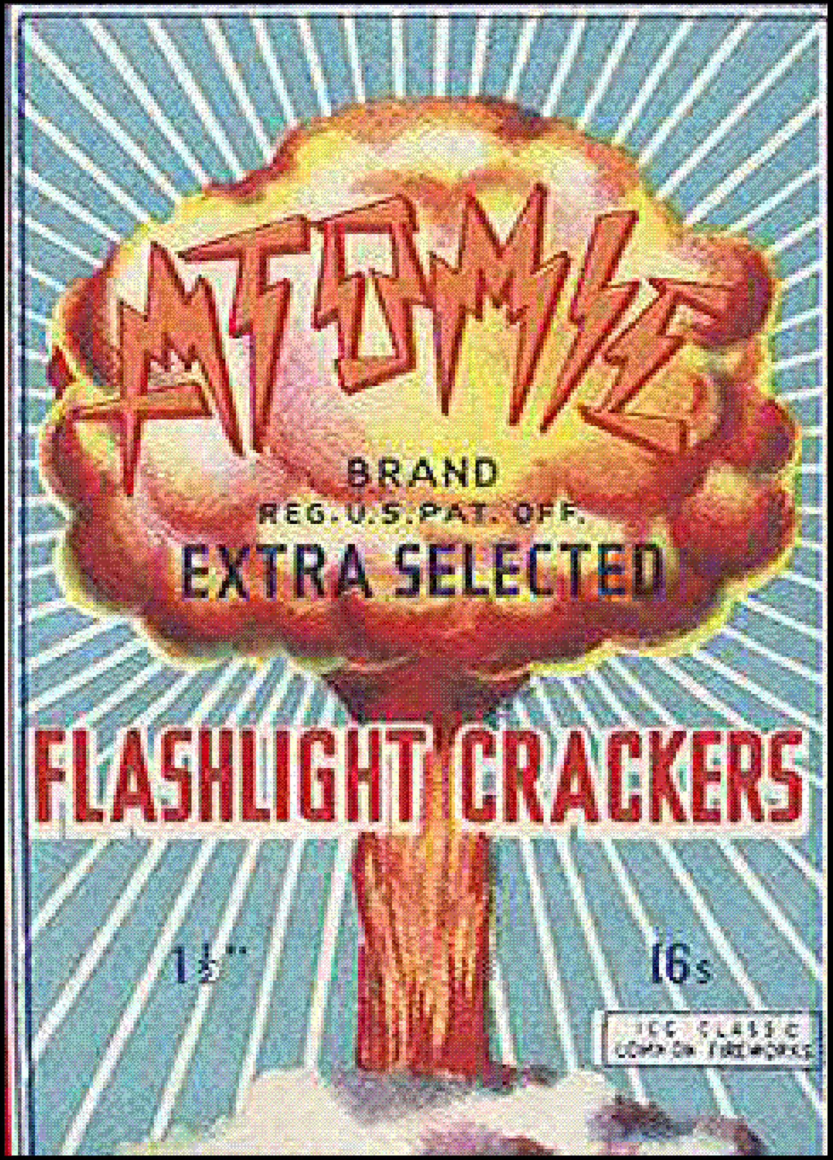
Magnetic Dipole Moments and Electric Quadrupole Moments

Ex(kev)	**$T_{1/2}$**	**Spin**	**m(nm)**	**Q(b)**	Ref. Std.	Method	Reference
6728	67 ps	3-	0.82(2)			RIV/D	PR C9 1748 (74)

N. J. Stone, Table of Nuclear Magnetic Dipole and Electric Quadrupole Moments, to be published. 2000 Courtesy of T. Burrows at BNL/NNDC.

Part 2

Nuclear Energy

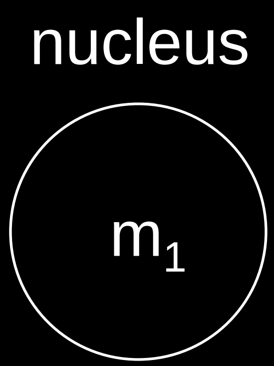


Enormous Energy

- When nuclei split, the energy released is millions of times greater than a chemical reaction
- Chemical energy is measured in electron volts, abbreviated ev
- Even dynamite or TNT yields only a few electron volts of energy **per atom** during an explosion
- Fission of U^{235} yields 200 million electron volts of energy **per atom**!

Einstein's Theory of Relativity is based on nuclear reactions

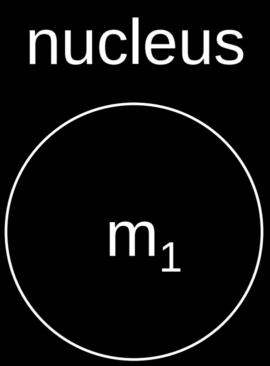
$$E = mC^2$$



A radioactive nucleus can decay or it can be split by bombarding it with subatomic particles

Einstein's Theory of Relativity is based on nuclear reactions

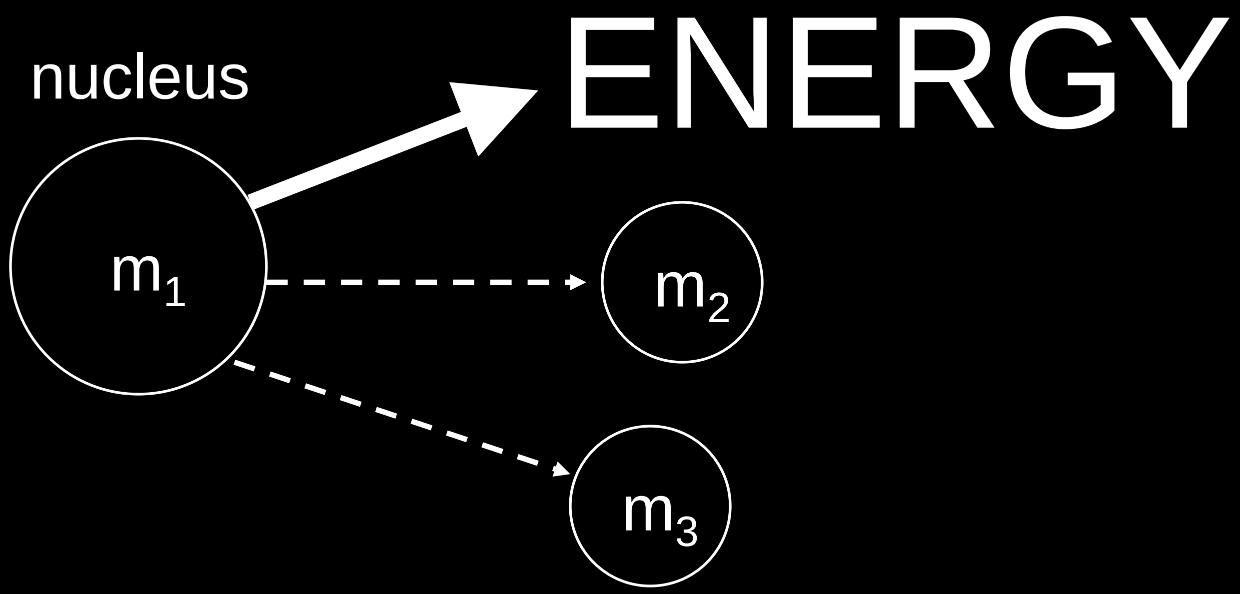
$$E = mC^2$$

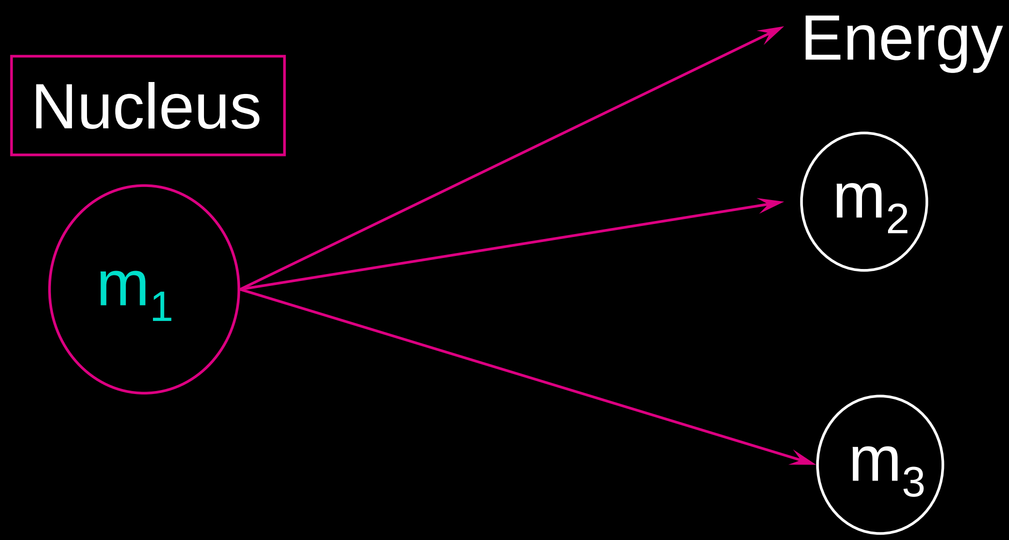


The nucleus splits into smaller masses and releases huge amounts of energy

Einstein's Theory of Relativity is based on nuclear reactions

$$E = mC^2$$





The Mass of m_1 is greater than $m_2 + m_3$

$E = ((m_1 - (m_2 + m_3)) c^2$ or $E = mc^2$

E → energy m → mass c → speed of photon

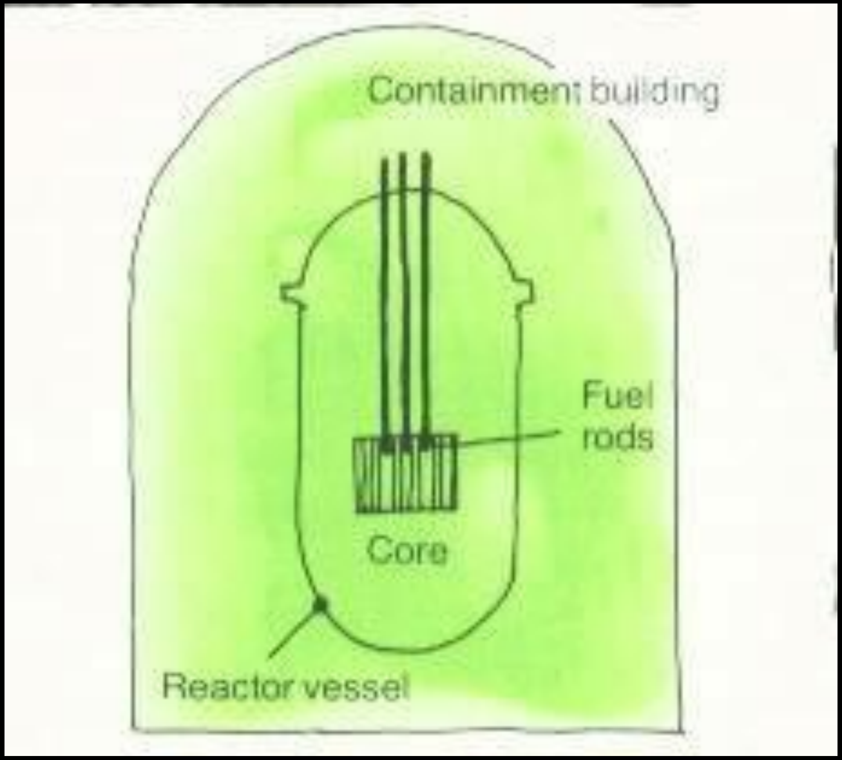
Managing Nuclear Power

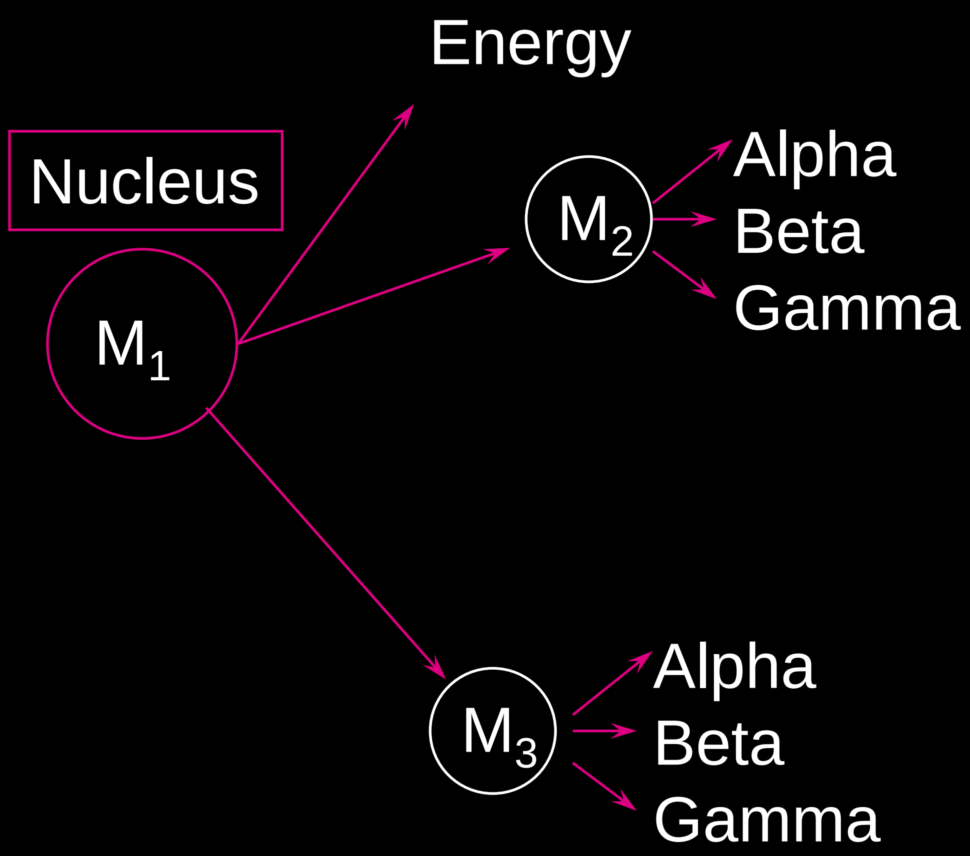
Most nuclear energy is harnessed through a reaction called

nuclear fission

- The nuclear fission reaction takes place in the "core" of the reactor vessel

- Fuel rods contain the Uranium 235 for nuclear fission



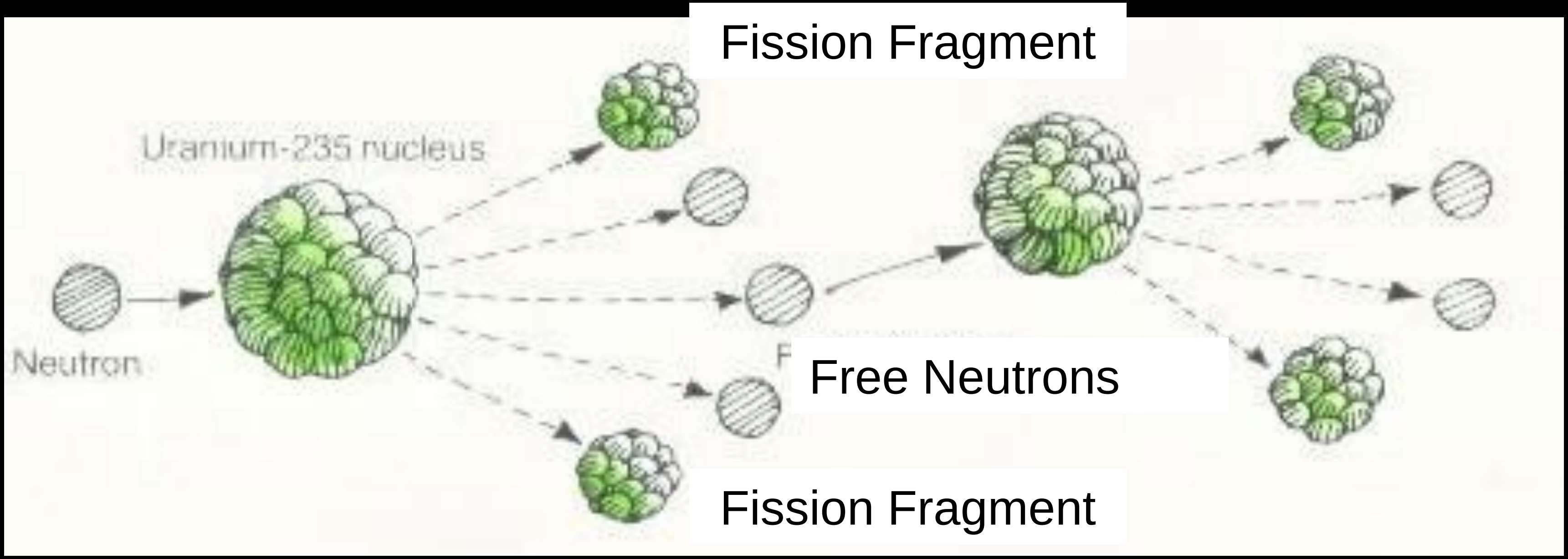


Nuclear Fission Products Are Highly Radioactive, yielding even more energy

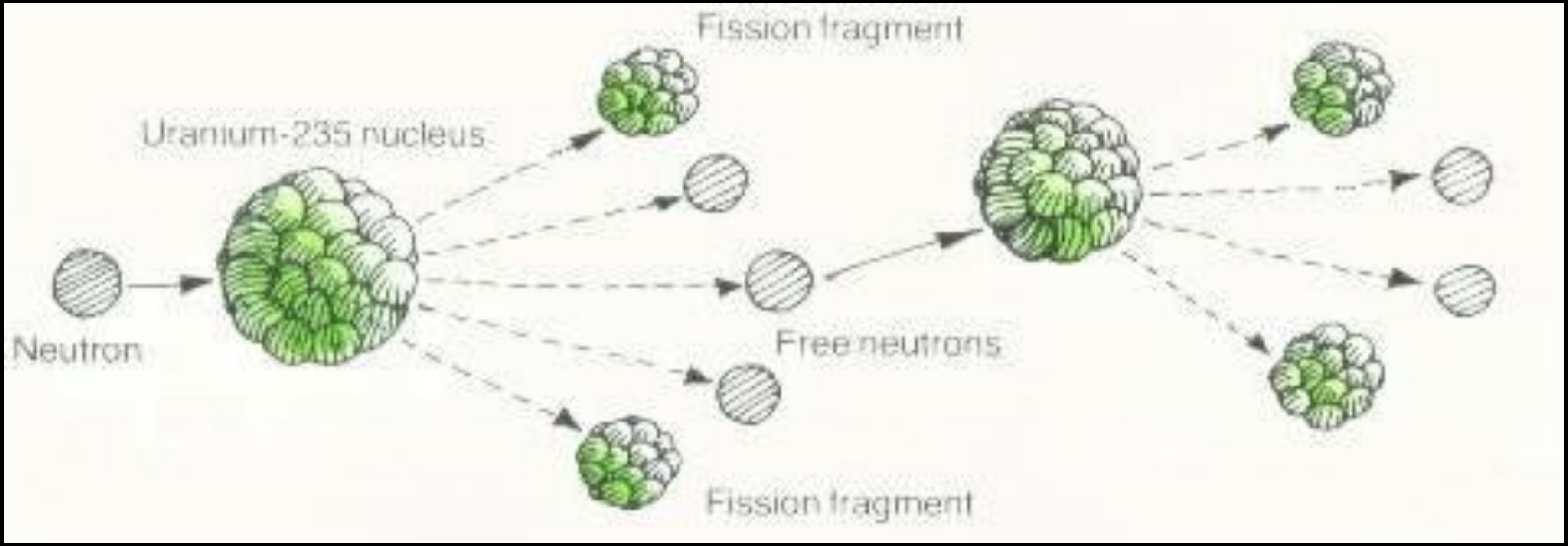
- Most large atoms can be forced into nuclear fission although few isotopes fission well
- Only two isotopes fission easily enough to maintain useful energy reactions: $_{92}U^{235}$ and $_{94}Pu^{239}$
- Uranium 235 and Plutonium 239

Uranium 235 $_{92}U^{235}$

is bombarded by a neutron to produce a chain reaction

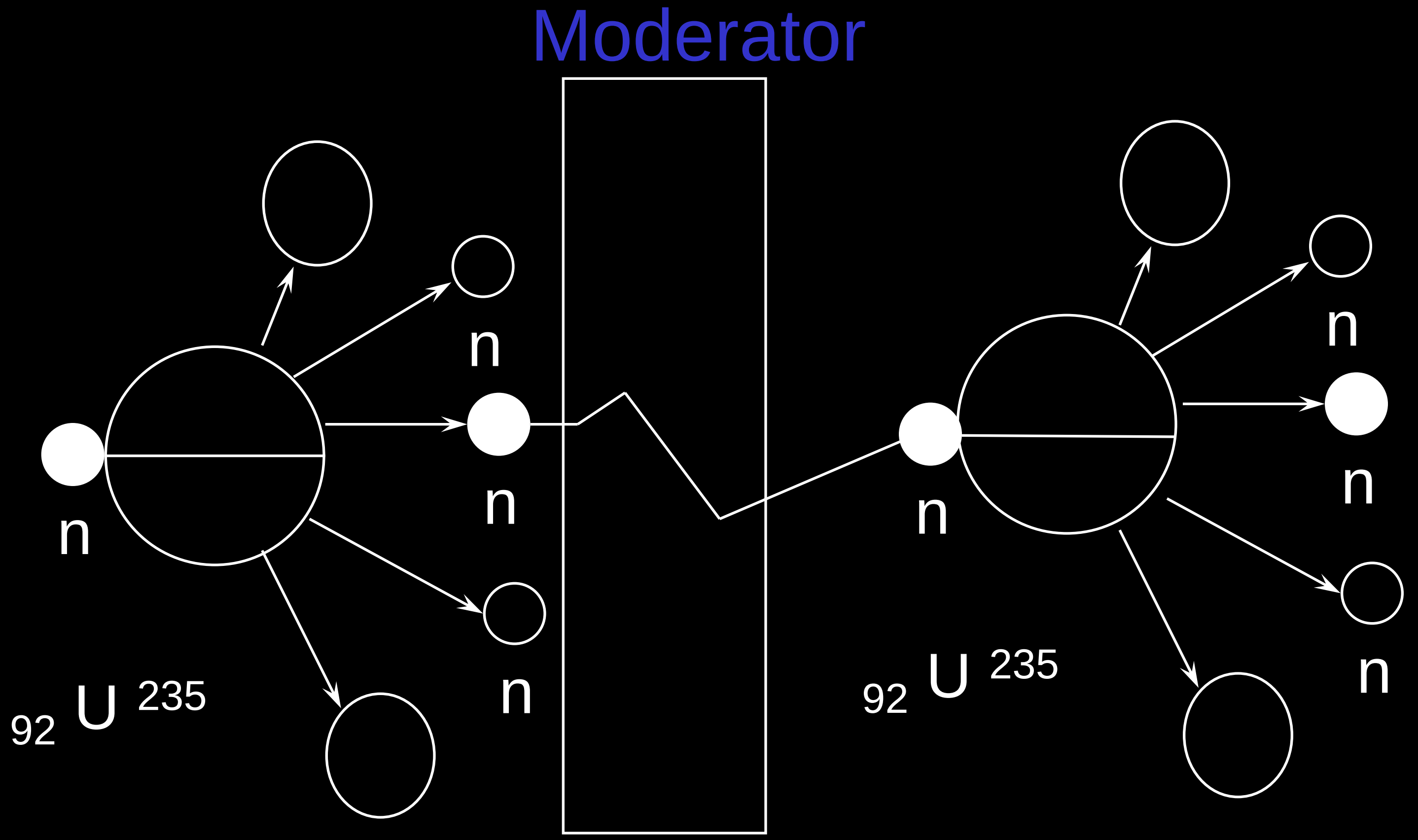


The chain reaction produced continues the nuclear fission and is used in nuclear reactors



To start and maintain the Chain Reaction

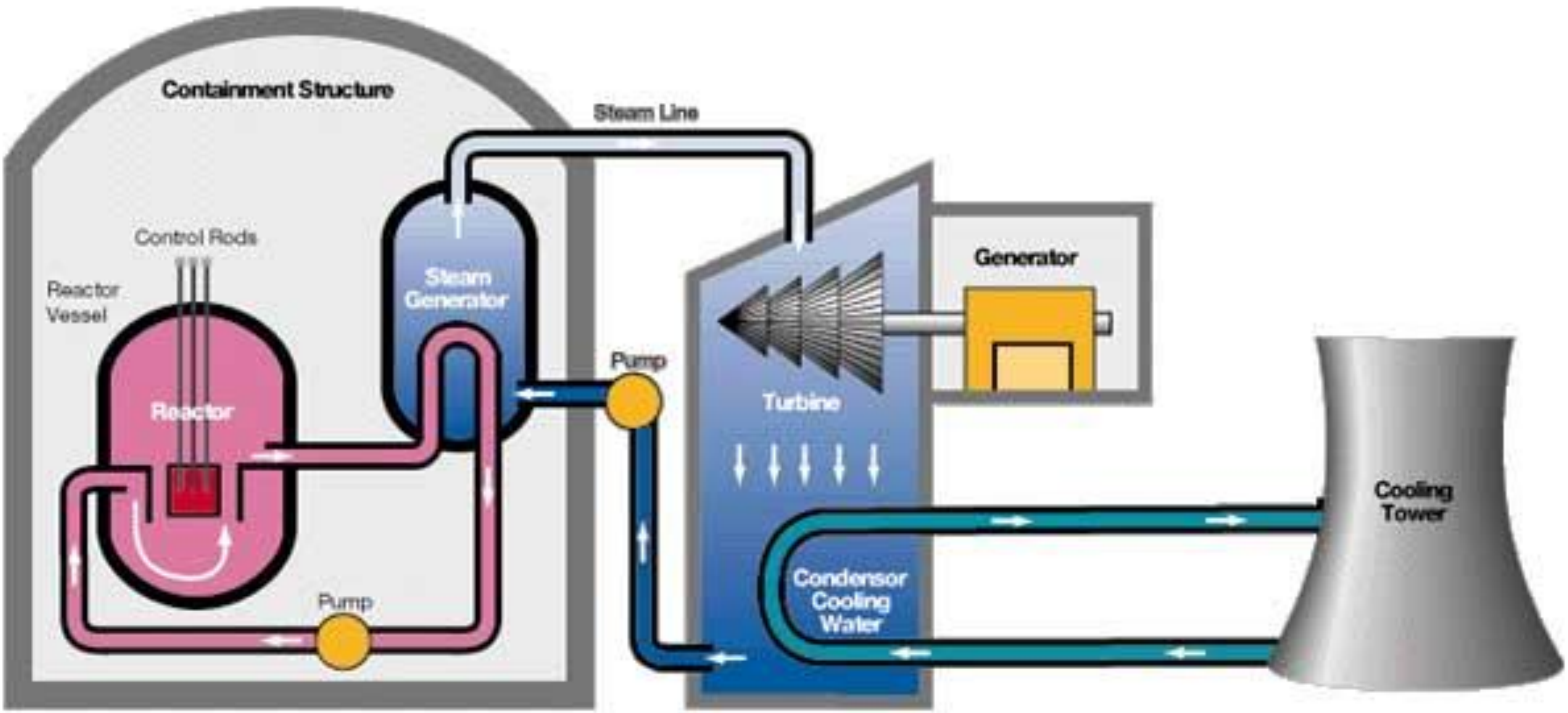
Neutrons need to be slowed down by "Moderators" to allow for fission (splitting) rather than just bouncing off



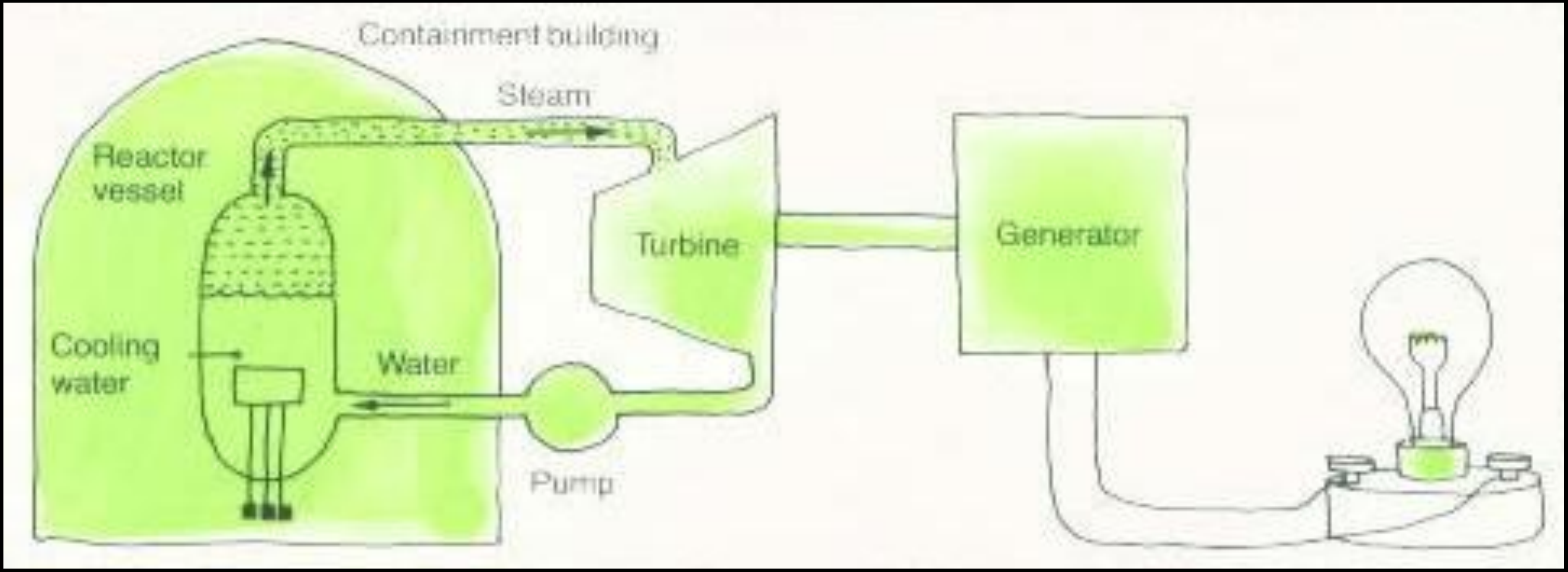
Moderators

- Two good moderators are water and graphite (a carbon “allotrope”)
- Reactors in the USA use water as a moderator and as a cooling agent
- Chernobyl, Russia used graphite as a moderator and it caught fire, helping to spread radioactive material abroad

One use of nuclear fission in nuclear reactors is to produce electricity



- The heat from the nuclear reaction boils water
- The steam produced turns a turbine generator
- And the generator produces electricity



Nuclear Reactors

- Are controlled nuclear reactions in which a fuel rod puts out energy for up to three years before it is replaced in a reactor

- Nuclear weapons in comparison, release their energy all at once and are rated in thousands or millions of tons of TNT

Nuclear Reactors

WATER can be used …

- as a moderator to produce nuclear fission
- as a coolant for the steam (produced by the fission reaction
- as a temporary and SAFE storage place for the nuclear fuel rods

Nuclear Reactors

- There is no real danger of a nuclear power plant exploding like a bomb because the % of Uranium 235 is too low

- However …

The Downsides of Nuclear Power

- A major international issue is the proliferation of **nuclear weapons**
- A universal fear related to nuclear power is the **radioactive waste** produced and the issue of where to store that waste

Nuclear Weapons Proliferation

- Only 0.7% (less than 1%) of naturally occurring uranium is U^{235}, the rest is U^{238}
- It is very difficult to separate concentrated U^{235} from U^{238} because they are so chemically similar
- The U^{235} concentration must be brought up to over 3% to be useful in a nuclear reactor and up to about 90% for a nuclear bomb

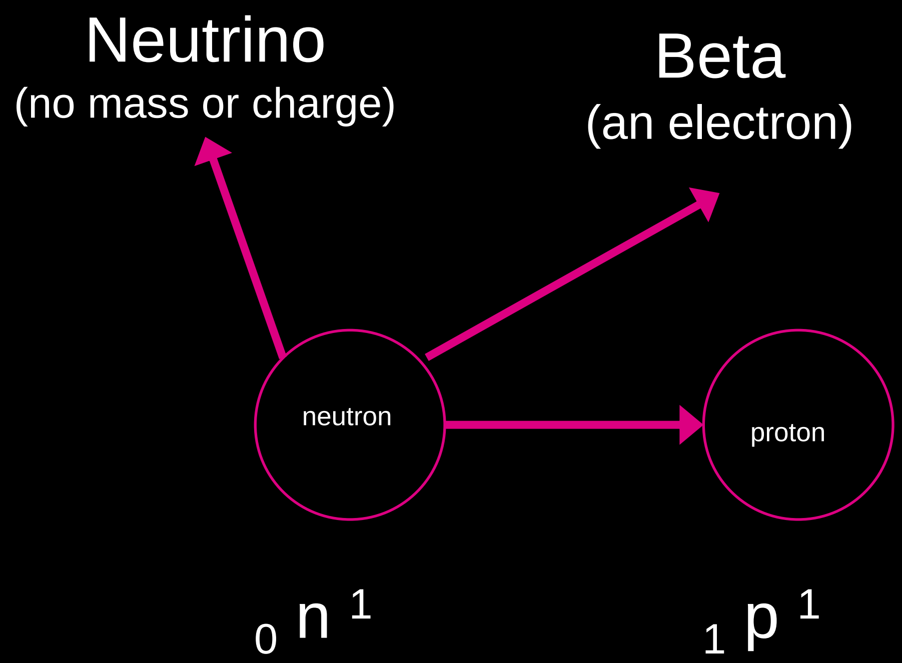
Nuclear Weapons Proliferation

- Plutonium 239 is another fissionable isotope that works very well for nuclear reactions
- Since Pu^{239} is chemically different than uranium, it is much easier to separate from U^{238} fuel rods and concentrate it into **bomb** material
- Less technically advanced countries have obtained nuclear weapons by reprocessing fuel rods from nuclear power reactors

Reprocessing Fuel Rods

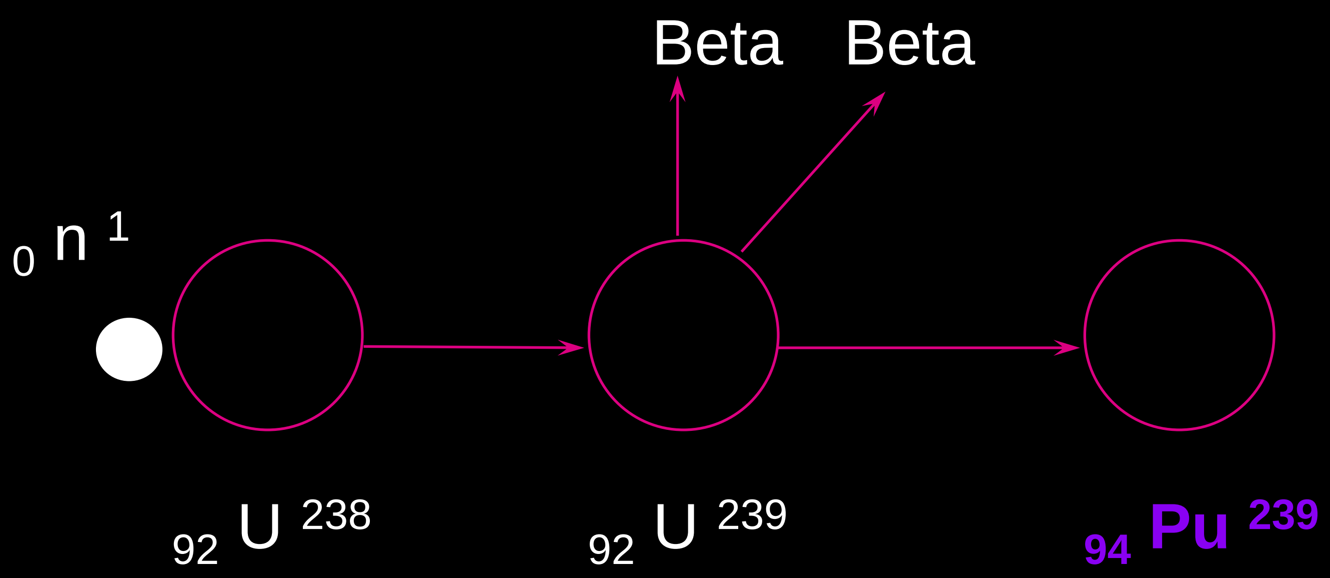
- "Breeder reactors" are designed to enrich abundant U^{238} into fissionable Pu^{239} to replace the U^{235} that was consumed
- Neutrons released at high energy do not get absorbed into a nucleus to produce fission, but they can change into a proton

Neutrons Can “Decay”



A high speed neutron can decay into a proton, changing the atom into a different element.

"Nuclear Enrichment" changes U^{238} into Pu^{239}



Plutonium 239 can fission as well as $_{92}U^{235}$

Plutonium 239

is used to make nuclear warheads and other nuclear bomb materials and is very dangerous

Storage of Nuclear Waste

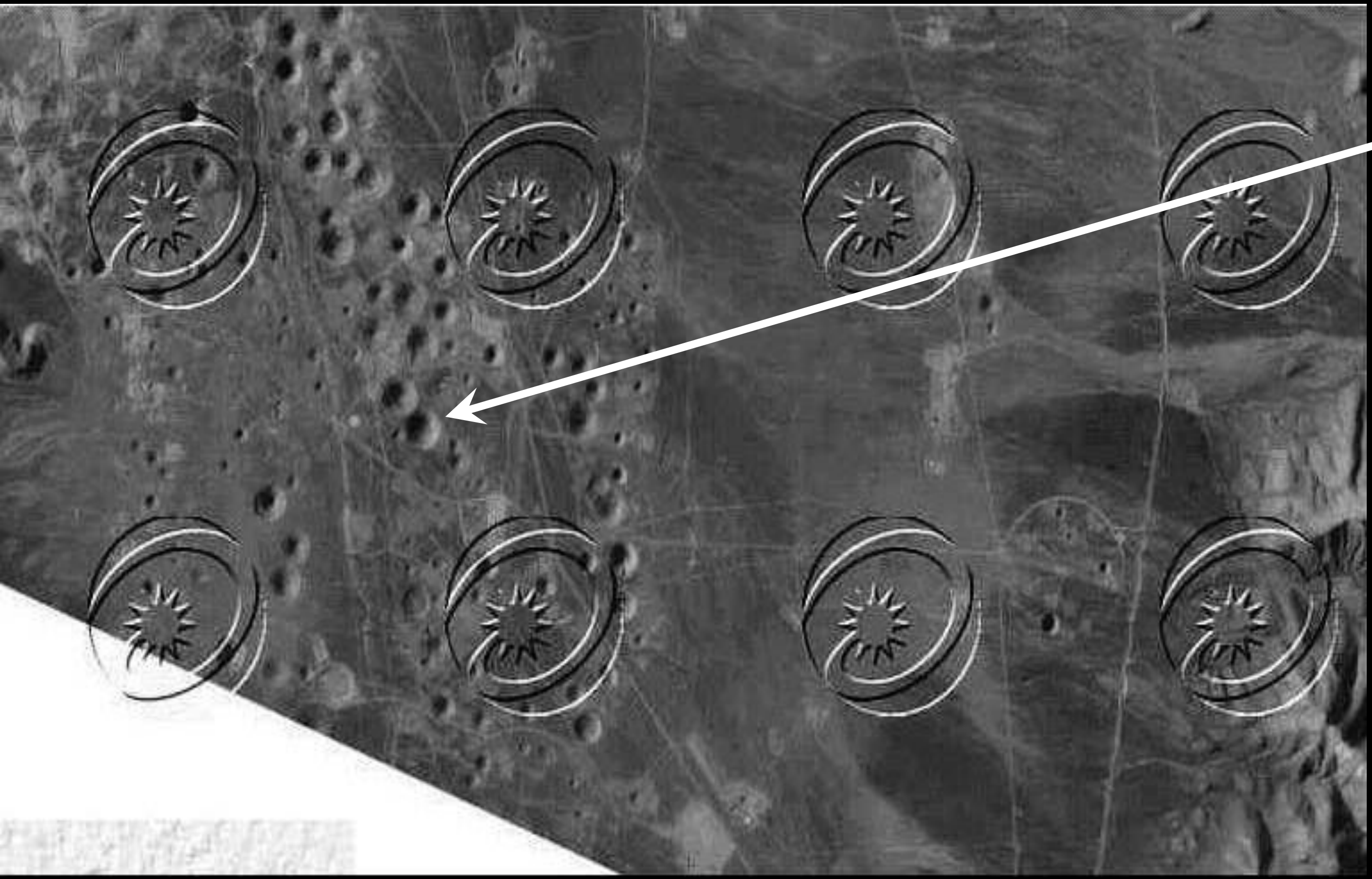
- Most nuclear power plants in the United States store their used fuel rods in a “swimming pool” of water
- If you piled all the nuclear waste ever produced in the U.S together, it would fill a football field twelve feet high
- Coal waste is more than that in one day

Waste Storage

- Eventually, the temporary storage in the "swimming pools" will need to be emptied
- Current lack of a permanent storage facility leaves nuclear waste above ground "on site" at each nuclear power plant
- "Yucca Mountain" in Nevada is a proposed site for permanent storage

Waste Storage

- Near Yucca Mountain is a Nevada bomb test site used for 825 underground tests



Surface craters produced when the ground below collapses after an underground explosion

Russian satellite image

Comparing
Monroe Coal Power Plant &
Ferme 2Nuclear Power Plants

	Tons of **Fuel** Burned per year	Tons of **Solid Waste** per year	**Electric Power** kWh per year
Coal			
Nuclear			

Comparing Monroe Coal Power Plant & Ferme 2Nuclear Power Plants

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Coal	~ 9 million		
Nuclear	~1 ton		

Comparing
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Coal		~560,000	
Nuclear		~1 ton	

Comparing
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Coal			20 Billion
Nuclear			8.5 Billion

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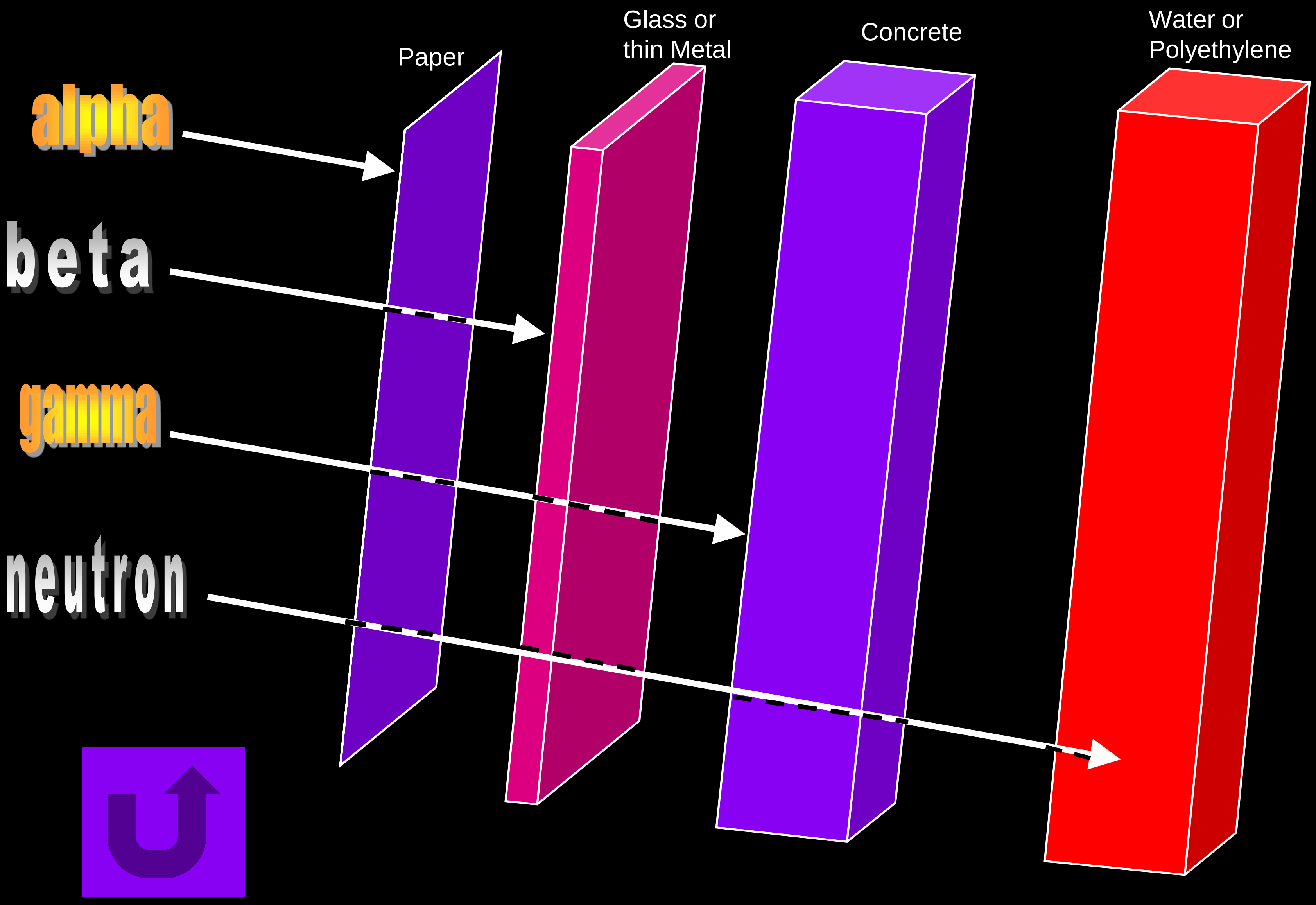
Paper
Glass or
thin Metal
Concrete
Water or
Polyethylene
alpha
beta
gamma
neutron