Nuclear Science Merit Badge

Butler County Community College
April 7, 2018

American Nuclear Society
Pittsburgh Section

Morning Overview

- Atoms and Elementary Particles [2a]
  - Build an Atom: Computer Model [2b]
  - Discuss Particle Accelerators [3b]
  - Build an Electroscope [4a]
- Radiation Overview [1a]
  - Demonstrate Half Life: Twizzler Decay
- Radiation Safety [1b]
  - Draw Radiation Hazard Symbol [1c]
  - Use a Geiger Counter [5a]

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Afternoon Overview

- Radon [5b]
  - Detection and Dilution
- Nuclear Fission [6a]
- Nuclear Science Applications [7]
  - Cloud Chamber [4b]
- Career Opportunities [8]

ANS

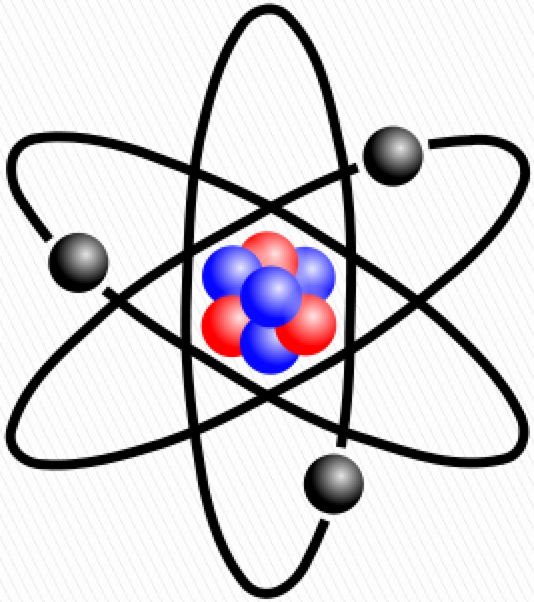
[2a]

Atoms and Elementary Particles

In this Section, we will discuss:

- Atom
- Nucleus
- Proton
- Neutron
- Electron
- Quark
- Isotope
- Alpha Particle
- Beta Particle
- Gamma Ray
- X-ray
- Ionization
- Radioactivity
- Radioisotope

Pop Quiz: What is this?



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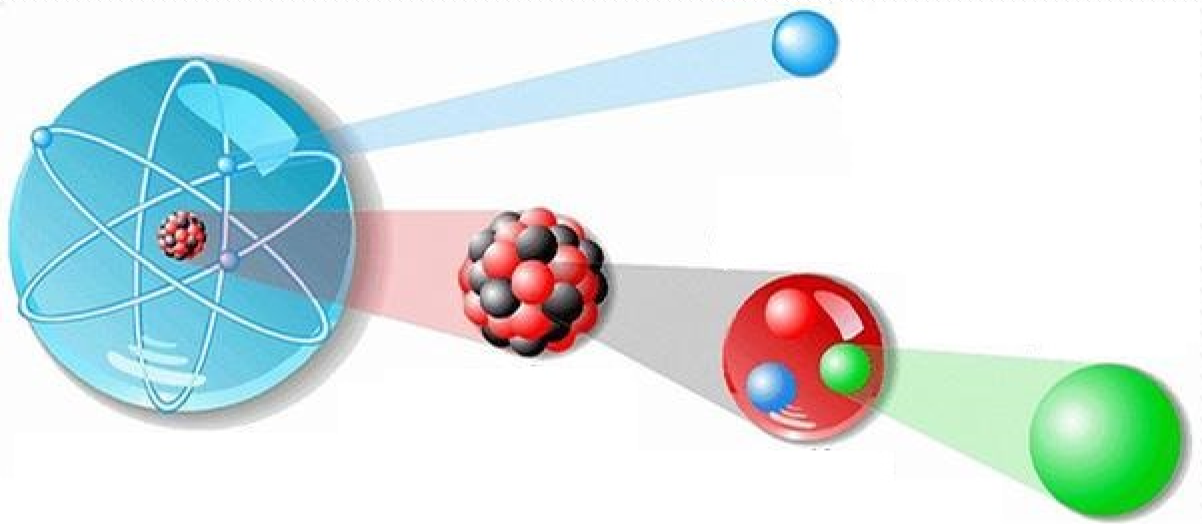
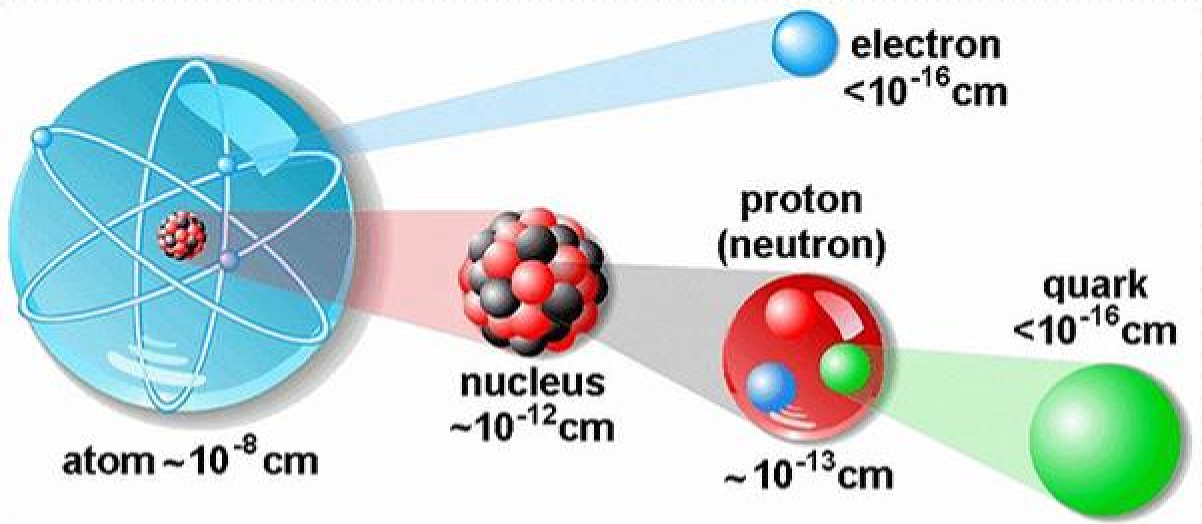
Elements

Atoms and Elementary Particles



Atoms and Elementary Particles



ANS

Atoms and Elementary Particles

- An atom is the smallest piece or unit of an element having the properties of that element.
- Elements are fundamental substances that can't be broken into simpler substances by chemical means.
- Familiar elements include hydrogen, oxygen, iron, and gold. Each element consists of one basic kind of atom.

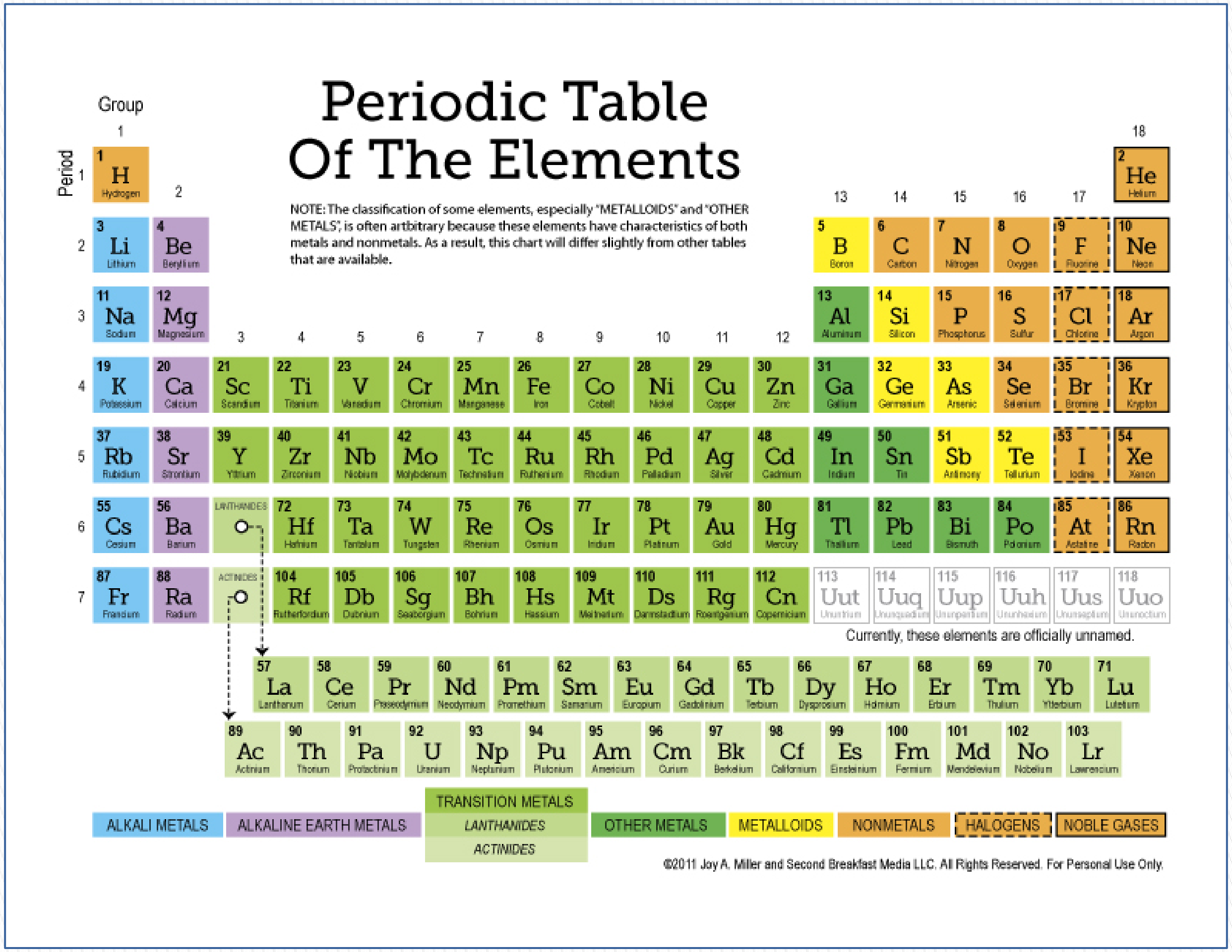
Atoms and Elementary Particles

- Atoms are made up of protons, neutrons & electrons: the building blocks of matter
  - Protons: + charge
  - Neutrons: no charge
  - Electrons: – charge

- Atoms want to be *neutral* and have no net charge
  - In other words:

    number of protons = number of electrons

Atoms and Elementary Particles



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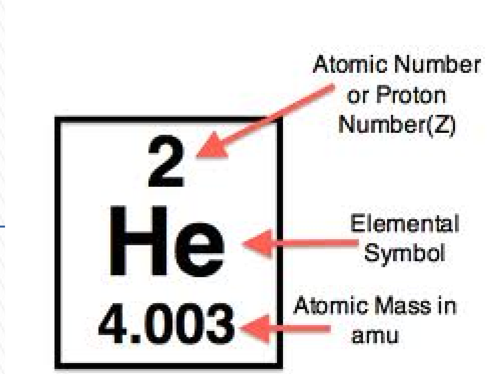
Protons

- Discovered in 1914 by Ernest Rutherford

- In 1914 Henry G. J. Mosely came up with *atomic number* (Z) as a way to count the number of positive electric charges.
  - *Atomic number* is the number of protons in the nucleus of an atom.
  - The number of protons determines the kind of element.



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Neutrons

- Neutron
  - Rutherford suggested the existence of a neutron in 1920.
    - Part of nucleus with no electric charge that was why the atomic number was different from atomic mass.
      - About equal in size to a proton.
  - James Chadwick found the neutron in 1932.
  - Discovery of neutron allowed scientist to better describe the atom, atomic number, mass number, atomic mass

Electrons

- In 1891 Irish physicist G. Johnstone Stoney theorized that electric current was the movement of small electrically charged particles called *electrons*.

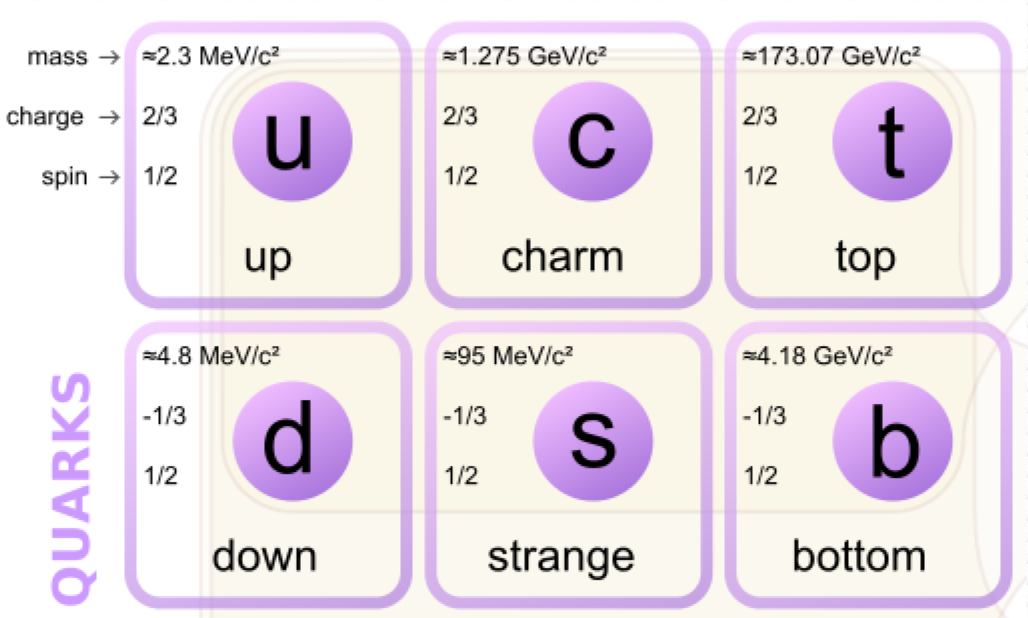
- Electrons have a negative electric charge and a tiny mass.

ANS

Quarks and Gluons

- In the late 20th century particle accelerators shattered protons and neutrons into pieces.

- Protons and neutrons are made up of much smaller particles (**quarks**)
  - Protons have two up quarks and 1 one down quark
  - Neutrons have two down quarks and 1 up quark
- **Gluons** are particles that keep the quarks from flying away from each other.



mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈173.07 GeV/c²
2/3
1/2
t
top
QUARKS
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom

ANS

Atomic Mass

- Masses of particles:
  - Mass of a Proton (Z) = 1 amu
  - Mass of a Neutron (N) = 1 amu
  - Mass of an Electron (e) = .000549 amu

- Since m_e is *so* small, the atomic weight of an atom (A) is roughly equal to Z + N, or:

$$A = Z + N$$

ANS

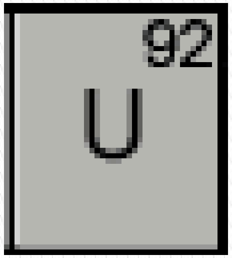
Atomic Mass

- Helium?
  - 2 protons + 2 neutrons + 2 electrons
  - 4
- Oxygen?
  - 8 protons + 8 neutrons + 8 electrons
  - 16
- Uranium-235?
  - 92 protons + 143 neutrons + 92 electrons
  - 235
- An alpha particle (a Helium *nucleus*)?
  - 2 protons + 2 neutrons
  - 4

Uranium 235

Symbols are used to represent specific atoms and their nuclei

$^{235}_{92}\mathrm{U}$ 143 Neutrons



Chemical symbol (U for uranium)

All uranium atoms have 92 protons in nucleus

A neutral uranium atom has 92 electrons orbiting the nucleus

Review

- What is an atom?

the smallest piece or unit of an element having the properties of that element.

- Elements are fundamental substances that can't be broken into simpler substances by chemical means.

For example: Hydrogen, Oxygen, Iron, Gold

Review

- What is the nucleus?

  the tiny core of an atom,
  consisting of protons and neutrons

- The number of protons and neutrons determine the atomic mass

$$A = Z + N$$

Atomic Mass = # Protons + # Neutrons

ANS

Review

- What is a proton?

  a fundamental building block of an atom with:
  Charge = Positive (+1)
  Mass = 1 AMU

- The number of protons determines the atomic number

Review

- What is a neutron?

  a fundamental building block of an atom with:
  Charge = Neutral (0)
  Mass = 1 AMU

- Two atoms of the same element can have a different number of neutrons

Review

- What is an electron?

  a fundamental building block of an atom with:
  Charge = Negative (–1)
  Mass = 0.000549 AMU

- Electrons orbit around the nucleus in shells

Review

- What is a quark?

  the fundamental building blocks of protons and neutrons

- They come in 6 flavors:
  - Up / Down
  - Strange / Charm
  - Top / Bottom

Review

- What is an isotope?

  atoms of the same element
  with different masses

- Same number of protons,
  but a different number of neutrons:

$$A = Z + N$$

Atomic Mass = # Protons + # Neutrons

Review

- What is an Alpha particle?

  two protons and two neutrons

- The nucleus of a Helium atom
- Positively charged (+2)
- Can be stopped by a sheet of paper

Review

- What is a Beta particle?

    free flying electrons

- Negatively charged (-1)

- Can be stopped by a 100 sheets of paper, or a sheet of aluminum

Review

- What is a Gamma ray?

    high energy light wave

- No charge (0)
- Higher energy than X-ray
- Can be stopped by thick concrete or lead

Review

- What is an X-ray?

  high energy light waves

- No charge (0)
- Lower energy than Gamma Ray,
  but higher energy than ultraviolet ray
- Can be stopped by concrete or lead

Review

- What is ionization?

    the process of becoming negatively or positively charged

- Ions have a different number of protons and electrons.

Review

- What is radioactivity?

  the process of giving off charged particles or rays (ionizing radiation)

Review

- What is a radioisotope?

atoms that give off energy (radiation)

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[p.10 / Req. 2b] Build an Atom: Computer Model

- Check out:

http://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html

- Click on Atom under "Build an Atom"

- Build your own atoms!

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[p.10 / Req. 2b] Build an Atom: Computer Model

- Fluoride is a stable, negatively charged Fluorine ion. Build a Fluoride Ion.
  - Check Element Name
    - How many protons does it take?
  - Check Neutral/Ion
    - How many electrons does it take, and where are they?
  - Check Stable/Unstable
    - How many neutrons does it take?
    - What is the atomic mass?

[p.10 / Req. 2b]
Build an Atom: Computer Model

- Build an atom with Z=10, N=13, e=9
  - What is the element name and symbol?
  - What is the charge?
  - How would you make the atom neutral?
  - Is the atom stable?
  - How can you make the atom stable?
  - How many isotopes are stable?

Build an Atom: Computer Model

- Build three isotopes of Hydrogen:
  - Protium : 1 Proton, 0 Neutron
  - Deuterium: 1 Proton, 1 Neutrons
  - Tritium: 1 Proton, 2 Neutrons

- Which isotopes are stable?

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[3b]

Discuss Particle Accelerators

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[3b]

Discuss Particle Accelerators

Large Hadron Collider (CERN)

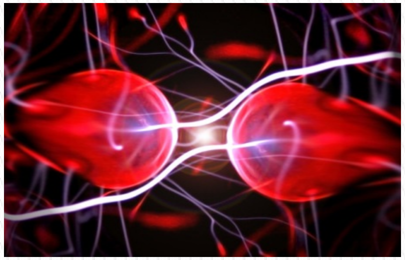
- Conseil Européen pour la Recherche Nucléaire (European Organization for Nuclear Research)
- Located in Geneva, Switzerland
- 17-mile long underground ring – largest ever

ANS

Discuss Particle Accelerators

Relativistic Heavy Ion Collider

- Brookhaven National Laboratory – Upton, NY
- The only operating collider in the US
- By using RHIC to collide ions traveling at relativistic speeds, physicists study the primordial form of matter that existed in the universe shortly after the Big Bang



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[3b]

Discuss Particle Accelerators

Fermi National Accelerator

- Batavia, IL
- Tevatron – smashes protons/antiprotons
- Examines basic building blocks of matter

Discuss Particle Accelerators

Thomas Jefferson National Accelerator

- Newport News, VA
- Fixed target accelerator
- Stream of electrons, stationary nuclei
- Examines quarks

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[3b]

Discuss Particle Accelerators

National Superconducting Cyclotron Laboratory

- Michigan State University
- Largest University nuclear facility
- Researches rare-isotopes
  - Only exist briefly in stars

ANS

[3b]

Discuss Particle Accelerators

Advanced Light Source

- Berkeley, CA
- Produces X-rays that examine the structure of atoms and molecules

Review

- Describe 3 Particle accelerators

Large Hadron Collider
Relativistic Heavy Ion Collider
Fermi National Accelerator
Thomas Jefferson National Accelerator
National Superconducting Cyclotron Laboratory
Advanced Light Source

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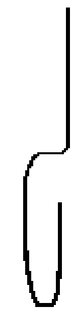
[4a]

Build an Electroscope

- Rob Flammang
- Westinghouse Nuclear Laboratory
- Churchill, PA

Build an Electroscope

1. Bend your paper clip like so:

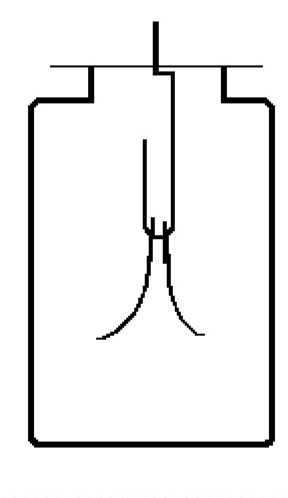


2. Put the hook of the paper clip through two strips of aluminum foil (1cm by 4cm).
3. Put the other end of the paperclip through an index card, and lay the card on the jar so that it suspends the assembly (use tape to secure, if needed).

ANS

Build an Electroscope

Place a source of electricity near the "sensor" (the end of the paperclip sticking out). What happens? Do the strips go in or out? Is that source positive or negative?



ANS

Build an Electroscope

Two Fundamental Properties

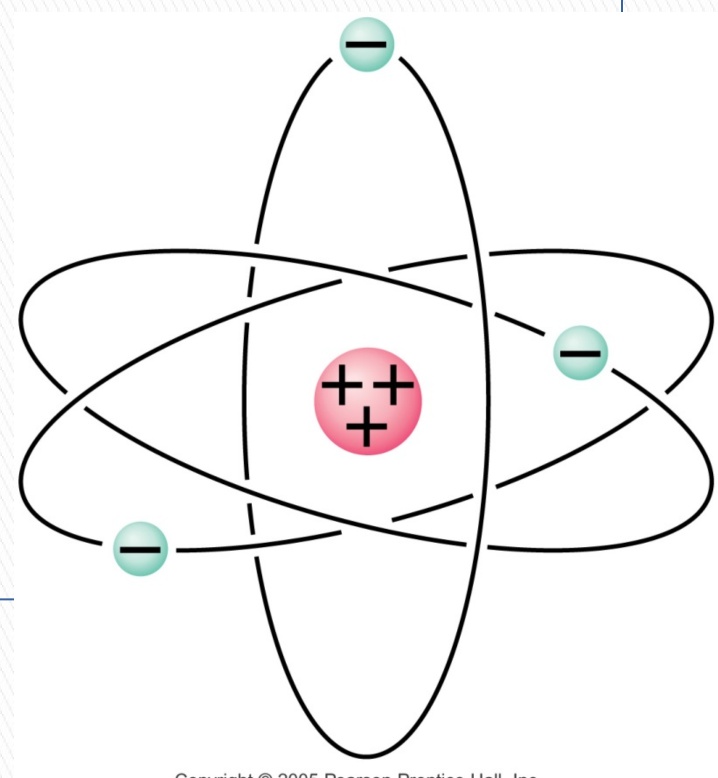
Mass: The property of an object that enables it to respond to a gravitational field and to exert a force on another mass.

Electric Charge: The property of an object that enables it to respond to an electric field and to exert a force on another electric charge

Build an Electroscope

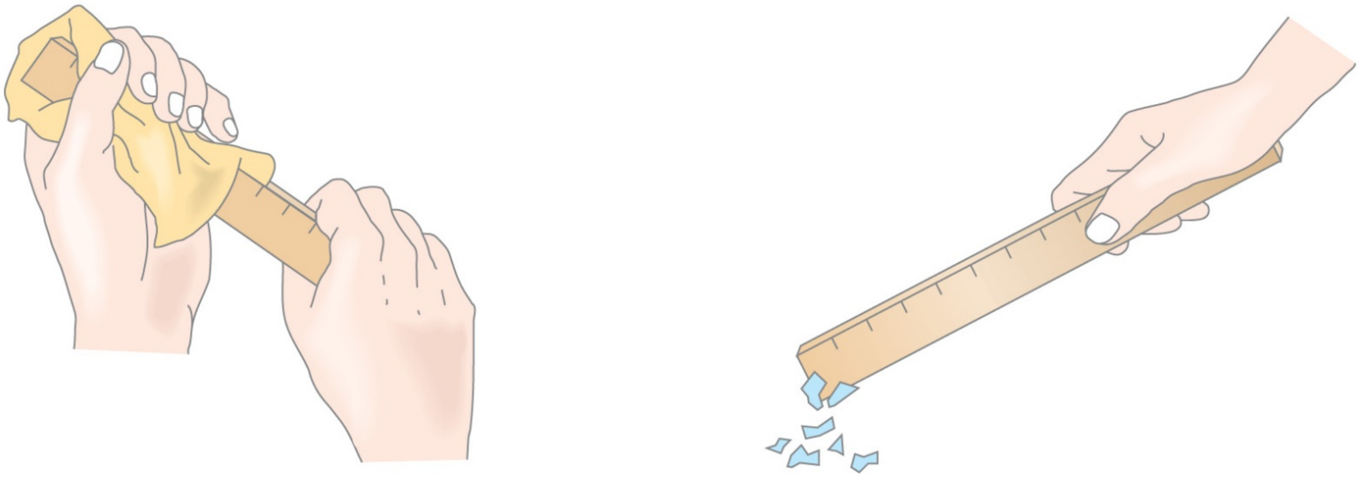
Electric Charge in the Atom:

- Nucleus (small, massive, positive charge)
- Electron cloud (large, very low density, negative charge



Build an Electroscope

- Atoms are normally electrically neutral.
- Rubbing two objects together can charge them by moving electrons from one to the other.



(a) (b)

ANS

Build an Electroscope

Static Electricity

Electric Charge,

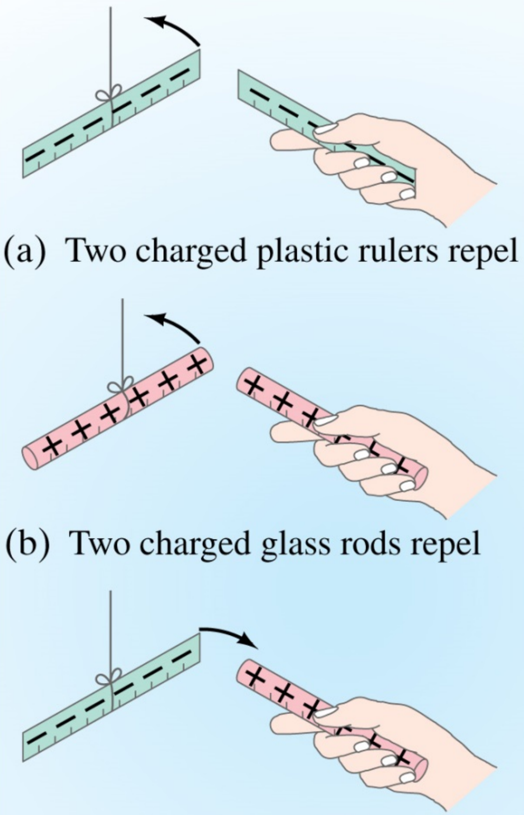
and Its Conservation

Charge comes in two types,

positive and negative;

like charges repel

and opposite charges attract



(a) Two charged plastic rulers repel

(b) Two charged glass rods repel

(c) Charged glass rod attracts charged plastic ruler

ANS

Build an Electroscope

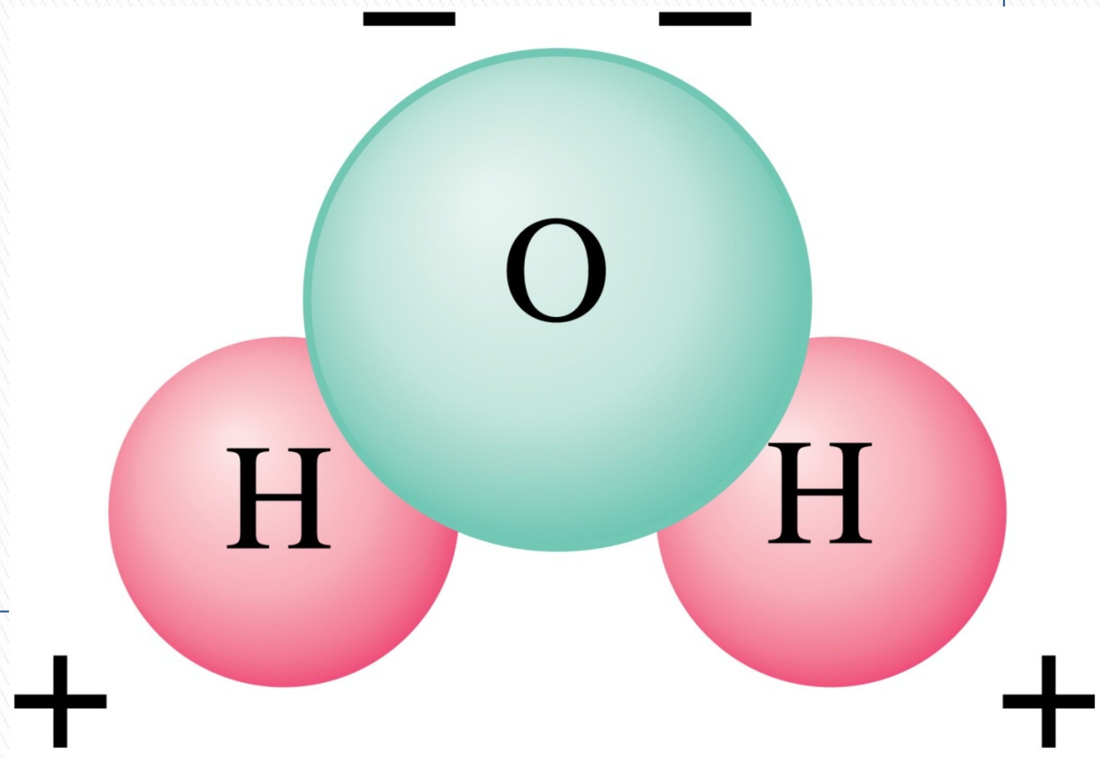
Static Electricity, Electric Charge, and Its Conservation

- Electric charge is conserved – the arithmetic sum of the total charge cannot change in any interaction.

Build an Electroscope

Electric Charge in the Atom

- Polar molecule: neutral overall, but charge not evenly distributed

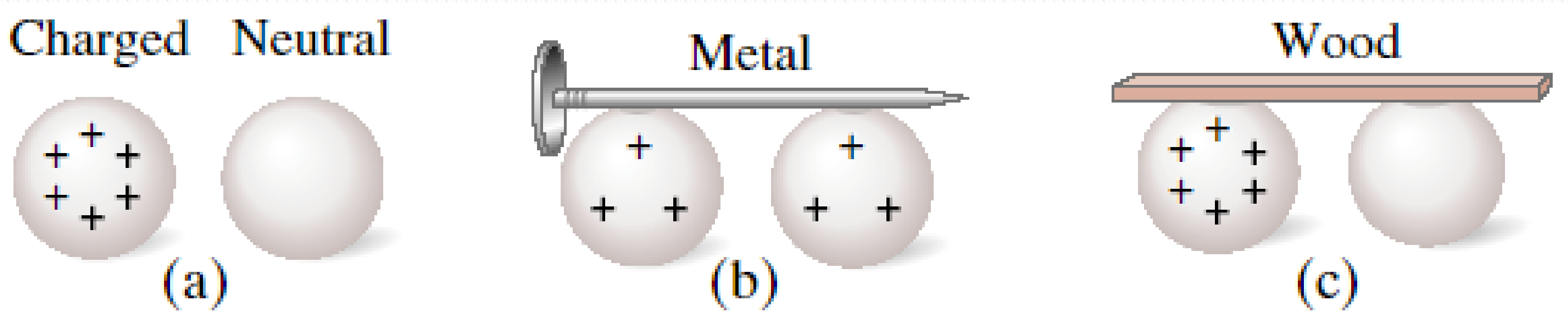


ANS

Build an Electroscope

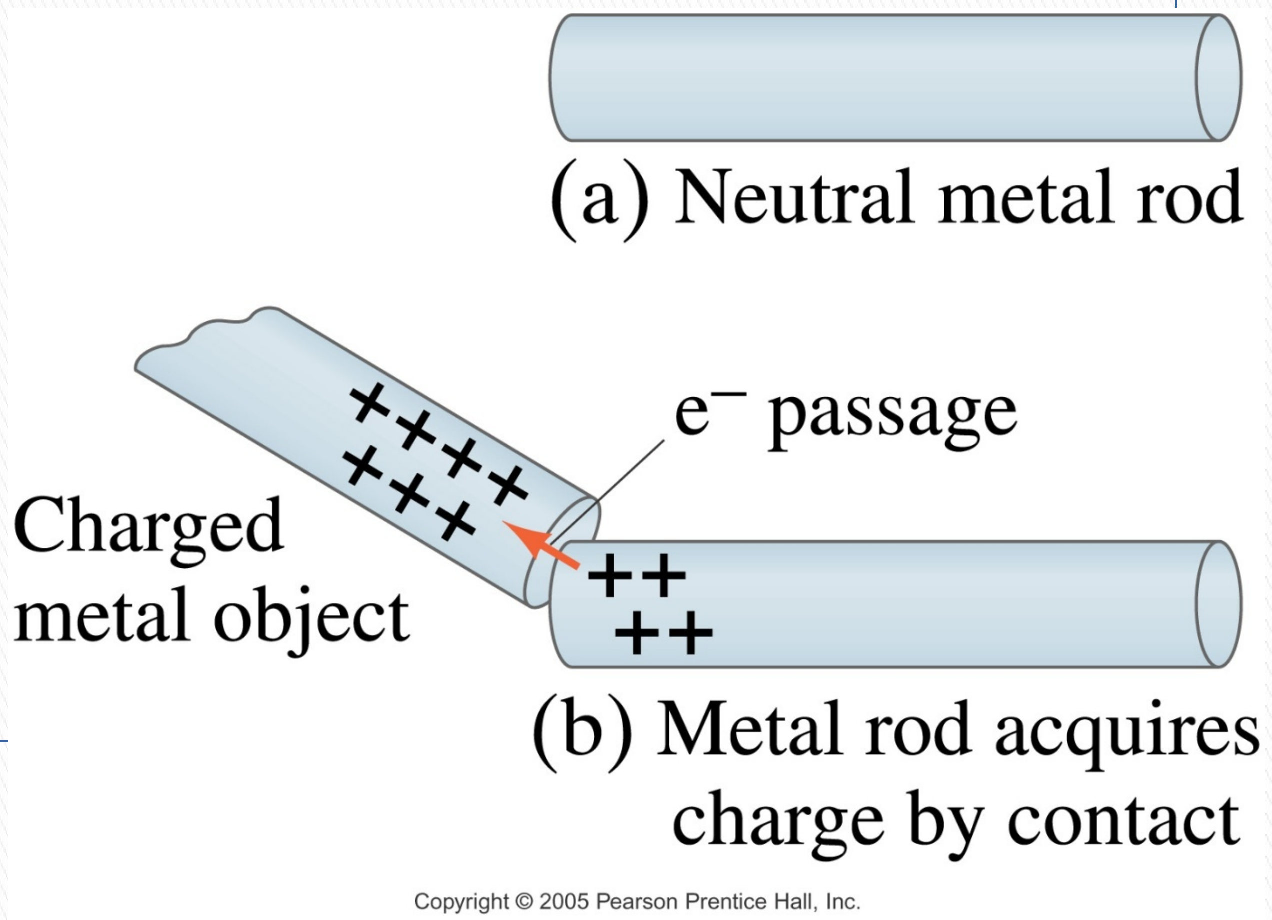
Conductor:	Insulator:
Charge flows freely	Almost no charge flows
Metals	Most other materials

Some materials are semiconductors.



Build an Electroscope

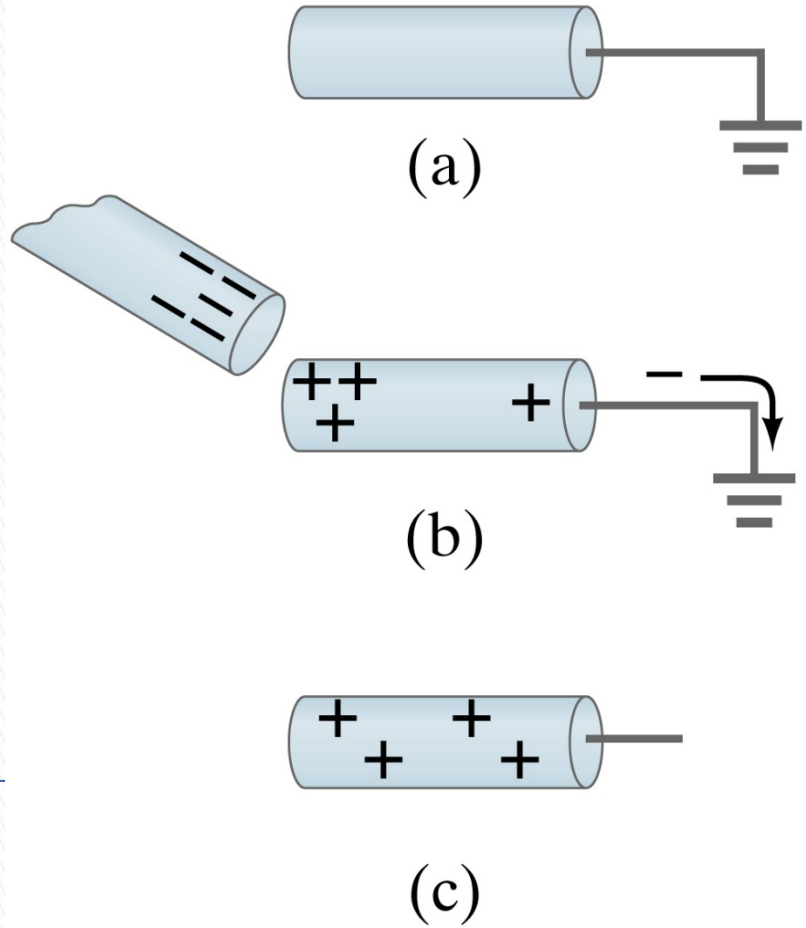
Metal objects can be charged by conduction:



[4a]

Build an Electroscope

They can also be charged by induction:



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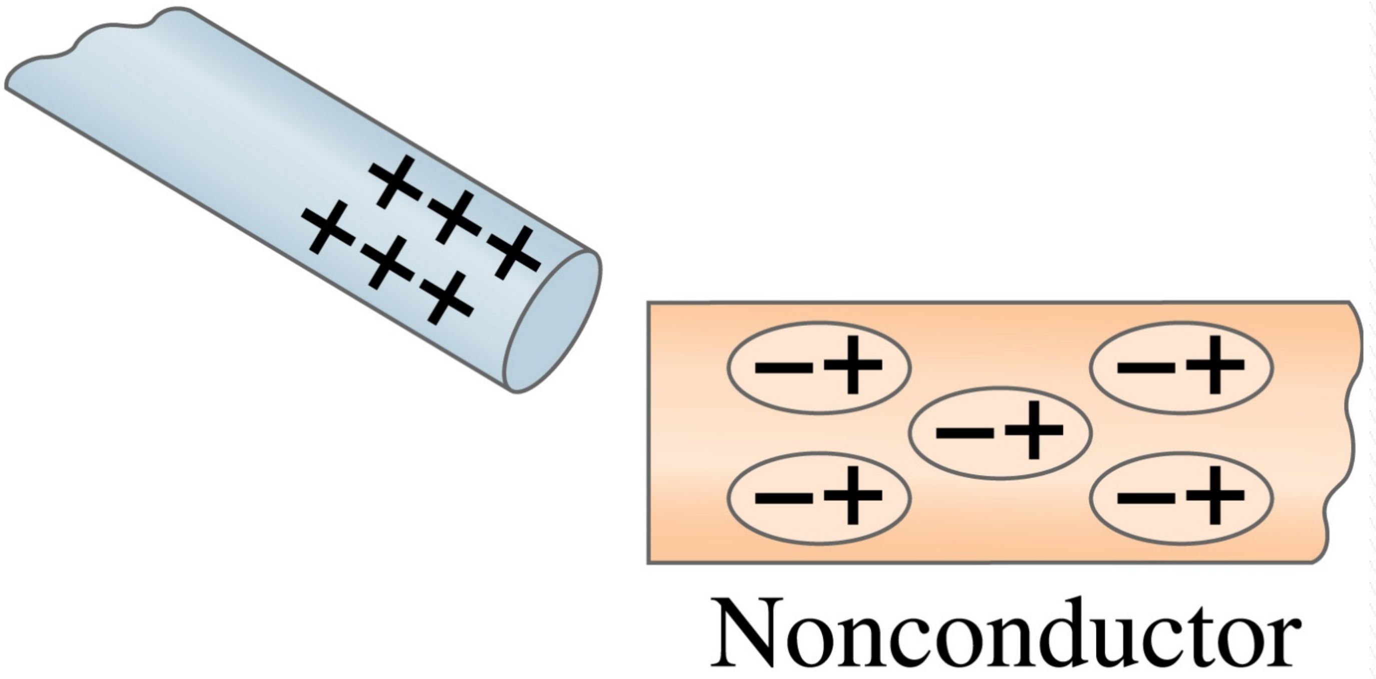
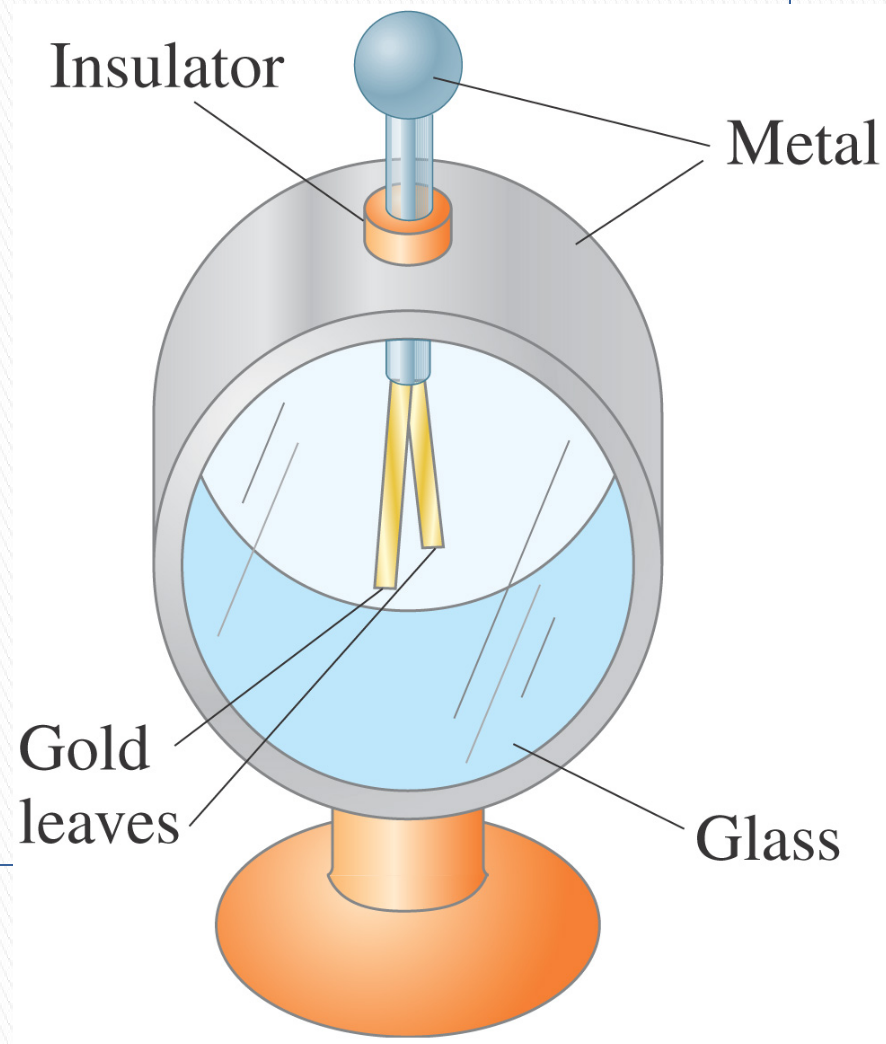
Build an Electroscope

Nonconductors won't become charged by conduction or induction, but will experience charge separation:



Build an Electroscope

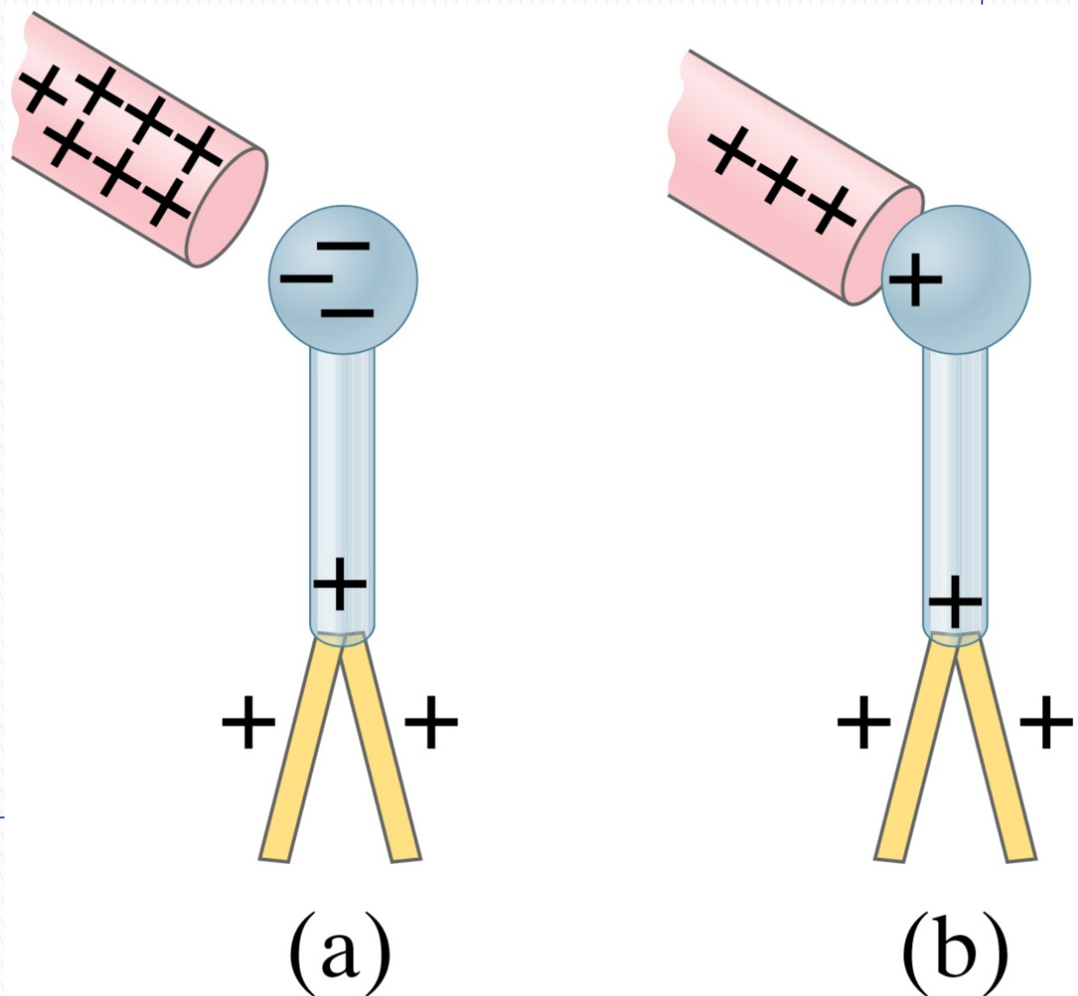
The electroscope can be used for detecting charge:



ANS

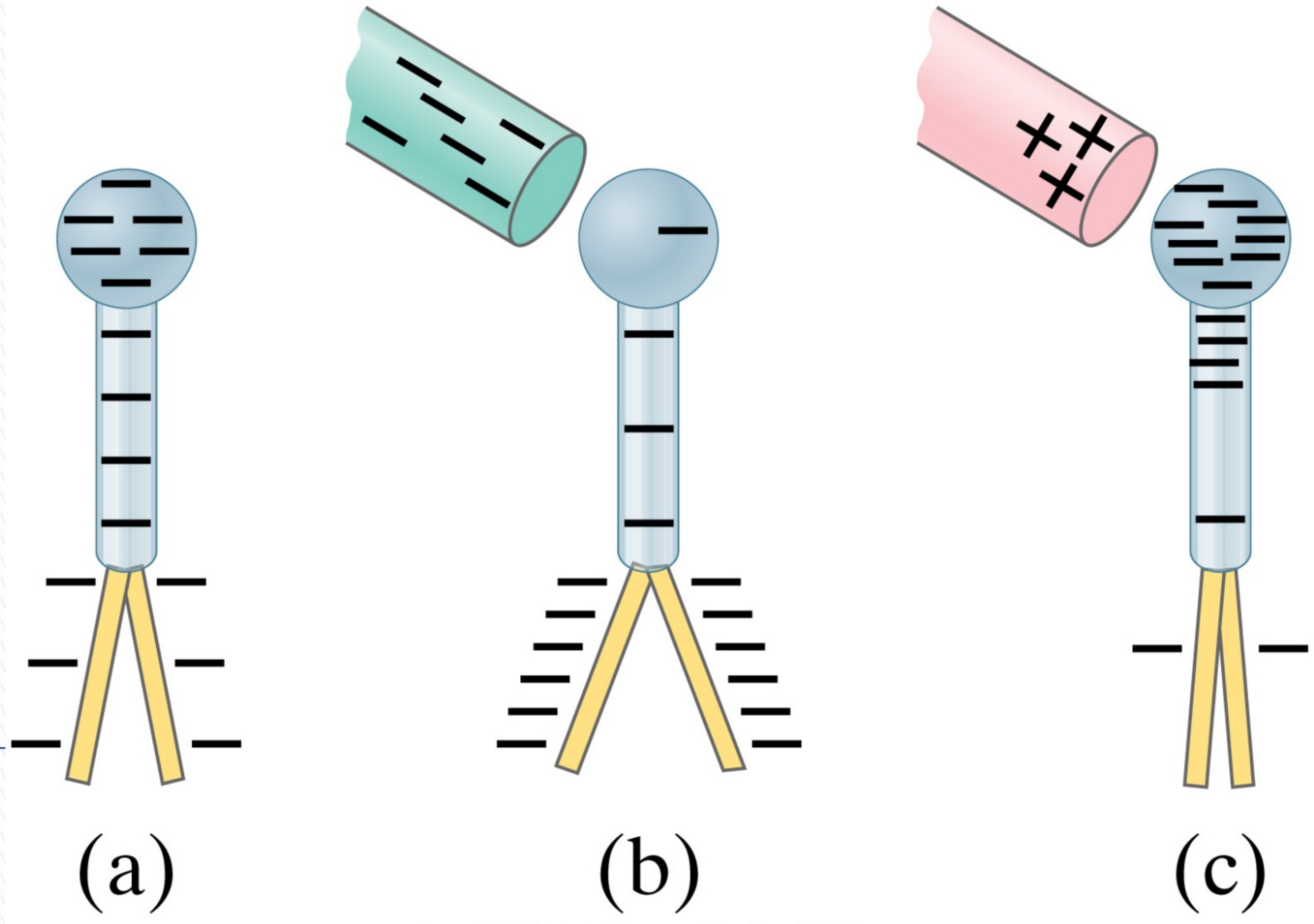
Build an Electroscope

The electroscope can be charged either by conduction or by induction.



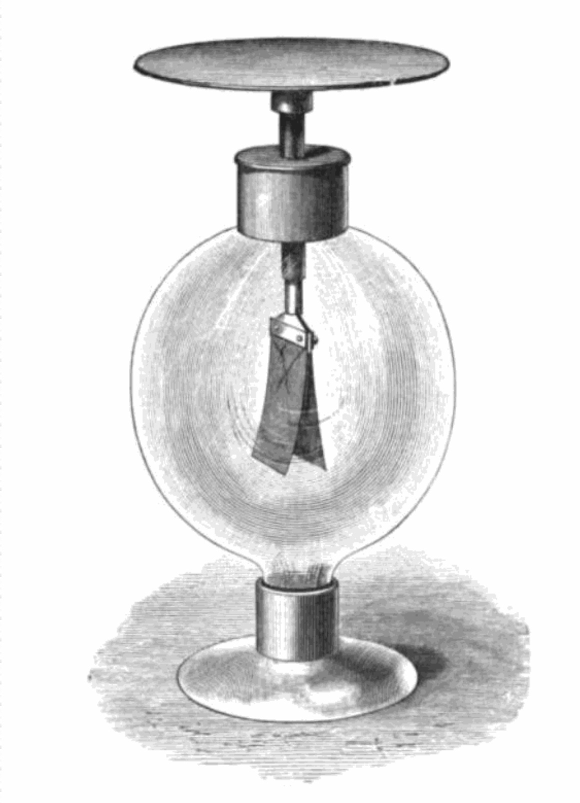
Build an Electroscope

The charged electroscope can then be used to determine the sign of an unknown charge.



Activity

- Build an electroscope



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ANS

Radiation Overview

- Radiation is energy in the form of particles or electromagnetic waves. It is how the universe transfers energy!
- Radiation is released to get rid of extra energy. It occurs regularly in nature, but can also be induced.
- Different types of radiation:
- Alphas (helium nuclei)
- Betas (electrons, positrons)
- Protons (positive electrical charge)
- Neutrons (no electrical charge)
- Electromagnetic Waves(visible light, radio waves, x-rays, gamma rays)
- If radiation interacts with an atom and has enough energy, it will ionize the atom. That atom will then be negatively or positively charged.
- An “ion” is an atom with too many (or too few) electrons, giving it a net electrical charge.

[1a]

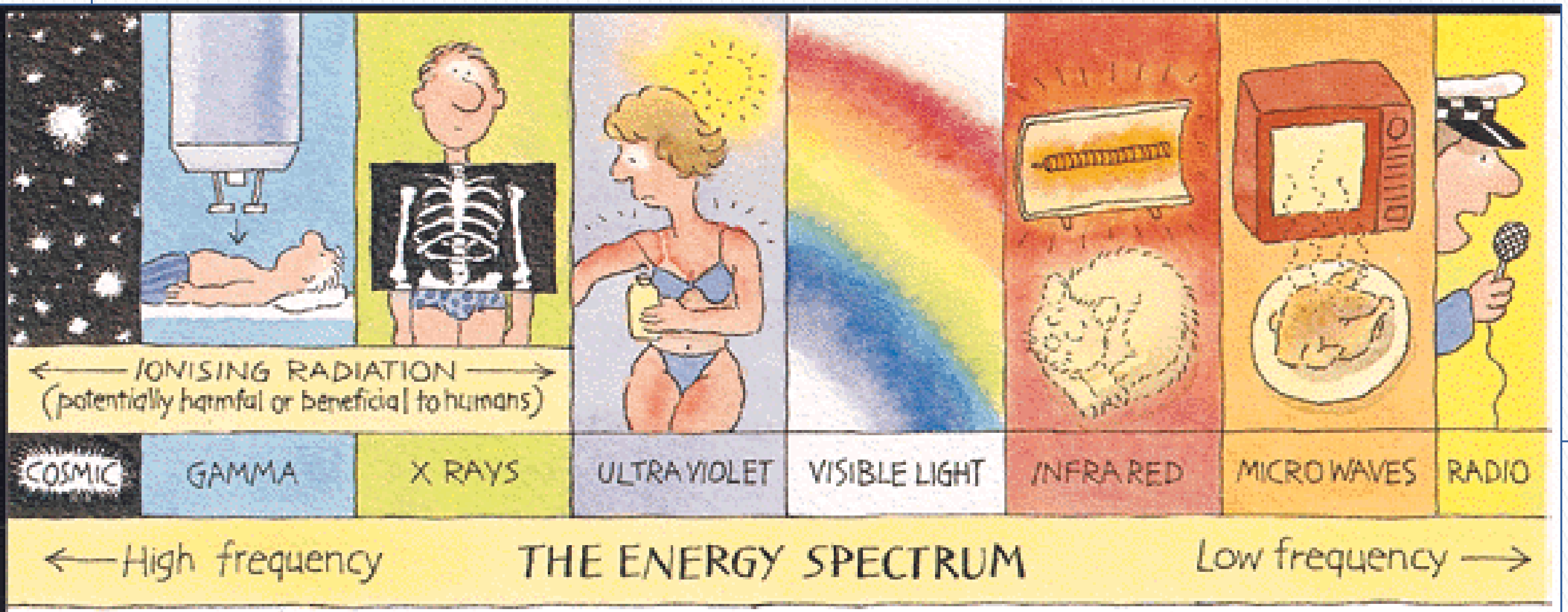
Radiation Overview

Ionizing radiation

- Produces ions in the material it strikes

Non-ionizing radiation

- Can cause damage by physically striking material



Radiation Overview

- Ionizing radiation has enough energy to remove an electron from an atom or molecule. This produces *free radicals*, atoms containing unpaired electrons, which tend to be especially chemically reactive.

Some examples of ionizing radiation are:

- Alpha particles
- Beta particles
- Photons
  - Gamma rays
  - X-rays

ANS

Radiation Overview

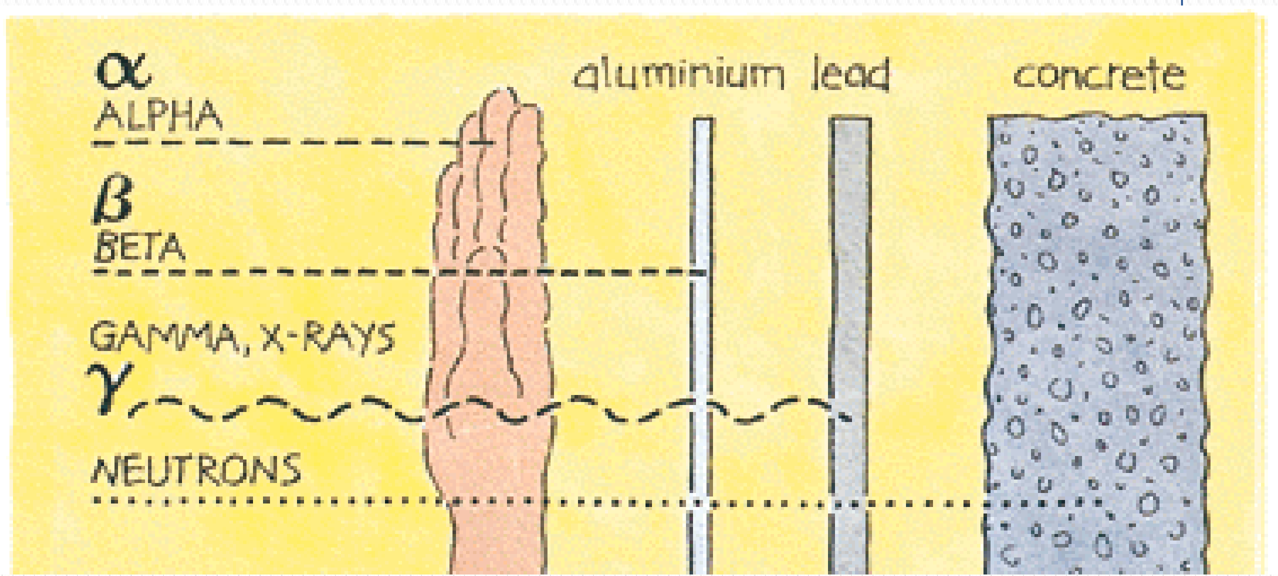
- Non-ionizing radiation interacts with matter by colliding into it, or causing electron "excitation" (moving to a higher energy state).
- Some examples of non-ionizing radiation are:
- Low energy photons
  - Such as visible light, infrared light, etc
- Neutrons
  - Neutral particle in nucleus
  - Like a proton but with no charge

Radiation Overview

- The sun
- Soil, water, and vegetation
- Internal sources
  - Potassium-40 (bananas)
  - Carbon-14 (air)
  - Lead-210 (radon)
- Man-made sources
  - Medical sources (x-rays, radiation…)
  - Nuclear Power

Radiation Overview

- Each type of radiation has different interaction properties.
- Energy deposition in soft tissue poses a health risk.
- The shielding used to limit exposure depends on the type of radiation.



ANS

Review

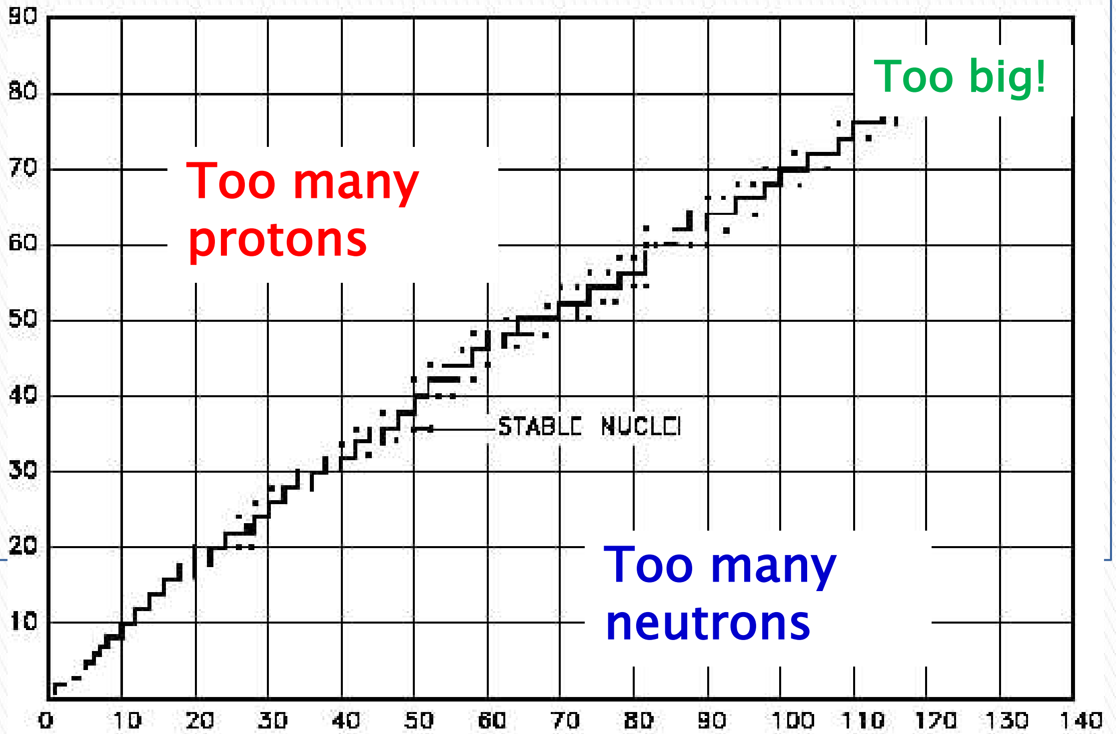
- What is radiation?

  energy or particles that come from a source and travel from one place to another

- Energy in motion

Radiation Overview

- Not all combinations of neutrons and protons are "stable".
  - Nuclei with an unfavorable combination will attempt to reach a lower energy state by emitting energy ("radiation") from the nucleus.



[1a]

Radiation Overview

- Radioactive material has a probability of *decaying.*

- Over time, this probability averages into a "half-life"

- Half-life = Amount of time it takes for *half* of the radioactive substance to decay

ANS

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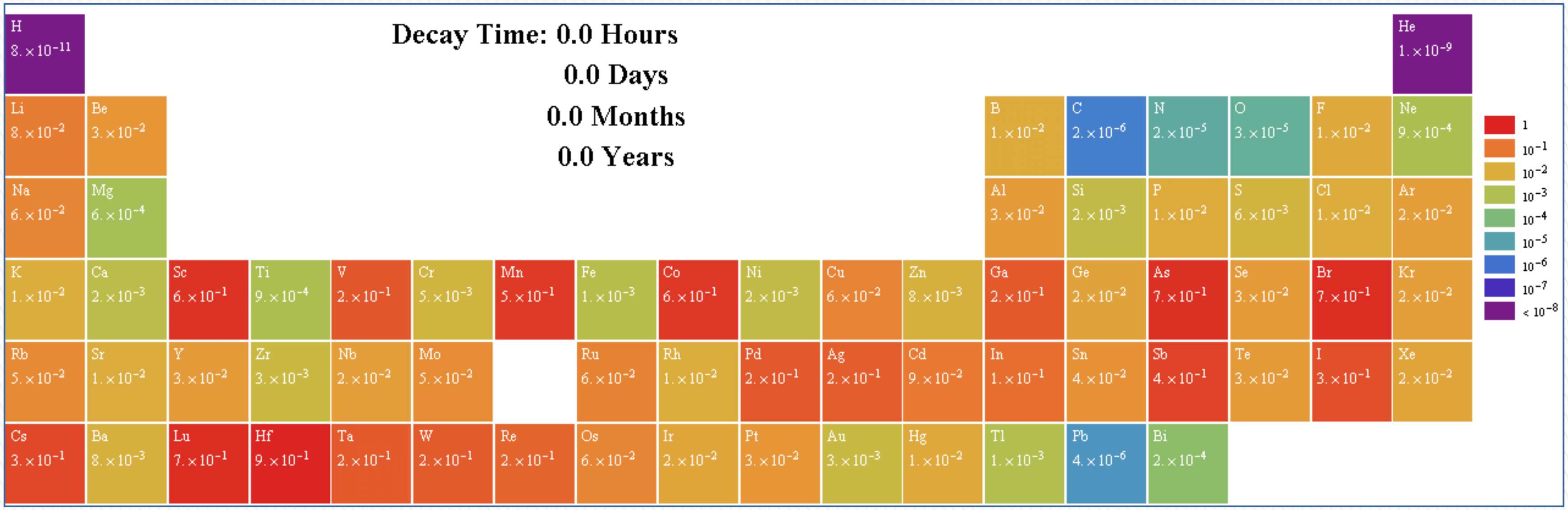
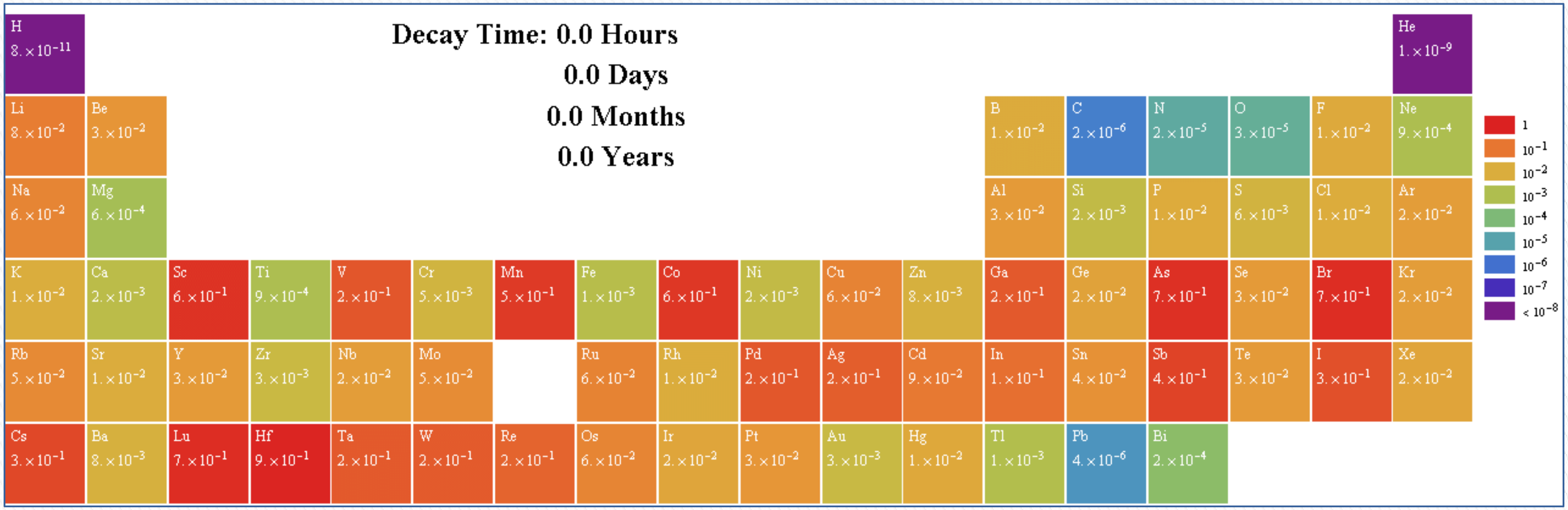
Elemental Decay



Elemental Decay



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Half Life: Twizzler Decay

- An isotope undergoing radioactive decay will emit Energy/radiation at a constant rate, known as the decay rate. Like your fingerprints are unique to you (and only you), the decay rate of an isotope is a unique and measurable value.

- Related to the decay rate is the half-life of an isotope. It is related by the equation:

$$T_{1/2} = \frac{\ln(2)}{\lambda}$$

- The half-life is defined as the time in which it takes half of the isotopes to decay.

- The Half-Life of a Twizzler is 1 minute. In other words: every 1 minute, half of the Twizzler "decays" and is eaten by you!

- Let's use the half life to plot the decay curve of a Twizzler. You will find that the shape of this curve ("exponential decay") is seen all throughout nature (Newton's Law of Cooling, Electric Discharge, Radioactive Decay).

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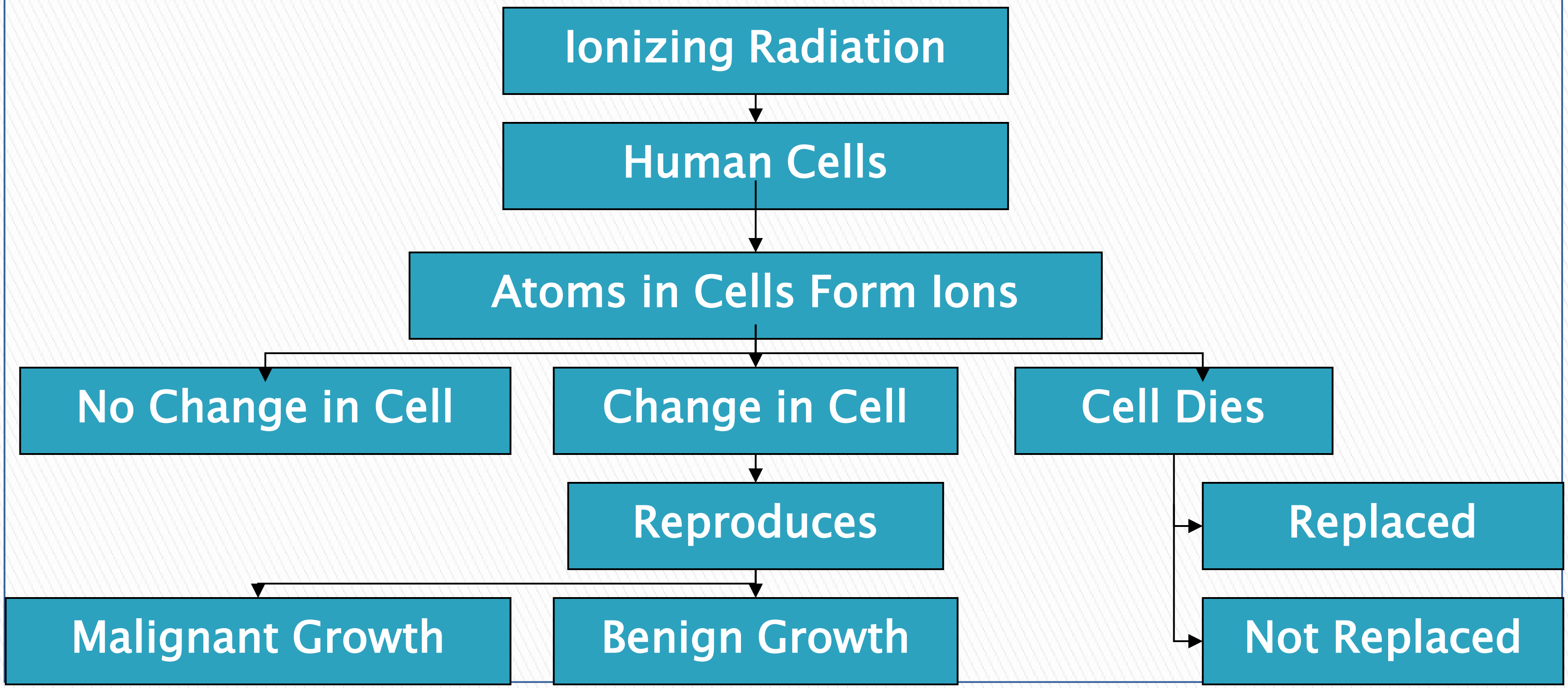
[1b]

Radiation Safety

- Effects of Radiation on a Human Cell



Radiation Safety

- Biological effects of radiation
- The effects of radiation can be broken into two groups according to how the responses (symptoms or effects) relate to dose (or amount of radiation received):
- *Stochastic* Effects
- *Deterministic* Effects

Radiation Safety

- Deterministic Effects

- Deterministic Effects are those responses which increase in severity with increased dose

- For example: a sunburn. The more you're exposed to the sun, and the higher the 'dose' of sunlight you receive, the more severe the sunburn is.

Radiation Safety

- Stochastic Effects
- Stochastic Effects are those effects which have an increased probability of occurrence with increased dose, but whose severity is unchanged.
- Example: skin cancer and sunlight. The probability of getting skin cancer increases with increasing exposure to the sun
- Stochastic Effects are like a light switch: they are either present or not present

Radiation Safety

- NRC Limits

Subjects Exposed	Time Frame	Dose (mrem)
Nuclear Worker	1 year	5000
General Public (from Nuclear Facility)	1 year	100
Pregnant Woman	9 months	500

Review

- What are the hazards of radiation?
  - ACUTE doses (without treatment) and Immediate, Stochastic Effects
    - 5-10 rem: blood changes
    - 50 rem: nausea (hours)
    - 55 rem: fatigue
    - 70 rem: vomiting
    - 75 rem: hair loss (2-3 weeks)
    - 90 rem: diarrhea
    - 100 rem: hemorrhage
    - 400 rem: possible death within 2 months
    - 1000 rem: destruction of intestinal lining, internal bleeding, and death in 1-2 weeks
    - 2000 rem: damage to CNS, loss of consciousness, and death within hours to days

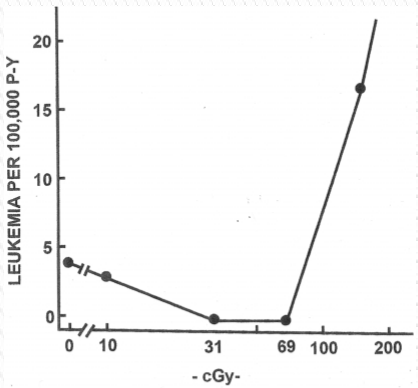
Review

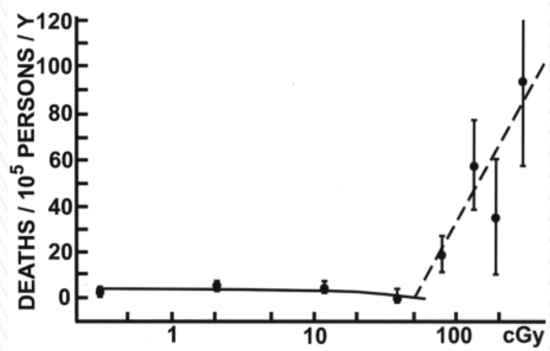
- What are the hazards of radiation?
  - CHRONIC doses or small acute doses
    - Much harder to answer
    - Current model is LNT: current standard
    - If we use LNT to look at the airline industry:
      - 79,000 excess cancers from flying
      - 40,000 yearly deaths
    - A lot of good evidence supports a 10 Rem/year healthy dose
    - At a certain level (between 20-70 Rem/year), linear effects start to manifest themselves and cancer risks increase
    - Large, cumulative doses can also damage eyes (cataracts) and heart valves

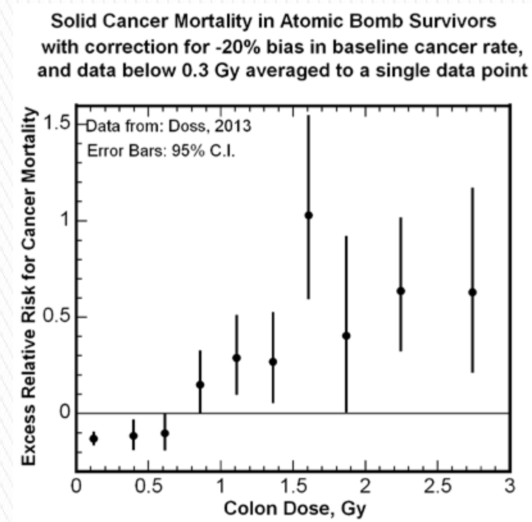
A Basis for Threshold or Hormesis

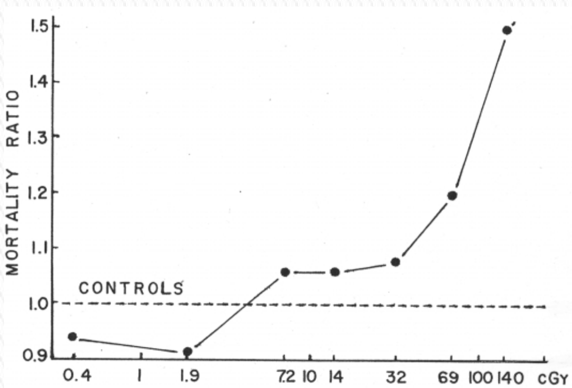
- 55,200 Single Strand Breaks (SSB) / cell / day
- 10-50 Double Strand Breaks (DSB) / cell / day
- 10 Rem dose?: 100 SSBs and 4 DSBs
- Cell has repair mechanisms
- A stressor on a cell will be communicated to other cells
- Cell responses get faster and more effective following a low-dose exposure

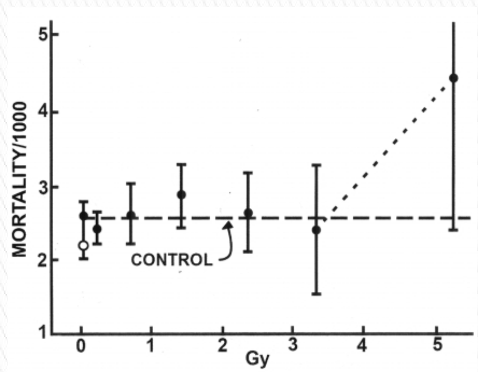
Data Used to Support 1956 BEAR Reports

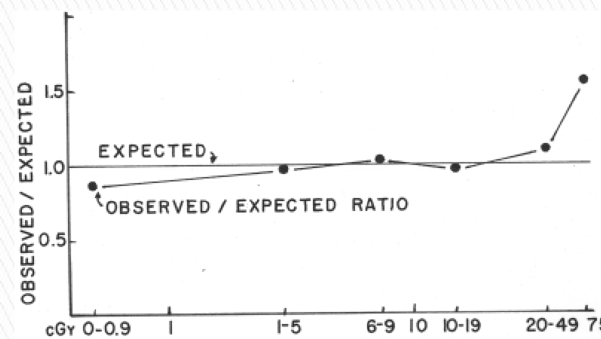












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Lies, Darned Lies, and Statistics

- How could they make that data look any good?

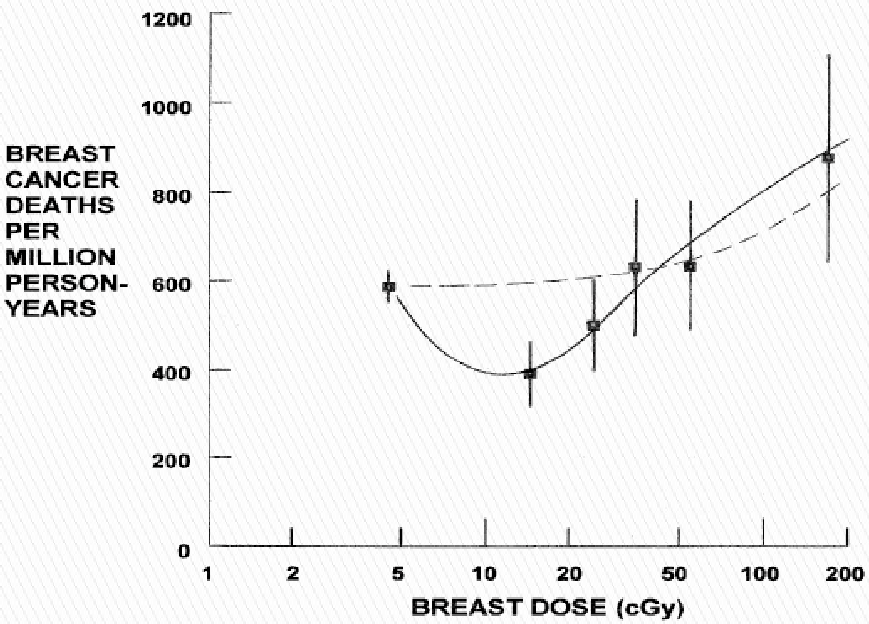
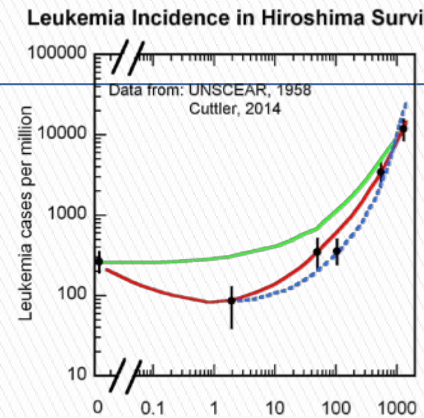
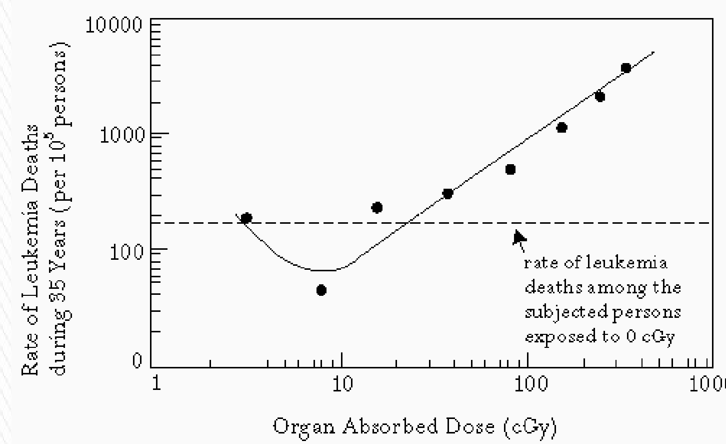


Figure 2. Reduced Breast Cancer Mortality for Tuberculosis Patients Who Received LDI During Fluoroscopy. Data from Miller et al.[18]





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AMERICAN NUCLEAR SOCIETY

Additional Studies/Examples

- Naval shipyard workers study
  - 27,872 High-Dose Nuclear Workers
  - 10,348 Low-Dose Nuclear Workers
  - 32,510 Control
  - *"The high-dose workers demonstrated significantly lower circulatory, respiratory, and all-cause mortality than did unexposed workers. Mortality from all cancers combined was also lower in the exposed cohort."*
- Ramsar Iran and Black Sands of Brazil
  - "People in some areas of Ramsar, a city in northern Iran, receive an annual radiation dose from background radiation that is more than five times higher than the 20 mSv. Yr^{-1} that is permitted for radiation workers. "
  - "The absorbed dose rate in some high background radiation areas of Ramsar is approximately 55-200 times higher than that of the average global dose rate. It has been reported that 3-8% of all cancers are caused by current levels of ionising radiation."
  - "Our cytogenetic studies show no significant differences between people in the high background area compared to people in normal background areas."
  - "There are no data to indicate a significant increase of cancer incidence in other high background radiation areas (HBRAs). Furthermore, several studies show a significant decrease of cancer death rates in areas with high backgrounds."

Additional Studies/Examples

- Chernobyl Workers
  - 200,000 Russian workers engaged with average dose (as measured by IAEA and WHO supervision) of 100 mSv (10 Rem)
  - 150 Leukemia deaths were predicted, but none were seen
  - No excess solid cancer deaths
  - Another study showed 48 Leukemia deaths out of 180,000 workers vs. 131 expected in normal society
  - 65,905 workers with external doses averaging 100 mSv were followed through 1991-1998
    - "The report indicated that the death rate of Chernobyl workers was 0.6-0.9, lower than the general public death rate of 0.82"
    - Cancer mortality of 110 persons / 100,000 person-years, or 515 in 8 years
    - Expected cancer deaths in a normal population: 1102

Why Does it Matter?

- LNT allows for the mantra of "No Safe Dose"
  - Radiation fear is taught, not learned
  - People are not good at rationalizing fear
  - So-called "Low-probability, High-consequence events" dominate many people's concerns
  - The added element of "invisible killer!" makes radiation a unique psychological stressor
- Rationality
  - If you went into a closet to do some painting and realized you were a bit loopy after 15 minutes, would the harm to your liver haunt you for years following?
  - When you have a close-call, or minor-accident driving your car, do you remember it as a defining moment in your life?
  - When you drive by Bruce Mansfield and can smell the smoke coming out of the stacks, do you worry about the fractional impact to your health?

[p.4 / Req. 1b]

Review

- What is radiation exposure?
  - A body is exposed when energy in the form of particles or waves passes through it
  - When the energy source is removed, the exposure stops
  - Dose is easy to calculate using dosimetry if dose is from external source

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Review

- What is contamination?
  - A body is contaminated when radioactive material is deposited on that body
  - Dose stops when contamination is removed or material decays away
  - Concern around alpha-emitting particles in the lungs
  - Strontium acts like calcium and centralizes in bones
  - Biological half-life must be considered

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Review

- Discuss the risks of nuclear power
  - Nuclear accidents can release a high-amount of short-term radiation
  - If no precautions are taken, significant, acute dose can be received
  - Workers on-site may be exposed to dangerous or fatal levels of radiation
  - Very small increases in cancer risk may be seen by those who do not take precautions
  - Public health impacts surrounding evacuations and mental health are significant and tragic
  - Economic impacts to local area can be severe
  - No conclusive model exists: “Conservative” approach taken

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Review

- Discuss the risks of medical radiation
  - Mis-calibrated equipment can be fatal
  - Extremely large doses used in cancer treatment can increase the cancer risk to surrounding tissue
  - Burns in localized areas

[p.5 / Req. 1b]

Review

- Discuss the risks of background radiation
  - Radon can be breathed into lungs and has an only radioactive decay chain
  - Some studies link radon to increased cancer risk
  - Some studies link radon to decreased cancer risk
  - R. William Field showed 50% increase in lung cancer at EPA action level of 4 pCi/L
  - Study of Worcester County, MA showed 60% reduction in lung cancer in levels encountered in 90% of American homes
  - Bernard Cohen used an ecological study of the entire U.S. to show reduced cancer levels with increasing levels of radon
  - Radon mines exist across the world to decrease inflammation

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Review

- Explain the ALARA principle
  - ALARA means "As Low as Reasonably Achievable"
  - Started off as a good practice soon after the advent of nuclear power
  - Lack of objective measurement
  - Has morphed into "As Low as Humanly Possible" in the opinions of many
  - Used as a key metric in determining plant performance
  - Enormous cost driver
  - Potentially dangerous in accident scenarios

Morning Overview

- Atoms and Elementary Particles [2a]
  - Build an Atom: Computer Model [2b]
  - Discuss Particle Accelerators [3b]
  - Build an Electroscope [4a]
- Radiation Overview [1a]
  - Demonstrate Half Life: Twizzler Decay
- Radiation Safety [1b]
  - Draw Radiation Hazard Symbol [1c]
  - Use a Geiger Counter [5a]

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[1c]

Draw Radiation Hazard Symbol

- To avoid accidental exposure, we use the radiation hazard symbol
- Colors
  - Magenta or Black
  - Yellow Background
- Color one of your own
  - Why must people use radioactive materials carefully?

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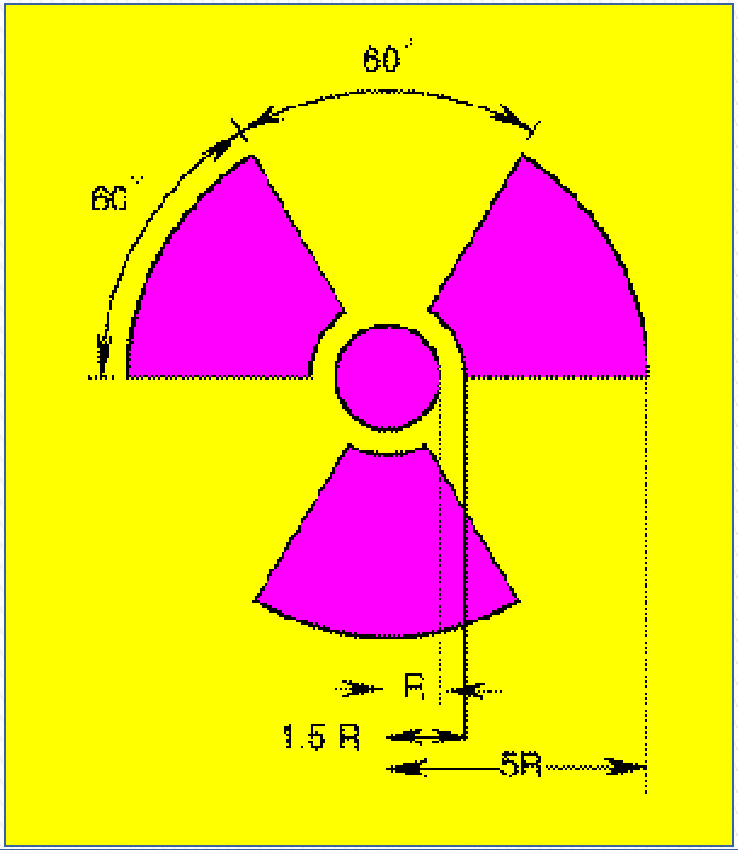
Activity

- Describe and draw the radiation symbol



Morning Overview

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Use a Geiger Counter

Activity

Use a Geiger Counter

- Test different sources
  - Source
  - Fiestaware
  - Banana
  - Your skin
- Test ALARA principles
  - Distance
  - Shielding
  - Time

Morning Review

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Break for Lunch

Afternoon Overview

- Radon [5b]
  - Detection and Dilution
- Nuclear Fission [6a]
- Nuclear Science Applications [7]
  - Cloud Chamber [4b]
- Career Opportunities [8]

Radiation Detection

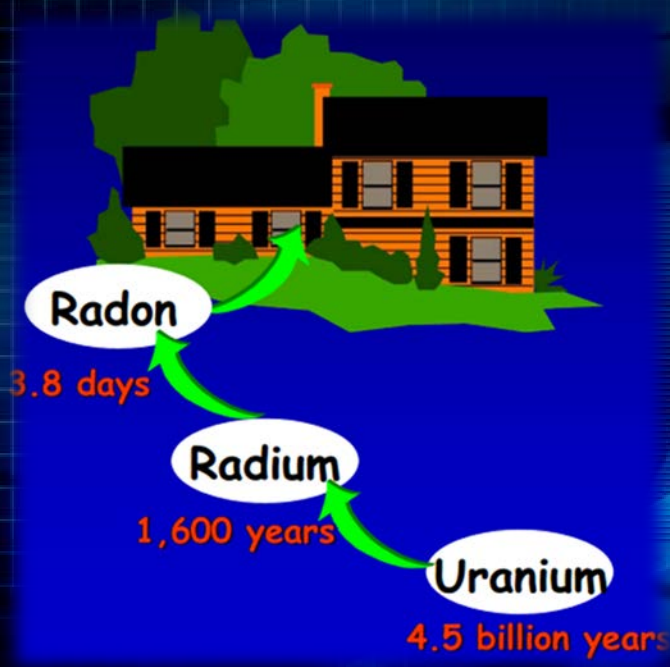
Radon-222

Radon is a gas

- It is naturally occurring outdoors

- In general - the primary source of radon is from the soil

- In most cases, builders do not choose to build homes radon resistant



Radon Decay Products

Radon-222	4 day	
↓ α,γ		
Polonium-218	3 min	
↓ α,γ		
Lead-214	27 min	
↓ β,γ		
Bismuth-214	20 min	
↓ β,γ		
Polonium-214	0.2 ms	
↓ α,γ		
Lead-210	22 yrs	
↓ β,γ		
Bismuth-210	5 day	
↓ β,γ		
Polonium-210	138 day	
↓ α,γ		
Lead-206	Stable	

^{218}Po and ^{214}Po deliver the radiologically significant dose to the respiratory epithelium

What happens when radon decay products are inhaled?

Double Strand Breaks

- Highly radioactive particles adhere to lung tissue, where they can irradiate sensitive cells.
- Radiation can alter the cells, increasing the potential for cancer.

Testing for Radon

Short-term Testing

•Most tests are short term
•Usually 12-48 hours, up to 90 days
•Don't give you a good year-round average measurement
•The short term kit will allow you to test each room quickly as radon levels can vary from room to room.
•Good choice if you have very high levels of radon

Charcoal Test

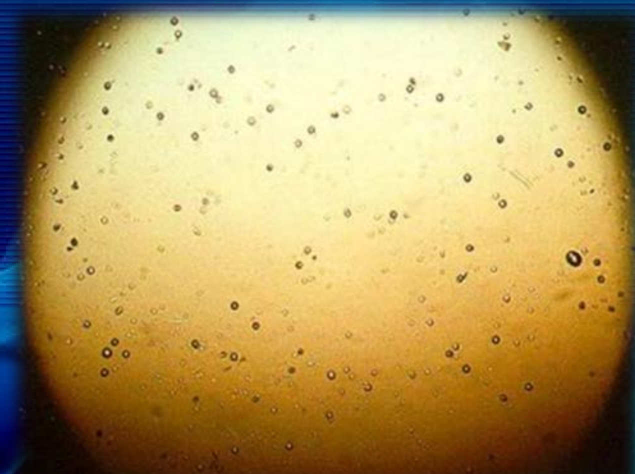
The most common way to test for radon is with an activated charcoal test kit. The charcoal collects radon atoms from the air that can be counted in a laboratory later. This is an inexpensive test and one that is easy to do yourself. About 95 percent of all radon testing is done this way.

Testing for Radon

Long-term Testing

•Long-term testing is done for longer than 90 days.
•Alpha track testing and electrets detectors are the most common types of tests done this way (though some types can be short term).
•This type of testing will give you a better reading of what your home's average radon level is as opposed to short-term testing.

Alpha Track Device
Alpha track devices work in a similar way to charcoal test kits. Alpha track devices are special pieces of plastic that are marked when hit by alpha particles in radon. This can be counted in a laboratory later. This is also an easy test to do yourself and relatively inexpensive.



Testing for Radon

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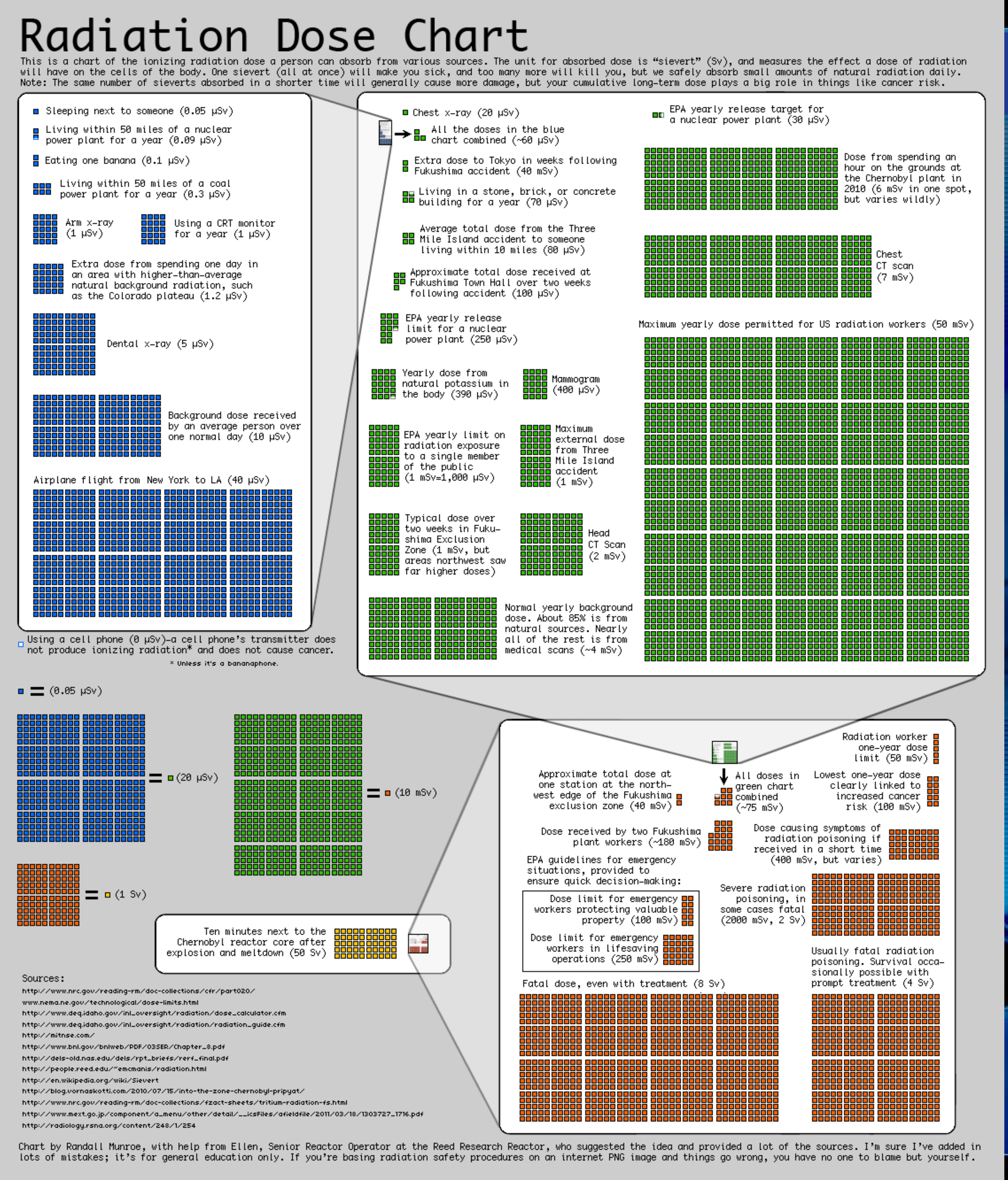
Electrets

An electret has a plastic disc that contains an electric charge. It is normally only used by professional radon inspectors because of the cost of the analysis equipment and the expertise needed to operate electrets.

Radon

- The EPA Recommends Mitigation for homes with > 4 piC/L
- 0.1 pCi/L value represents a dose of 50 mrem/year = 500µSv

For Compa



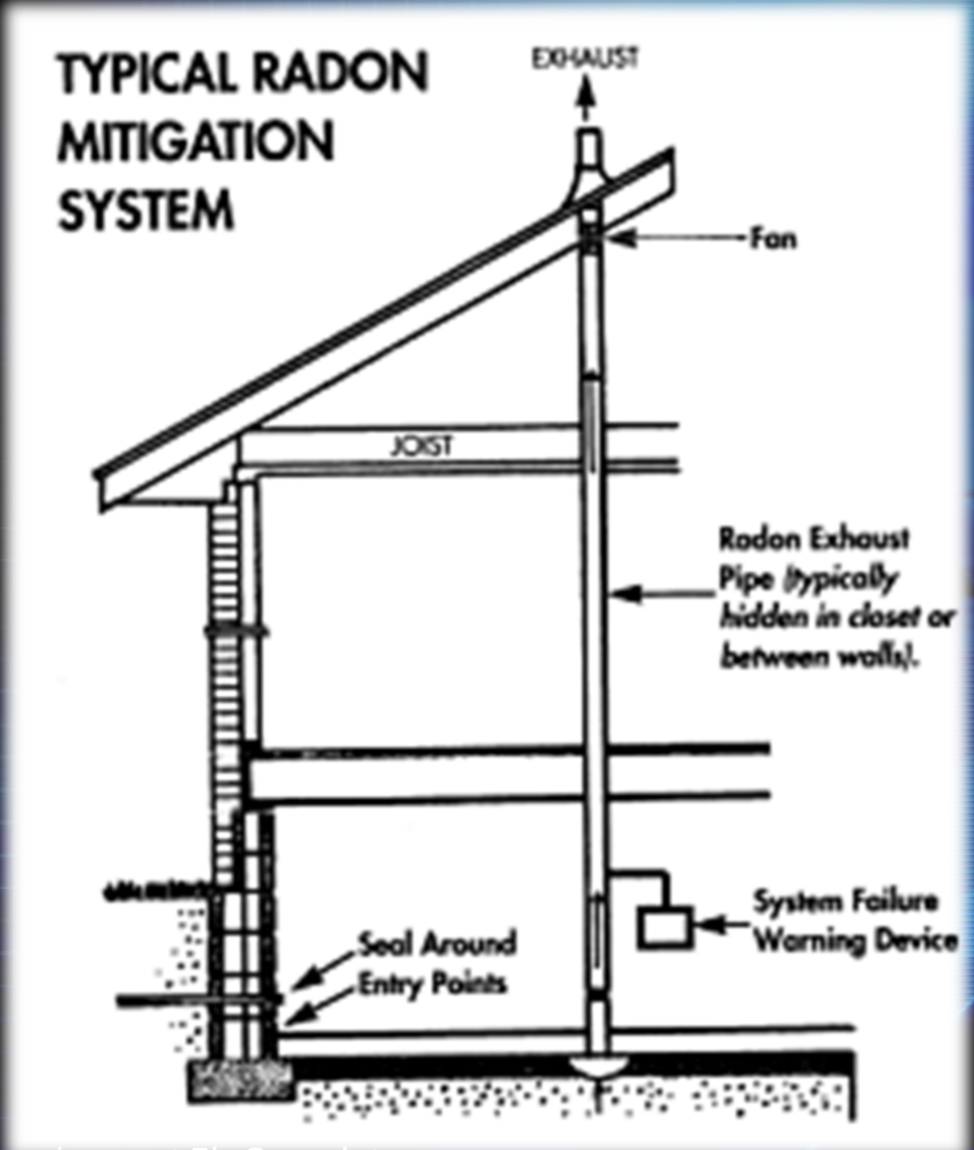
Radiation Dose Chart
This is a chart of the ionizing radiation dose a person can absorb from various sources. The unit for absorbed dose is "sievert" (Sv), and measures the effect a dose of radiation will have on the cells of the body. One sievert (all at once) will make you sick, and too many more will kill you, but we safely absorb small amounts of natural radiation daily. Note: The same number of sieverts absorbed in a shorter time will generally cause more damage, but your cumulative long-term dose plays a big role in things like cancer risk.
Sleeping next to someone (0.05 μSv)
Living within 50 miles of a nuclear power plant for a year (0.09 μSv)
Eating one banana (0.1 μSv)
Living within 50 miles of a coal power plant for a year (0.3 μSv)
Arm x-ray (1 μSv)
Using a CRT monitor for a year (1 μSv)
Extra dose from spending one day in an area with higher-than-average natural background radiation, such as the Colorado plateau (1.2 μSv)
Dental x-ray (5 μSv)
Background dose received by an average person over one normal day (10 μSv)
Airplane flight from New York to LA (40 μSv)
Using a cell phone (0 μSv)—a cell phone's transmitter does not produce ionizing radiation* and does not cause cancer.
* Unless it's a bananaphone.
Chest x-ray (20 μSv)
All the doses in the blue chart combined (~60 μSv)
Extra dose to Tokyo in weeks following Fukushima accident (40 mSv)
Living in a stone, brick, or concrete building for a year (70 μSv)
Average total dose from the Three Mile Island accident to someone living within 10 miles (80 μSv)
Approximate total dose received at Fukushima Town Hall over two weeks following accident (100 μSv)
EPA yearly release limit for a nuclear power plant (250 μSv)
Yearly dose from natural potassium in the body (390 μSv)
Mammogram (400 μSv)
EPA yearly limit on radiation exposure to a single member of the public (1 mSv=1,000 μSv)
Maximum external dose from Three Mile Island accident (1 mSv)
Typical dose over two weeks in Fukushima Exclusion Zone (1 mSv, but areas northwest saw far higher doses)
Head CT Scan (2 mSv)
Normal yearly background dose. About 85% is from natural sources. Nearly all of the rest is from medical scans (~4 mSv)
EPA yearly release target for a nuclear power plant (30 μSv)
Dose from spending an hour on the grounds at the Chernobyl plant in 2010 (6 mSv in one spot, but varies wildly)
Chest CT scan (7 mSv)
Maximum yearly dose permitted for US radiation workers (50 mSv)
= (0.05 μSv)
= (20 μSv)
= (10 mSv)
= (1 Sv)
Ten minutes next to the Chernobyl reactor core after explosion and meltdown (50 Sv)
Radiation worker one-year dose limit (50 mSv)
Approximate total dose at one station at the north-west edge of the Fukushima exclusion zone (40 mSv)
All doses in green chart combined (~75 mSv)
Lowest one-year dose clearly linked to increased cancer risk (100 mSv)
Dose received by two Fukushima plant workers (~180 mSv)
Dose causing symptoms of radiation poisoning if received in a short time (400 mSv, but varies)
EPA guidelines for emergency situations, provided to ensure quick decision-making:
Dose limit for emergency workers protecting valuable property (100 mSv)
Dose limit for emergency workers in lifesaving operations (250 mSv)
Severe radiation poisoning, in some cases fatal (2000 mSv, 2 Sv)
Usually fatal radiation poisoning. Survival occasionally possible with prompt treatment (4 Sv)
Fatal dose, even with treatment (8 Sv)
Sources:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/
www.nema.ne.gov/technological/dose-limits.html
http://www.deq.idaho.gov/inl_oversight/radiation/dose_calculator.cfm
http://www.deq.idaho.gov/inl_oversight/radiation/radiation_guide.cfm
http://mitnse.com/
http://www.bnl.gov/bnlweb/PDF/03SER/Chapter_8.pdf
http://dels-old.nas.edu/dels/rpt_briefs/rerf_final.pdf
http://people.reed.edu/~emcmanis/radiation.html
http://en.wikipedia.org/wiki/Sievert
http://blog.vornaskotti.com/2010/07/15/into-the-zone-chernobyl-pripyat/
http://www.nrc.gov/reading-rm/doc-collections/fzact-sheets/tritium-radiation-fs.html
http://www.mext.go.jp/component/a_menu/other/detail/__icsFiles/afieldfile/2011/03/18/1303727_1716.pdf
http://radiology.rsna.org/content/248/1/254
Chart by Randall Munroe, with help from Ellen, Senior Reactor Operator at the Reed Research Reactor, who suggested the idea and provided a lot of the sources. I'm sure I've added lots of mistakes; it's for general education only. If you're basing radiation safety procedures on an internet PNG image and things go wrong, you have no one to blame but yourself.

Mitigation

- Prevent entry
  - Remove entry routes (seal)
  - Remove driving forces (soil depressurization)
  - Pressurization

- Remove after entry
  - Ventilation (without heat recovery)
  - Adsorption
  - Catalytic oxidation, etc.

Mitigation



Badge Requirement 5b Complete

Afternoon Overview

Radon	[5b]
Detection and Dilution	
Nuclear Fission	[6a]
Nuclear Science Applications	[7]
Cloud Chamber	[4b]
Career Opportunities	[8]

Activity: Radiation Measurement

Let’s break into teams!

- Water filled mason jars
- Food coloring

- How much does it take to dilute the food coloring?????

Review [p.13 / Req. 5b]

How is radon detected and reduced?

Afternoon Overview

Radon [5b]

- Detection and Dilution

Nuclear Fission [6a]

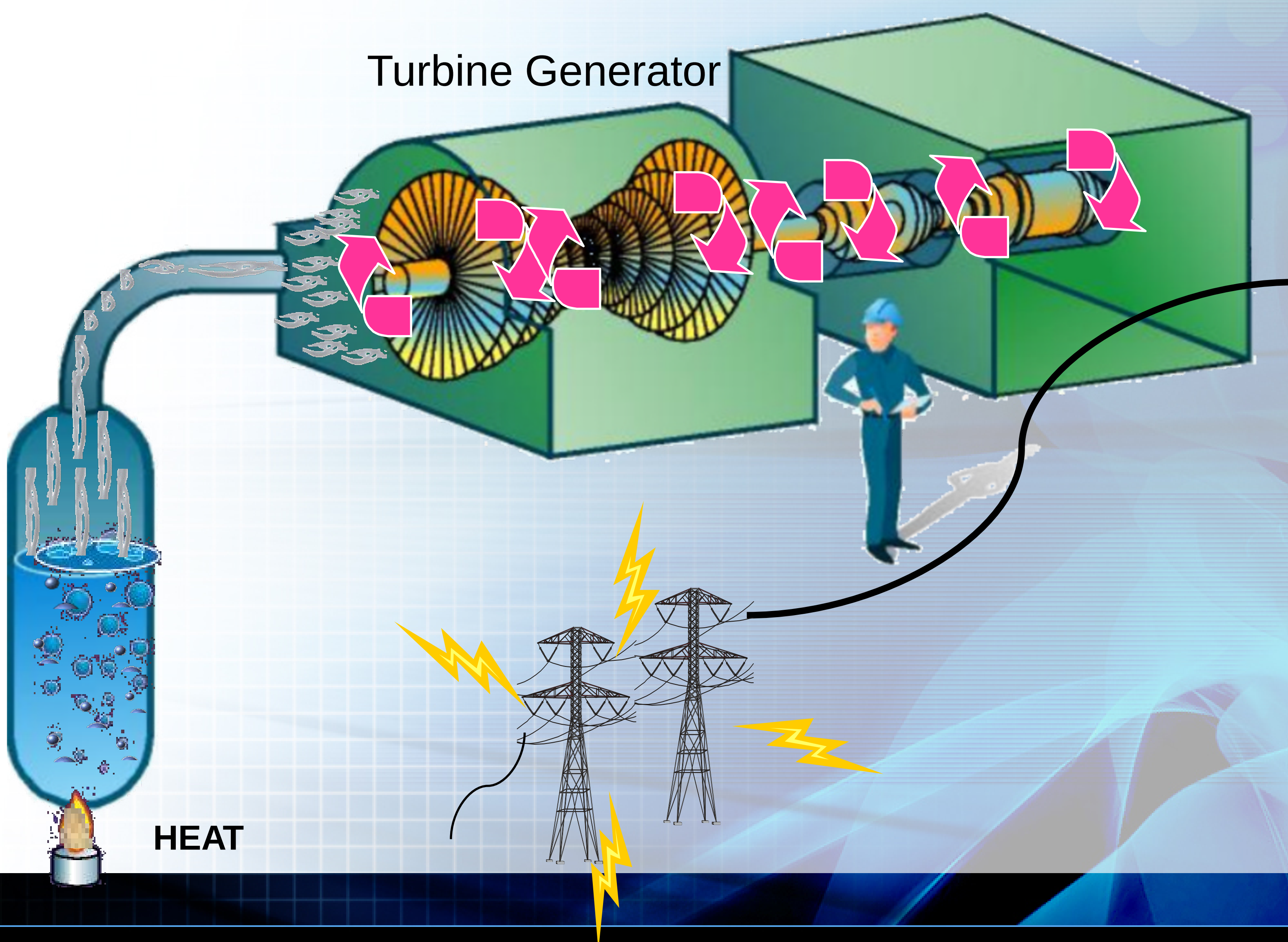
Nuclear Science Applications [7]

- Cloud Chamber [4b]

Career Opportunities [8]

Nuclear Power

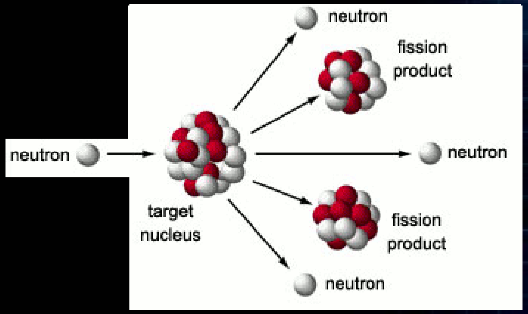
Basic Electrical Power Plant



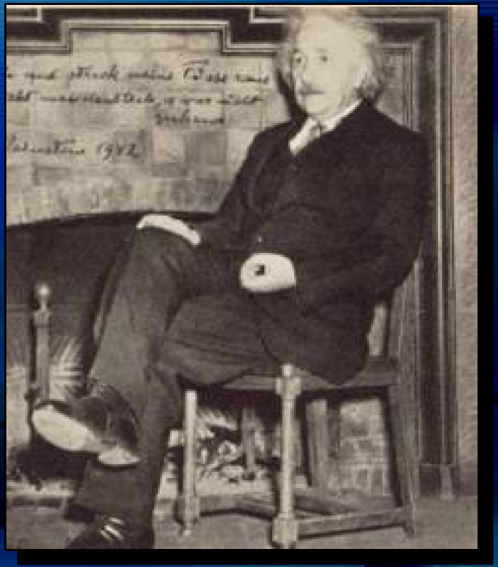
So how do we get the “heat” from Uranium to boil the water?

Fission and Energy

The fission process (splitting an atom) converts **mass** into **energy**.



$$E = mc^2$$



The sum of the **mass** of all the particles is slightly less than the **mass** of the original atom and neutron. This **missing mass** has been converted to **energy.**

Combustion vs Fission

- Combustion is a **chemical** reaction

  $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + **2eV**

- Fission is a **nuclear** reaction

  $n + U235 \rightarrow U236^* \rightarrow Ba139 + Kr94 + 3n$ + **200,000,000eV**

Fission releases **100 MILLION** times more energy per reaction than combustion!

Not all Uranium Can Split/Fission!

Uranium 235

Symbols represent specific atoms and nuclei

Mass (A)
(number of protons +
number of neutrons)

$^{235}_{92}\mathrm{U}$

143 Neutrons

Atomic number (Z)
(number of protons)

Chemical symbol (U for uranium)

All uranium atoms have 92 protons in nucleus

A neutral uranium atom has 92 electrons orbiting the nucleus

Isotopes of Natural Uranium

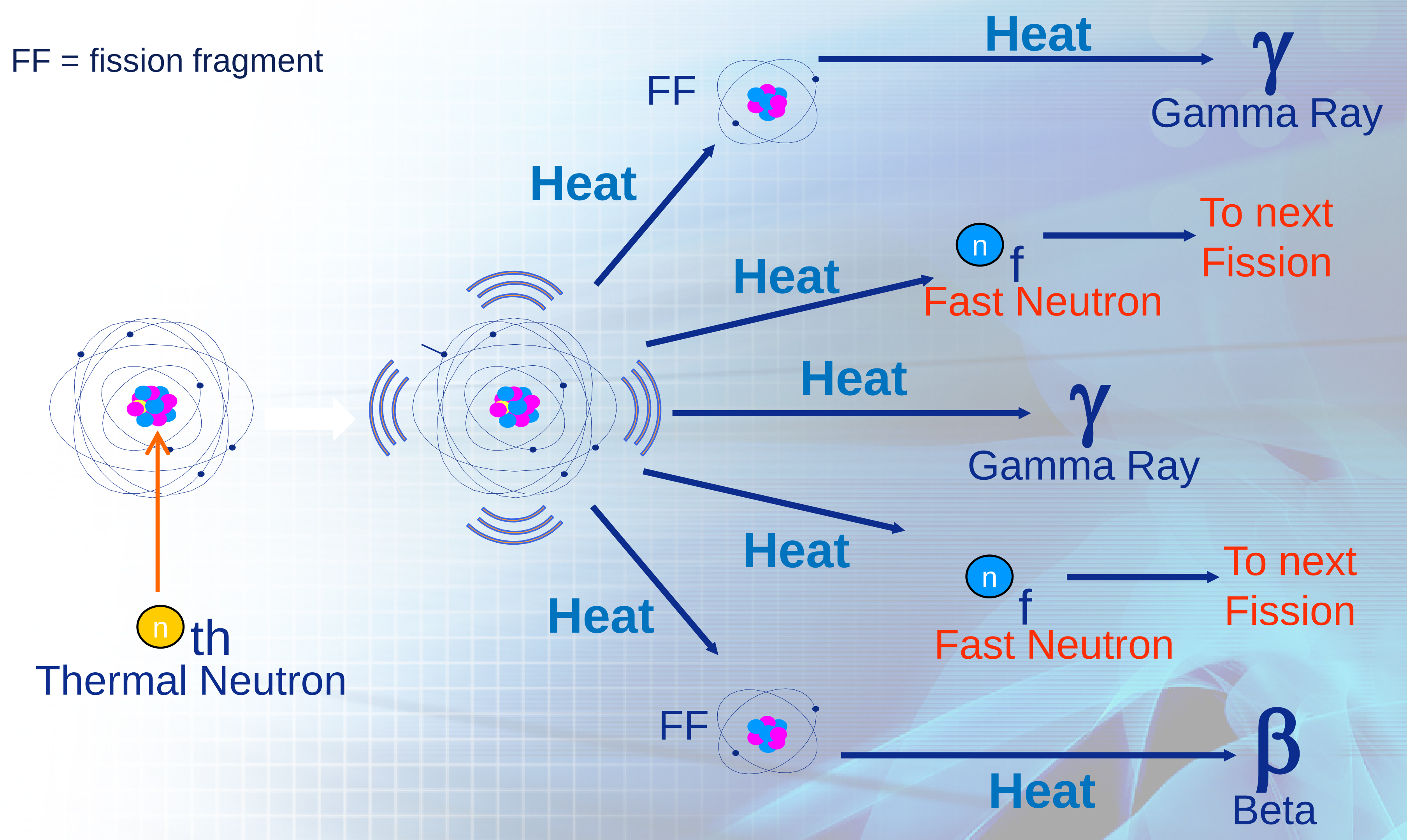
- Natural uranium consists of three isotopes: Uranium-238, Uranium-235, and Uranium-234.

- Uranium isotopes are radioactive. The nuclei of radioactive elements are unstable.

Uranium Isotopes			
Isotope	**% in Natural U**	**# Protons**	**# Neutrons**
Uranium-238	99.284	92	146
Uranium-235	0.711	92	143
Uranium-234	0.0055	92	142

Let’s “Split” a U-235 Atom

Energy Releases from U-235 Fission



Activity: Chain Reaction

- Let’s draw a Chain Reaction!

- Any ideas on how to *stop* a chain reaction once it has been started…?

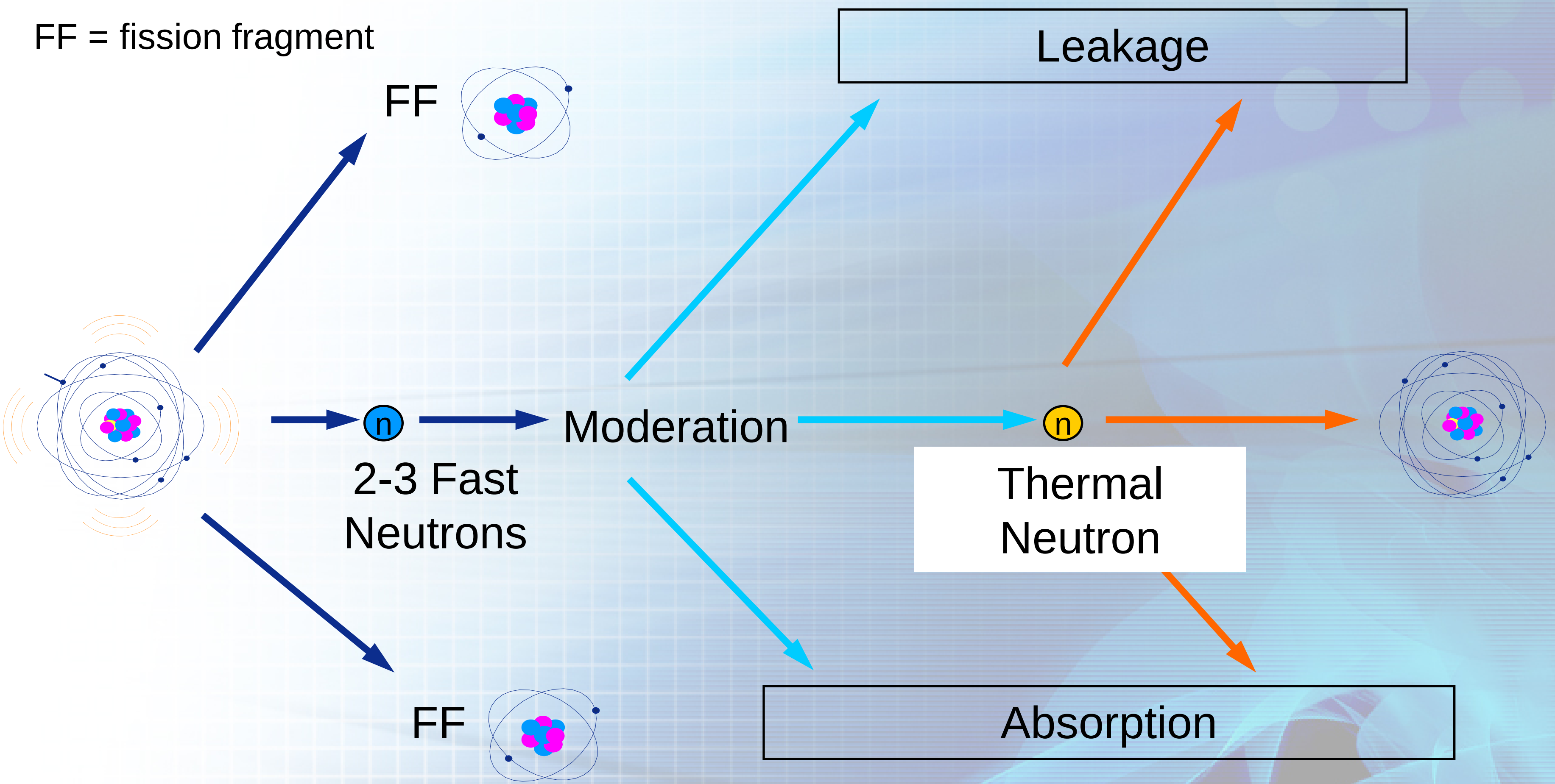
Ping Pong Ball Chain Reaction

In Slo-Mo…

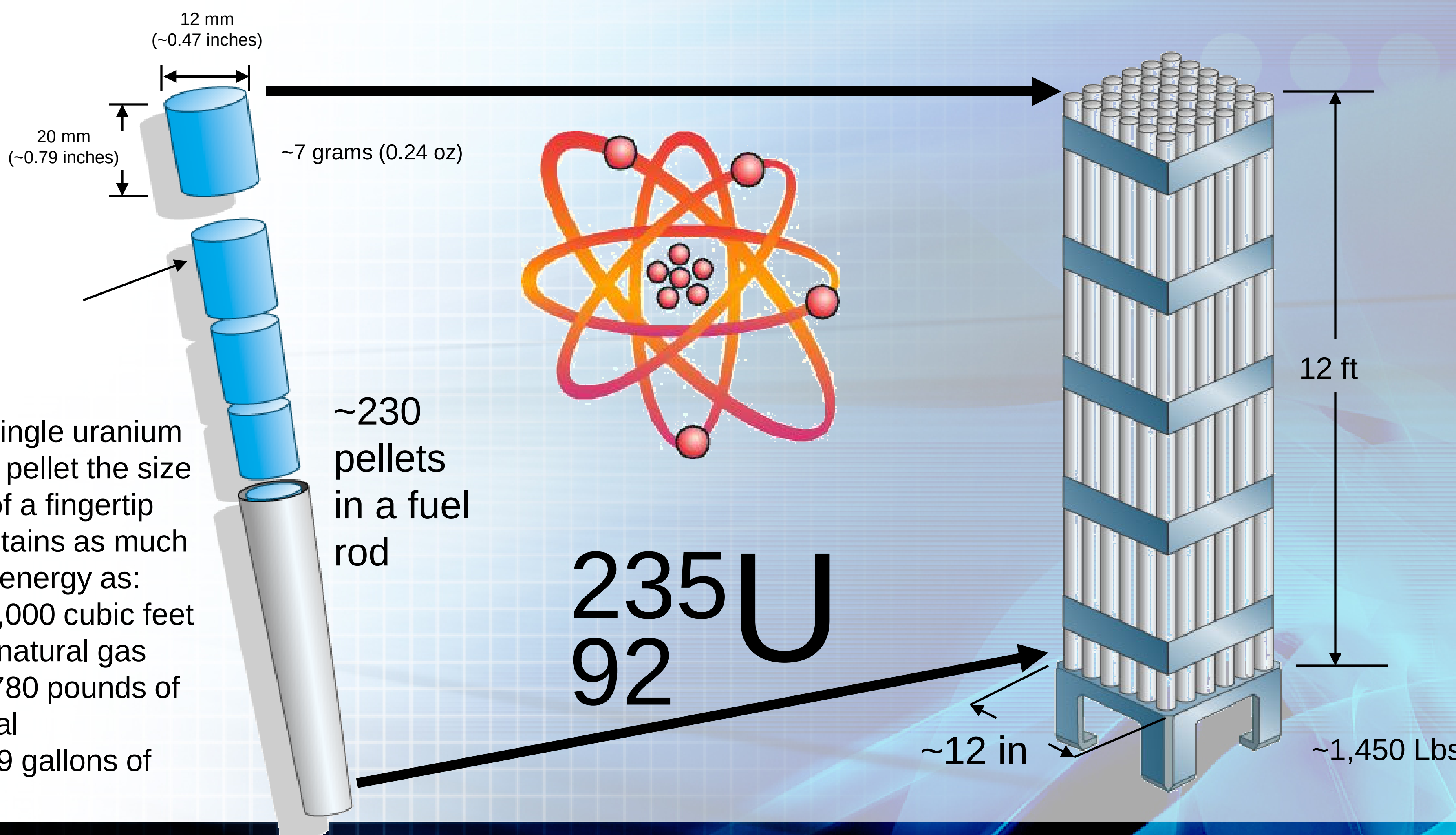
So the KEY to Harnessing the Heat Produced by Fission is to CONTROL the Fission Rate

Let’s Explore “The Core”

What Happens to Neutrons Between Fissions?



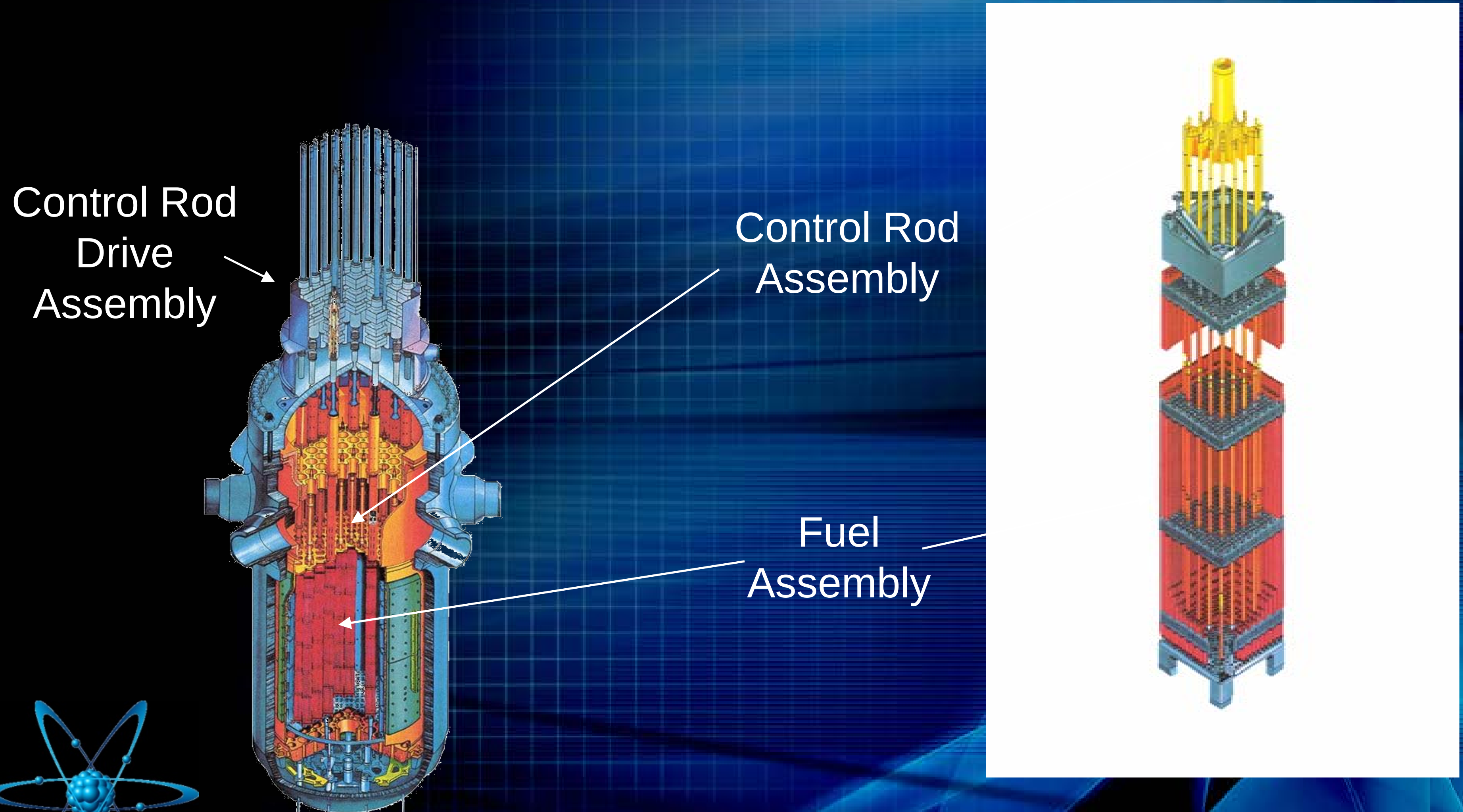
U235: The Fuel in Fuel Rods and Fuel Assembly



A single uranium fuel pellet the size of a fingertip contains as much energy as:

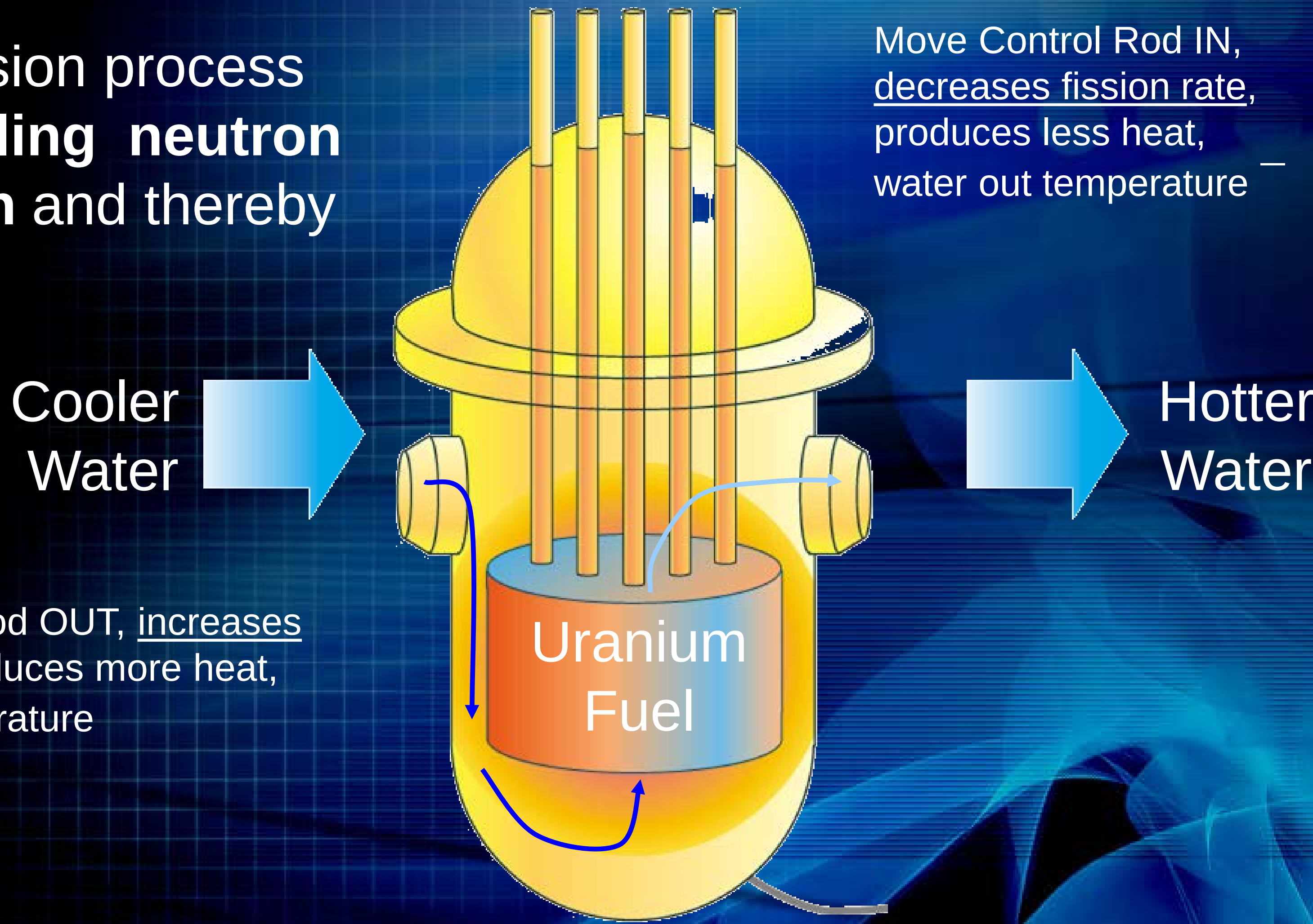
- 17,000 cubic feet of natural gas
- 1,780 pounds of coal
- 149 gallons of oil.

Reactor Core and Control Rods



Reactor Control

Control fission process by **controlling neutron population** and thereby fission rate



Move Control Rod IN, decreases fission rate, produces less heat, water out temperature –

Move Control Rod OUT, increases fission rate, produces more heat, water out temperature

Reactor Control

- Control rods – insertion of materials that absorb neutrons.

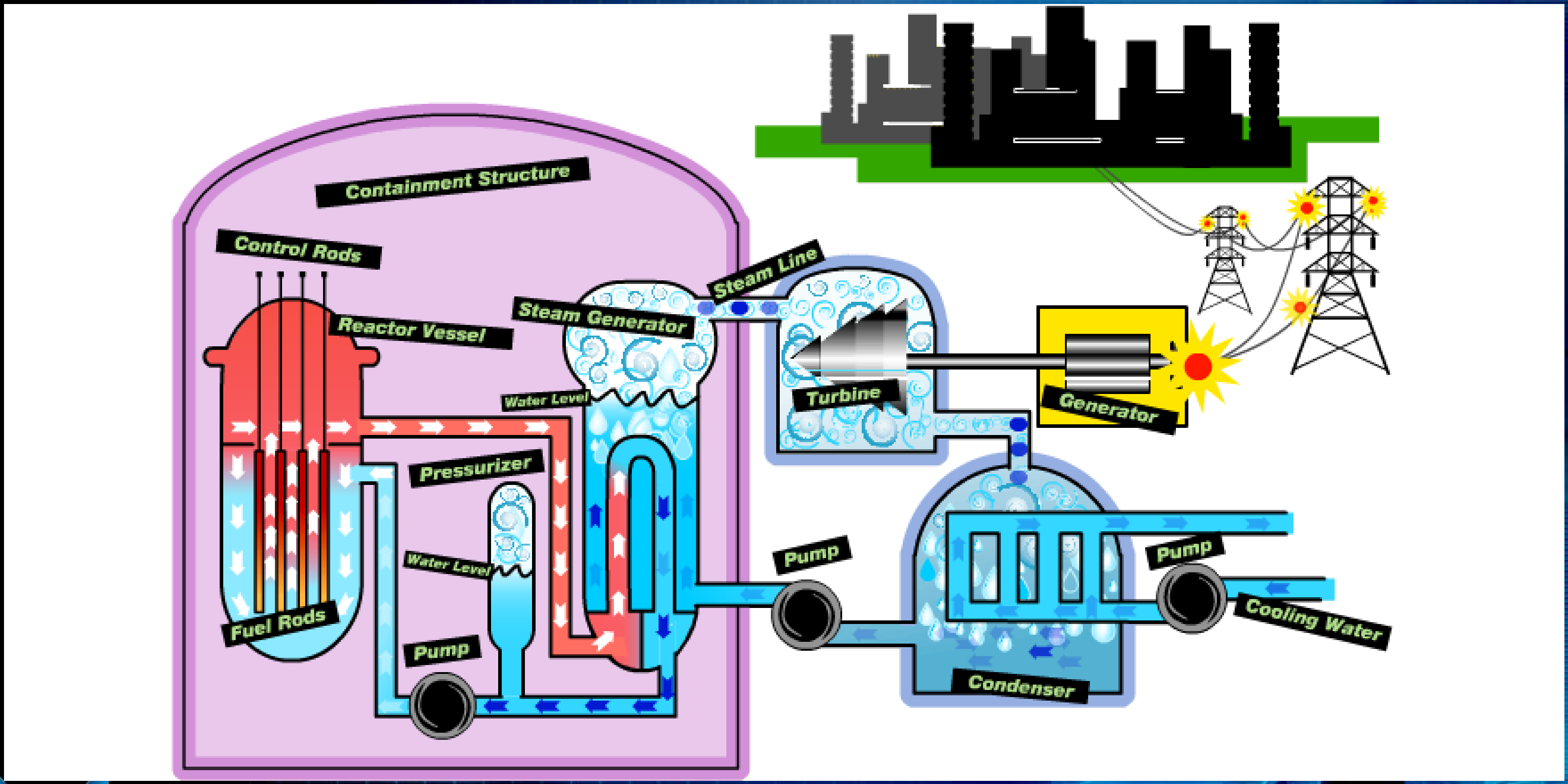
- Boron – soluble chemical added to the coolant in the form of boric acid; absorbs neutrons.

- Moderator Temperature – cold water is denser. Denser water will slow the neutrons down faster. Thus, a lower probability of being absorbed in another material or leaking out of the core. This must be balanced with the need to produce steam.

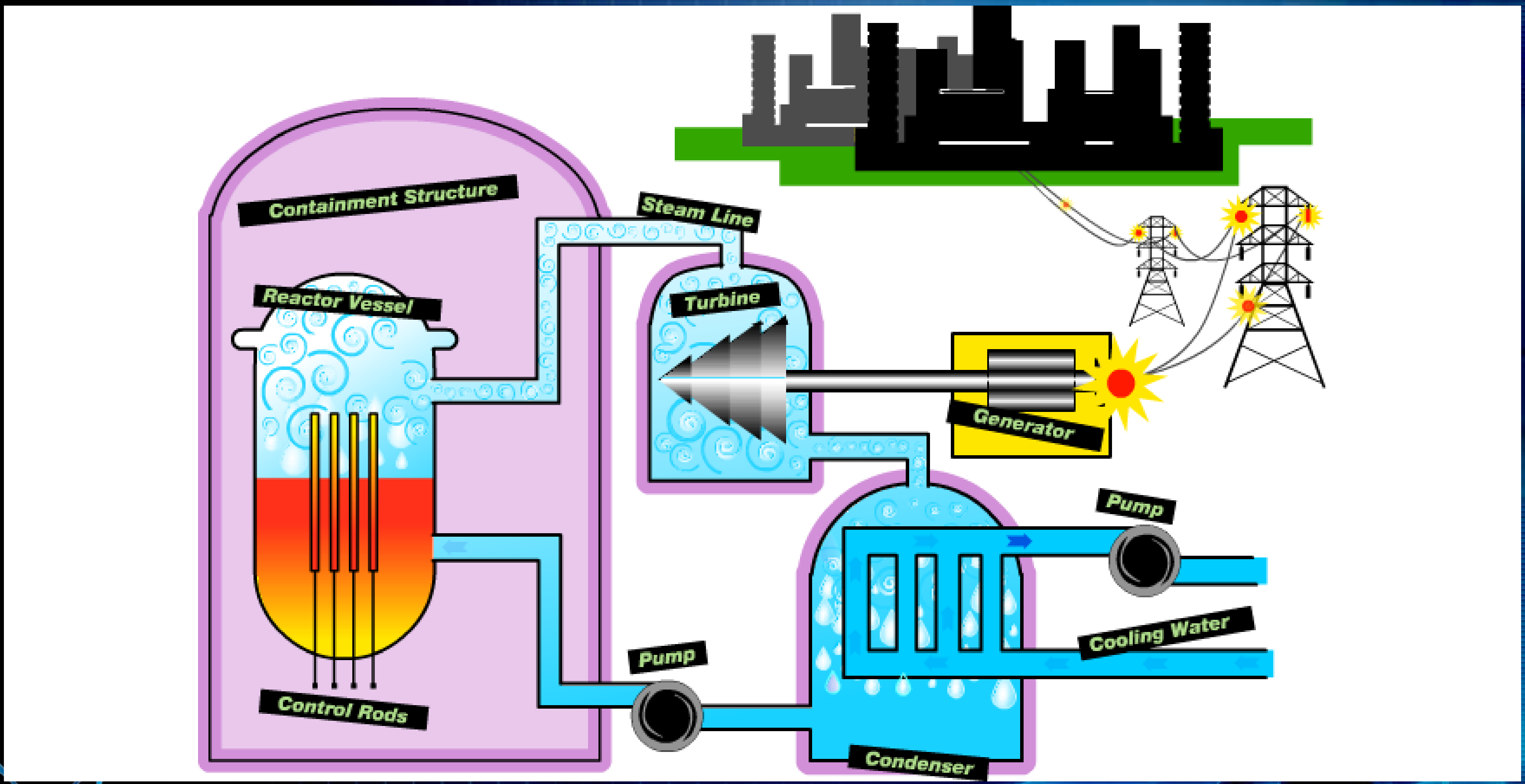
A stable neutron populations means a stable power level. Neutron population is proportional to power.

Put it all together and you get a Nuclear Power Plant !

Pressurized Water Reactor



Boiling Water Reactor



Spent Fuel

- The concentration of fission fragments and heavy elements produced in a fuel bundle will increase to the point where it is no longer practical to continue to use the fuel.

- After 12-24 months the 'spent fuel' is removed from the reactor.
  - Kept in underwater storage for 5-10 years.
  - Transferred to “Dry Casks” and stored on site.

Storage Pool and Dry Cask

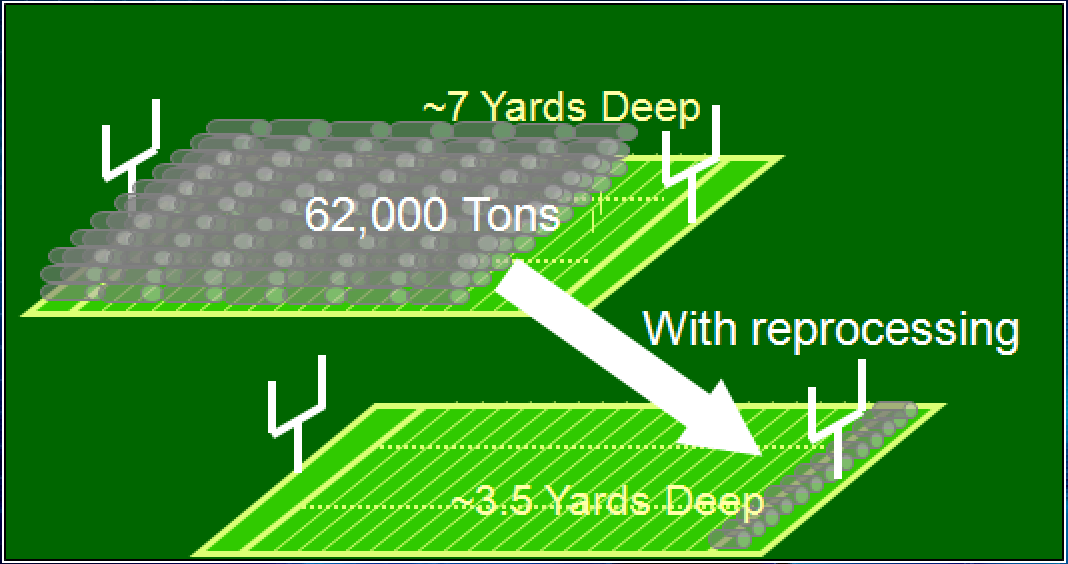
Spent Fuel Inventory in the US

- Total amount of spent fuel generated is small and manageable

After 50 years of US plant operations, the high-level waste volume would fill an area the size of a football field seven yards deep.

<u>With reprocessing</u>, the amount of waste is even less.

- ~62,000 metric tons
- ~½ ton per fuel assembly
- ~ 150,000 assemblies
- Only ~5% is true waste



Reprocessing

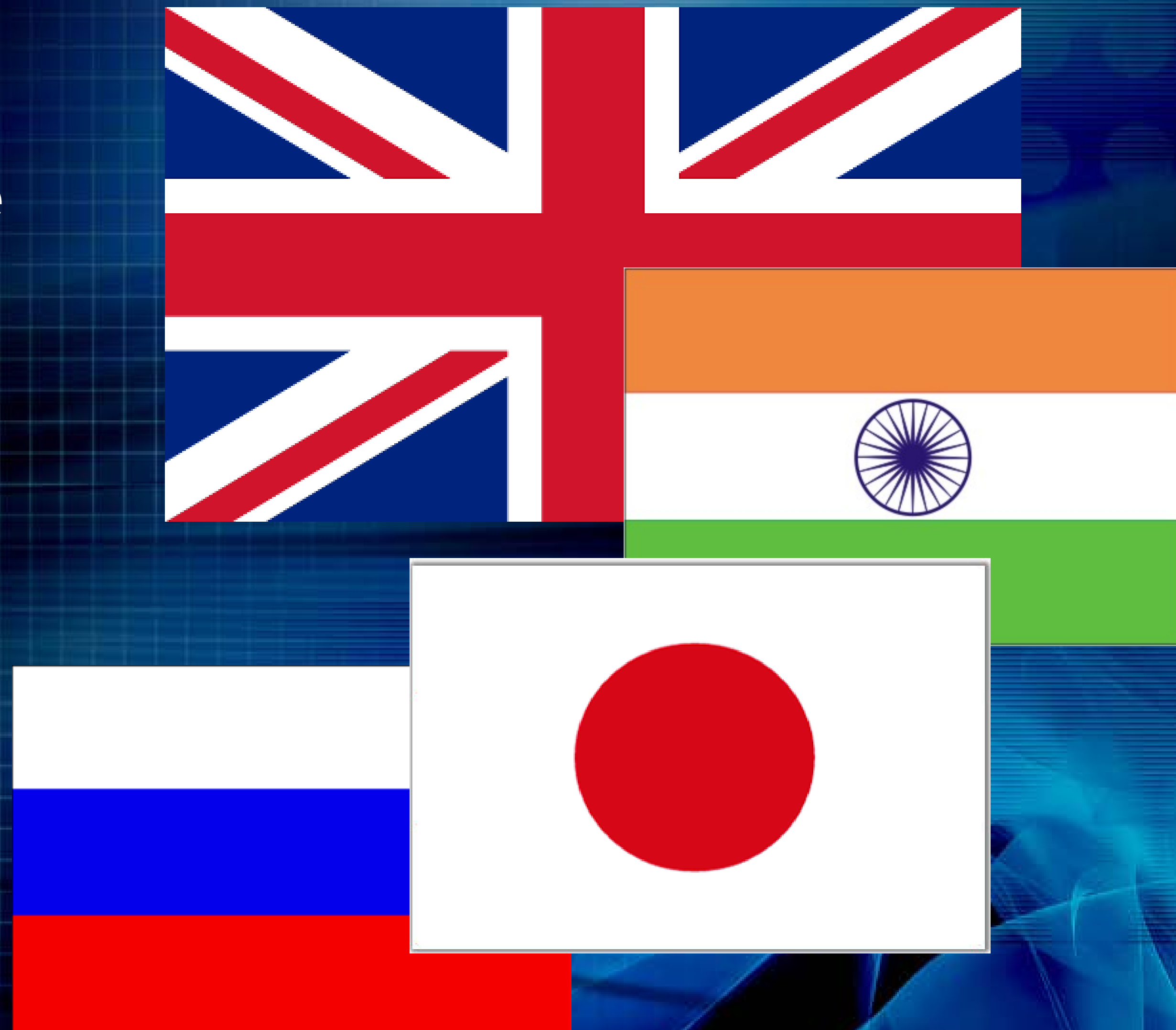
- Only 5% of the fissionable material in fuel is used in a once-through cycle.
- In a reprocessing facility, the spent fuel is separated into its three components: uranium, plutonium, and waste.
- Reprocessing enables recycling of the uranium and plutonium into fresh fuel
  - Produces significantly less waste (compared with treating *all* used fuel as waste).

La Hague Plant, France

- Recycled Fuel runs in French plants
- French High Level Waste Volume reduced to a single room

Who Else Recycles Fuel?

- United Kingdom – Sellafield Plant
- Russia – Mayak Chemical Combine
- Japan – Tokai
- India - Tarapur



What about SAFETY ?

Three Main Safety Barriers

- Fuel pellet and fuel rod

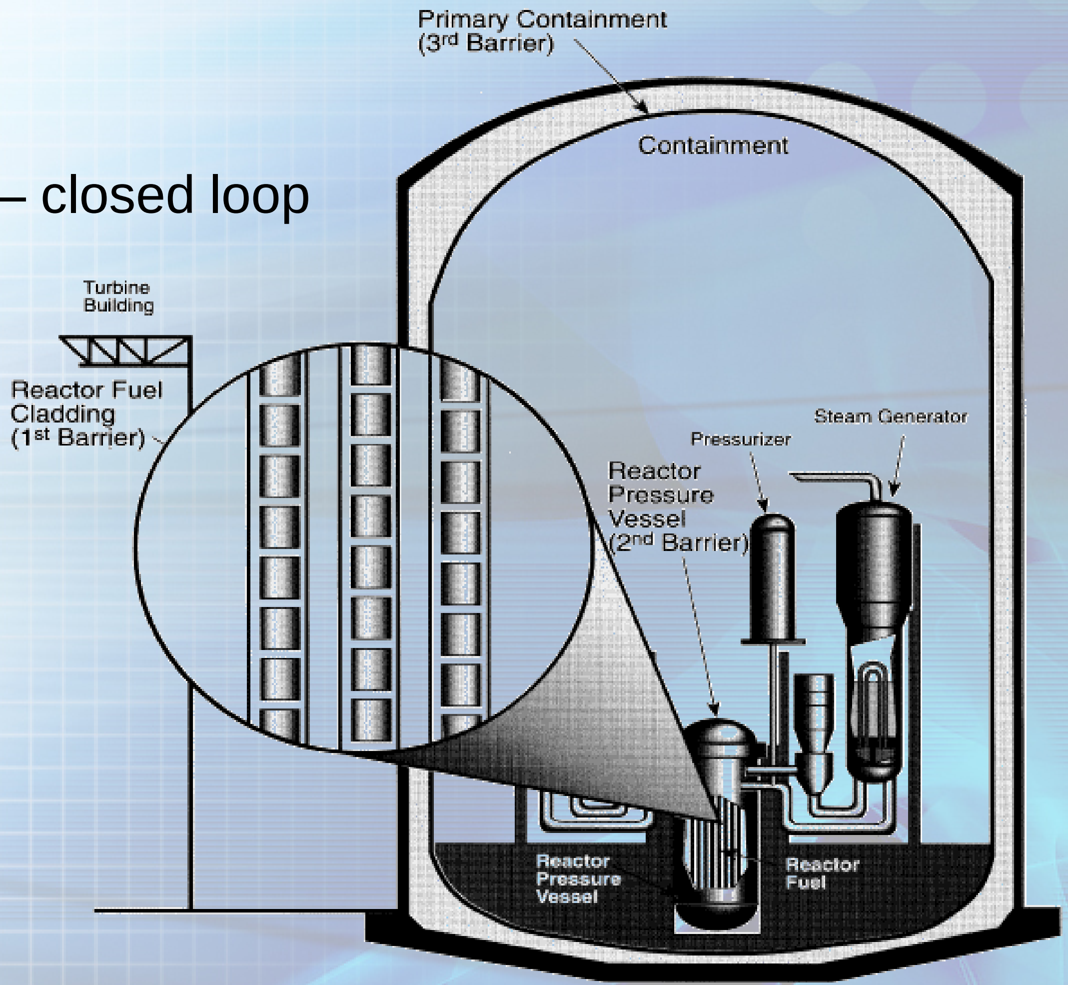
(Designed to withstand temperatures up to 2200^{0}F)

- Reactor coolant system – closed loop

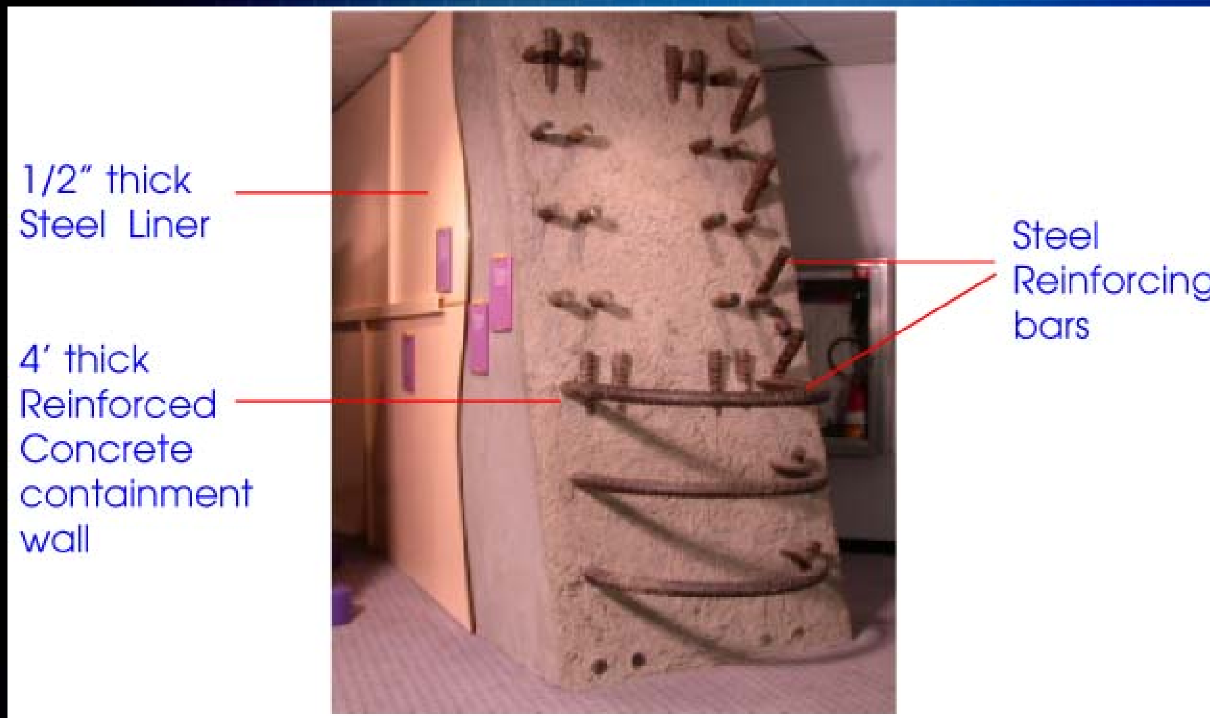
(Designed to withstand internal pressures up to 2375 psig)

- Containment building

(Designed to withstand internal pressures up to 65 psig)



Containment Building Wall



Construction of Containment Wall

NPP’s Cannot Result in a “Nuclear” Explosion!

- Naturally occurring U-235 is 0.711% concentration and must be “enriched”
- Commercial Grade Fuel: ~3-5% U-235
- Weapons Grade Fuel: >90% U-235
- Much Lower Fuel Enrichment Level than Weapons Grade Fuel

A commercial power reactor simply CANNOT explode like a nuclear bomb.

Nuclear Reactors vs. Nuclear Bombs

In addition to different enrichment levels:

- Nuclear reactors have moderators and absorbers; Bombs are pure fissile material.

- Reactors are designed to have a *barely* self-sustaining chain reaction. The chain reaction in a bomb accelerates exponentially.
  - Reactors have a controlled geometry that maintains constant neutron leakage.
  - Bombs explode when the mass of fissile material is compressed into a very small volume so that no neutrons can escape.

Safety of Nuclear Power in the US

There has NEVER been a single death as the result of a commercial nuclear power accident in the US…

…EVER!!!

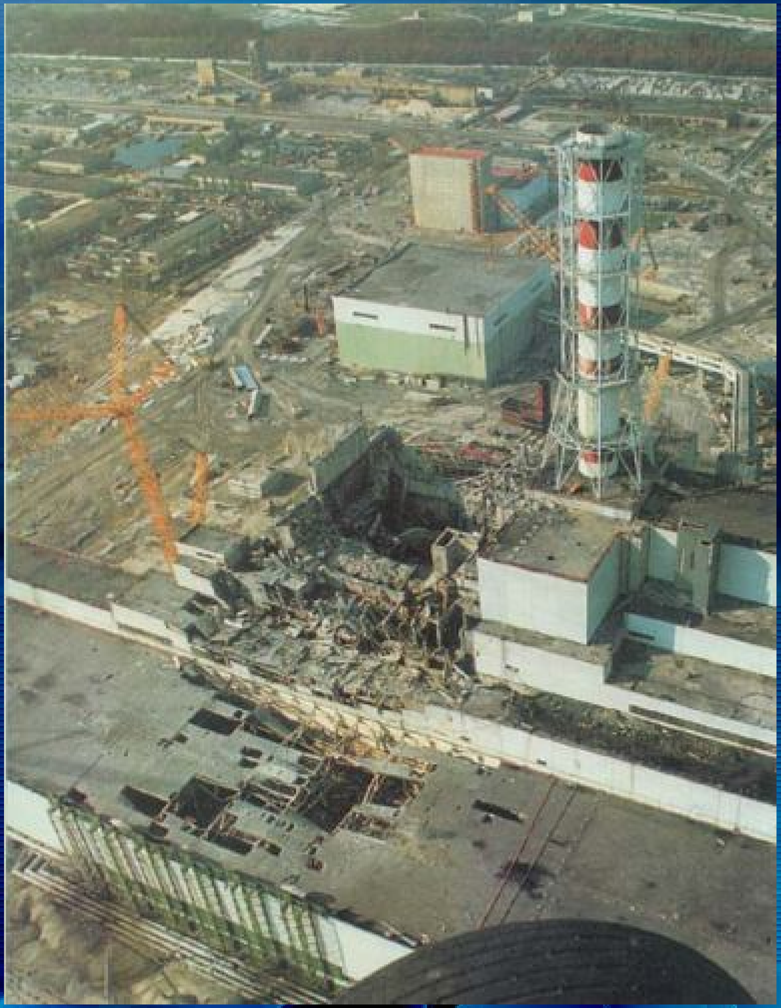
Three Mile Island

- Partial Core Melt: March 28, 1979 – Pennsylvania
- Containment building prevented radiation release
- No deaths or injuries resulted
- Maximum dose at site boundary was 100 mrem
- Average dose to 2M people in area was 1 mrem

Source: www.nrc.gov

Chernobyl

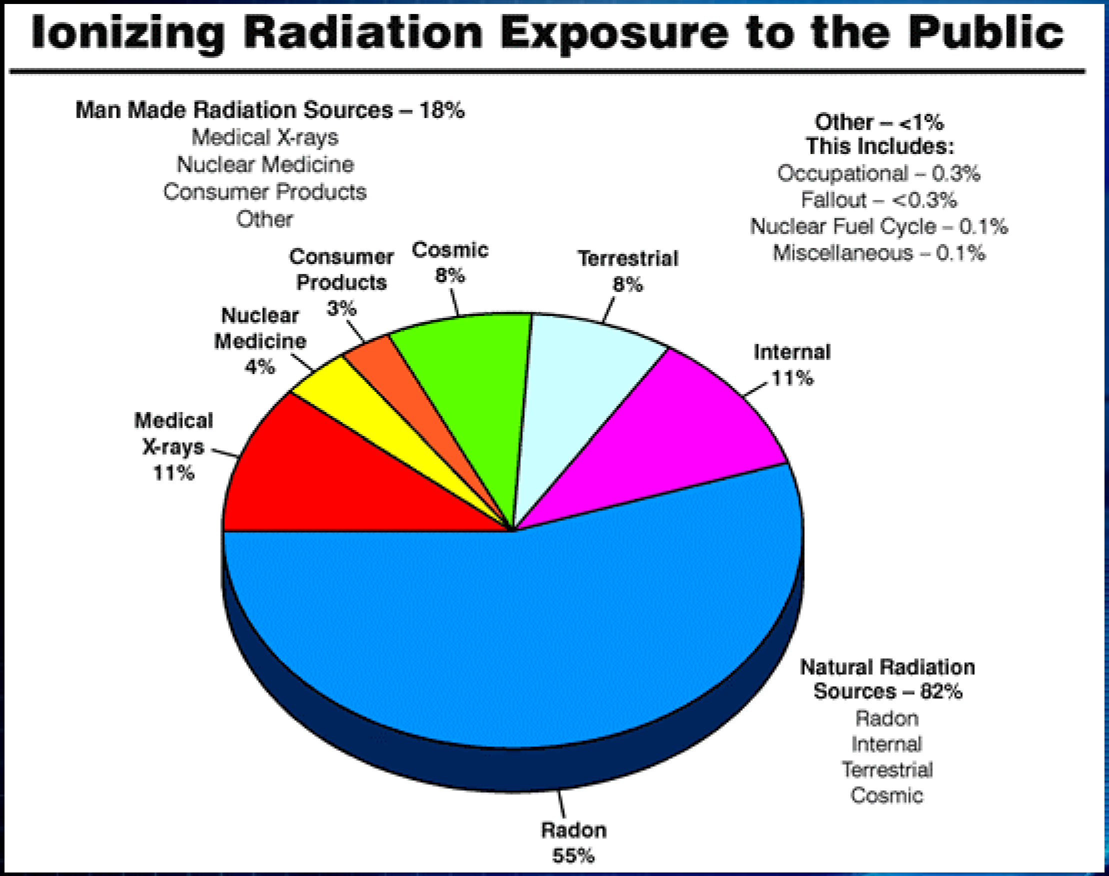
- Explosion: April 25, 1986 – Ukraine
- No containment building
- 134 workers received high dose (80,000+ mrem)
- 57 died from radiation poisoning within a few months
- 500 were hospitalized



Fukushima Daiichi

- A series of ongoing equipment failures following the 9.0 magnitude Tohoku earthquake and tsunami on March 11th, 2011.
- Evidence of partial core meltdown in reactors 1, 2, and 3.
- No deaths from radiation poisoning.
- Estimates put fallout at around 10% of Chernobyl.

Sources of Radiation Exposure



Badge Requirement 6a Complete

Review [p.14 / Req. 6a]

- Describe nuclear fission

Afternoon Overview

Radon [5b]

    Detection and Dilution

Nuclear Fission [6a]

Nuclear Science Applications [7]

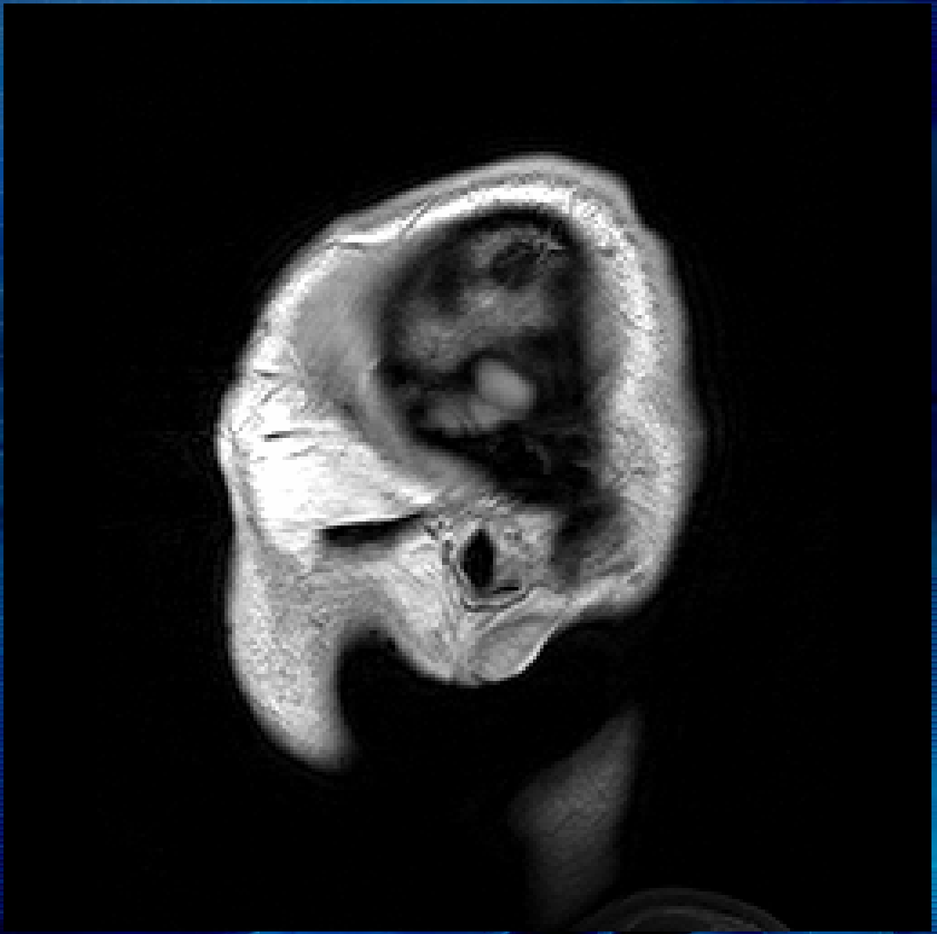
    Cloud Chamber [4b]

Career Opportunities [8]

Other Applications of Nuclear Science

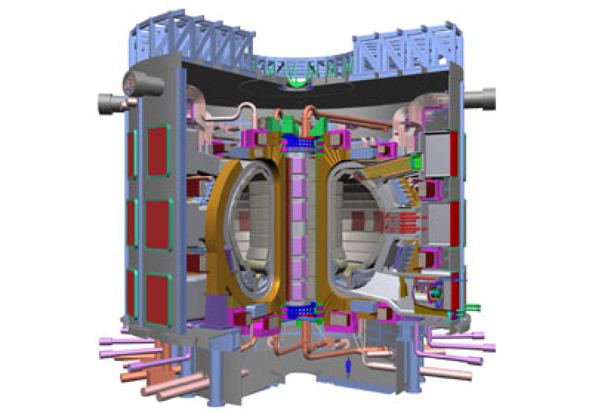
Medical Physics

- Application of physics to medicine.
- Medical imaging (x-rays, MRIs, PET)
- Nuclear medicine (Lasers, Gamma Knives, source radiotherapy)
- Physiological measurements (endoscopy, spectroscopy, electrocardiography)
- Radiation Protection.



ITER – International Thermonuclear Experimental Reactor

- Currently under construction, ITER will be the world's largest and most advanced experimental *tokamak* nuclear fusion reactor.
  - A *tokamak* is a device using a magnetic field to confine a plasma in the shape of a torus (doughnut).
- The project is funded by seven member entities – the EU, India, Japan, China, Russia, South Korea, and the US and has a project cost of $12.8B, with first plasma being achieved in 2019.
- *Fission* is splitting an atom. *Fusion* is combining atoms.
  - $\text{D2} + \text{T3} \rightarrow \text{He4} + \text{n} + 17.6\text{MeV}$
- The Sun fuses Helium nuclei in to Helium



CERN Experiments - Search for the Higgs Boson

- The “Higgs Boson” is a hypothetical massive elementary particle predicted to exist by the “Standard Model”.
  - The Standard Model concerns the electromagnetic, weak, and strong nuclear interactions – it is a theory to tie everything together!
- It is the only particle that has not been observed in particle physics experiments.
- The Higgs-mechanism is the part of the SM that explains why particles have **mass**.
- Experiments at CERN show a few events that *could* be the Higgs, but researchers are seeking out a 95% confidence that it exists. Some researchers, however, believe this interval is too much and that some attention should be paid to these events…

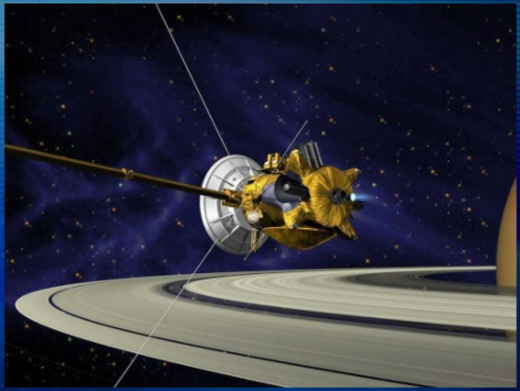
Nuclear Power is Also Used…

- Nimitz Class Aircraft Carrier
  - 1,092 feet long
  - 224 million pounds
  - Max speed of 40 mph
  - Produces 260,000hp

- Los Angeles Class Submarine
  - Operating depth of 650 feet
  - Max speed of 30 mph
  - Endurance of 90 days

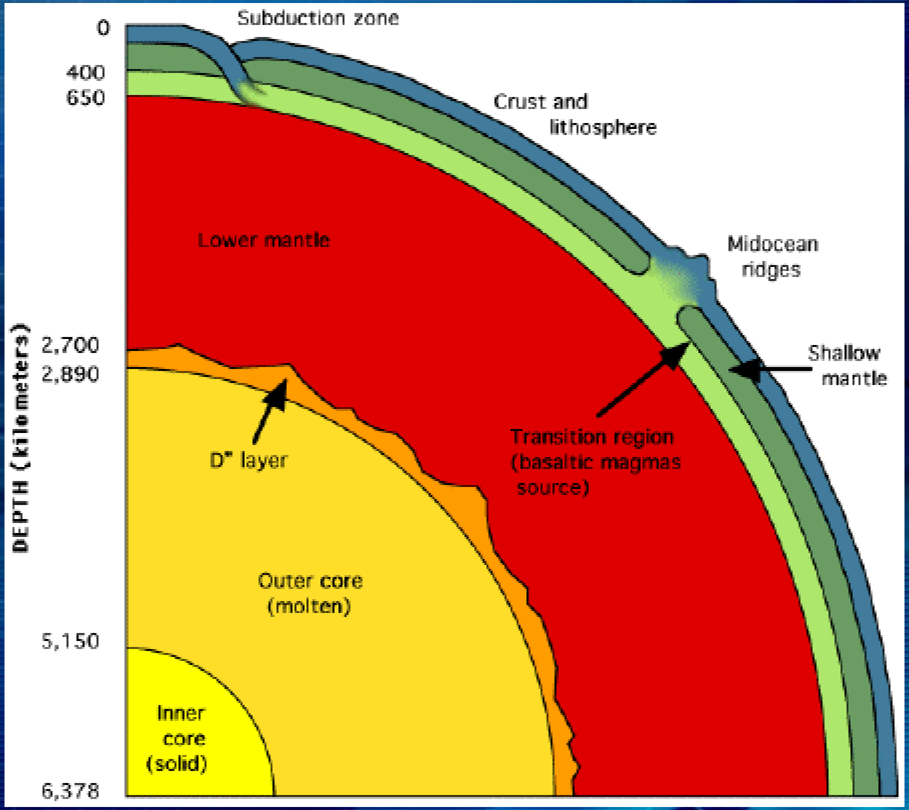
Nuclear Power is Also Used…

- **Space Exploration**
  - Radioisotope Thermoelectric Generators (RTGs)
    - Converts the decay heat of a radioactive material into electricity
    - 6 Spacecraft, Viking Landers
  - Nuclear Reactors
    - RORSAT
    - SNAP-10A



Nuclear Power is Also Used…

- **To Heat Our Planet!**
  - Earth's internal heat comes from:
  - 10-30% from gravitation forces and residual heat from earth's formation.
  - 60-90% from the decay of Uranium and Thorium.



Review [p.15 / Req. 7]

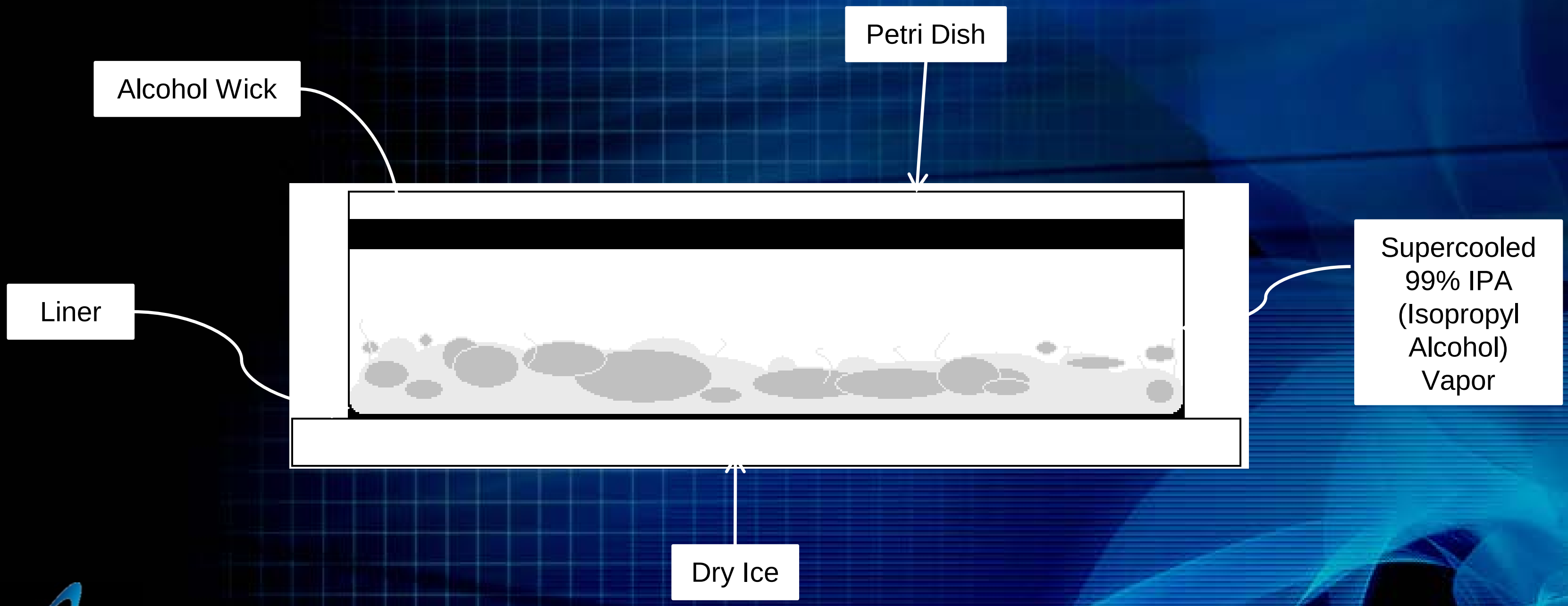
- Applications in nuclear medicine
- Environmental applications
- Industrial applications
- Applications in space exploration
- Applications in radiation therapy

Afternoon Overview

- Radon [5b]
  - Detection and Dilution
- Nuclear Fission [6a]
- Nuclear Science Applications [7]
  - <u>Cloud Chamber [4b]</u>
- Career Opportunities [8]

Activity: The Cloud Chamber

- Also known as a Wilson Cloud Chamber, this device helped discover the positron, the first observed form of antimatter. **Cloud chambers allow observers to "see" ionizing radiation.**



Cloud Chamber Theory

- Since the top of the chamber is at room temperature, the alcohol evaporates from the wick and slowly sinks downwards.

- The dry ice keeps the bottom extremely cold – so the vapor, once it has fallen, is in a super-cooled state.
  - This means that the alcohol is in a vapor form at a temperature at which vapor would not normally exist.

- Because there is so much vapor, the chamber becomes super-saturated.
  - Super-saturation means that a medium (air) is holding more of a material (alcohol) than could be achieved under normal conditions.

- The super-cooled, super-saturated vapor is very unstable and will condense into liquid with the slightest disturbance.

- In these conditions, a charged particle will ionize molecules in the vapor as it travels through it, causing condensation around the particle track. It is this condensation trail that is visible in a Cloud Chamber.

What to Expect from the Cloud Chamber

Radiation Type and Trail Characteristics:

- Alphas – straight, dense trails.
- Betas – wispy, irregular trails.
- Gammas/Cosmic Rays – curly, jagged trails.

Try to observe the following:

- Straight paths suddenly shooting off into another direction – possible decay event.
- Three paths intersecting – often the result of a cosmic ray striking another particle.

Chamber_Trial.MOV

Badge Requirement 4b Complete

Activity: Cloud Chamber [p.12 / Req. 4b]

Chamber_Trial.MOV

Afternoon Overview

Radon	[5b]
Detection and Dilution	
Nuclear Fission	[6a]
Nuclear Science Applications	[7]
Cloud Chamber	[4b]
Career Opportunities	[8]

Careers in Nuclear

- Industry
  - Vendors
    - Ex: Westinghouse
  - Utilities
    - Ex: FENOC
- Government
  - National Agency
    - Ex: U.S. NRC
  - Military (Navy/Air Force)
- Medical
- Research

Review [p.16 / Req. 8]

- Name 3 careers in nuclear science

Afternoon Overview

Radon [5b]

- Detection and Dilution

Nuclear Fission [6a]

Nuclear Science Applications [7]

- Cloud Chamber [4b]

Career Opportunities [8]