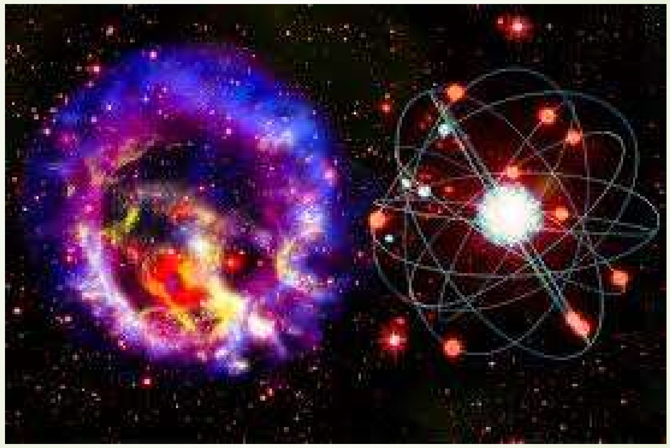
The Nucleus



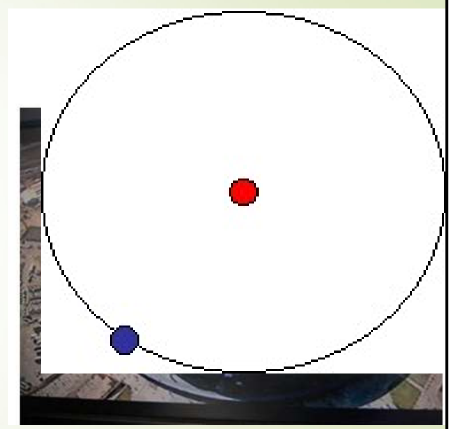
John Michael Preston

Understanding the outer layers of electrons in atoms revolutionized the sciences of chemistry, biology, computers, and communications. Revealing the secrets of the atom's nucleus helps us understand our origins, cure disease, and provide energy for our future.

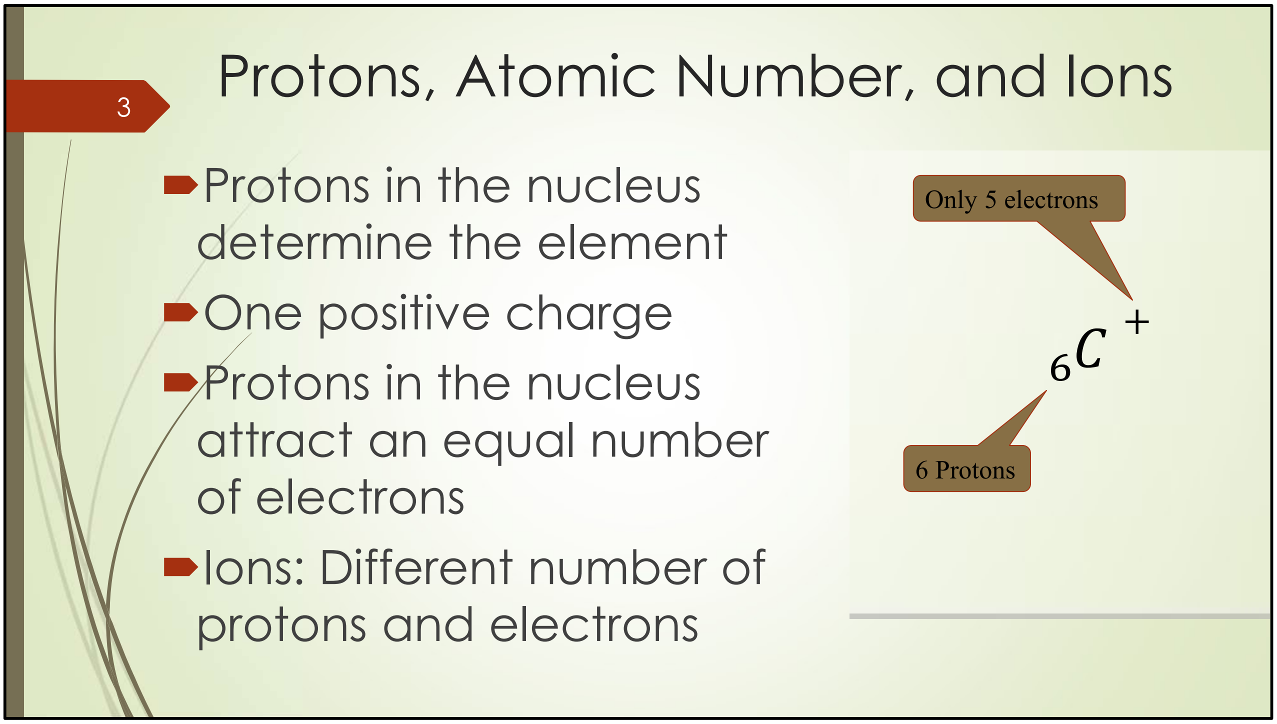
Size of the Nucleus

2

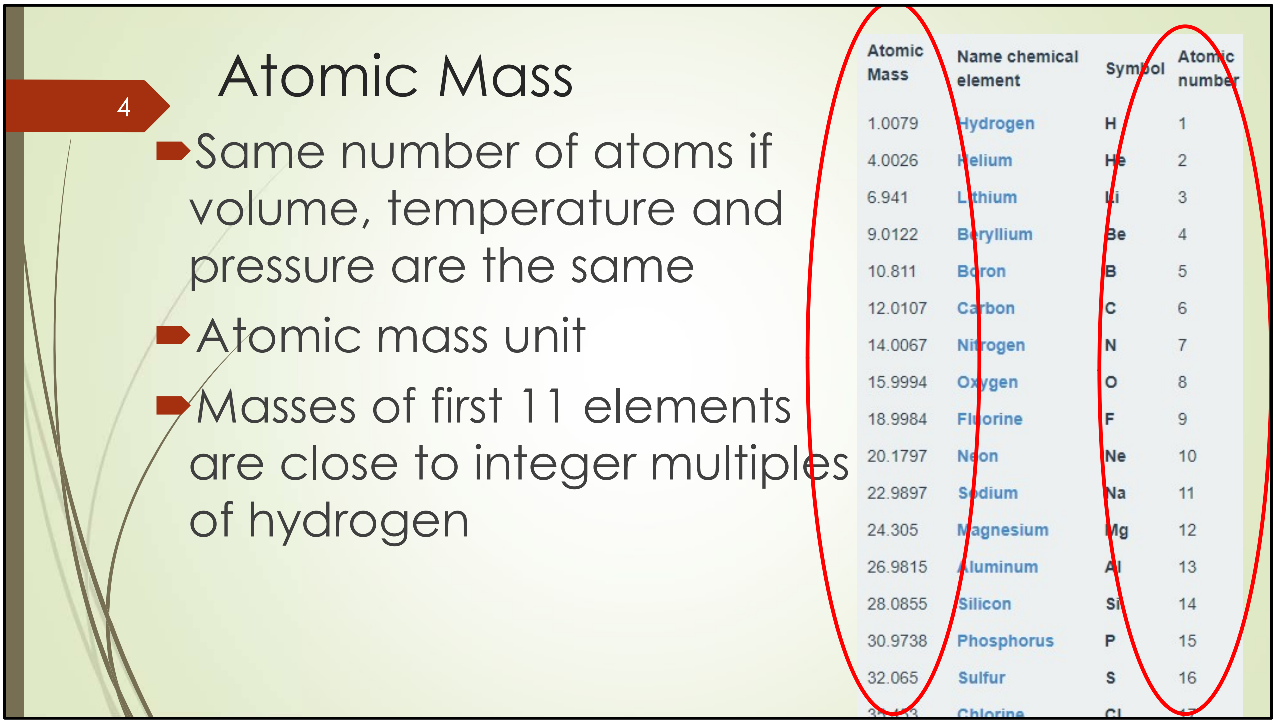
- 6.02 x 10^{23} atoms in a mole
- Positive charges repel each other
- Nucleus
  - all of its positive charge
  - 1/100,000 of the volume
  - >99.8% of its mass
- Drawings of atoms are not to scale



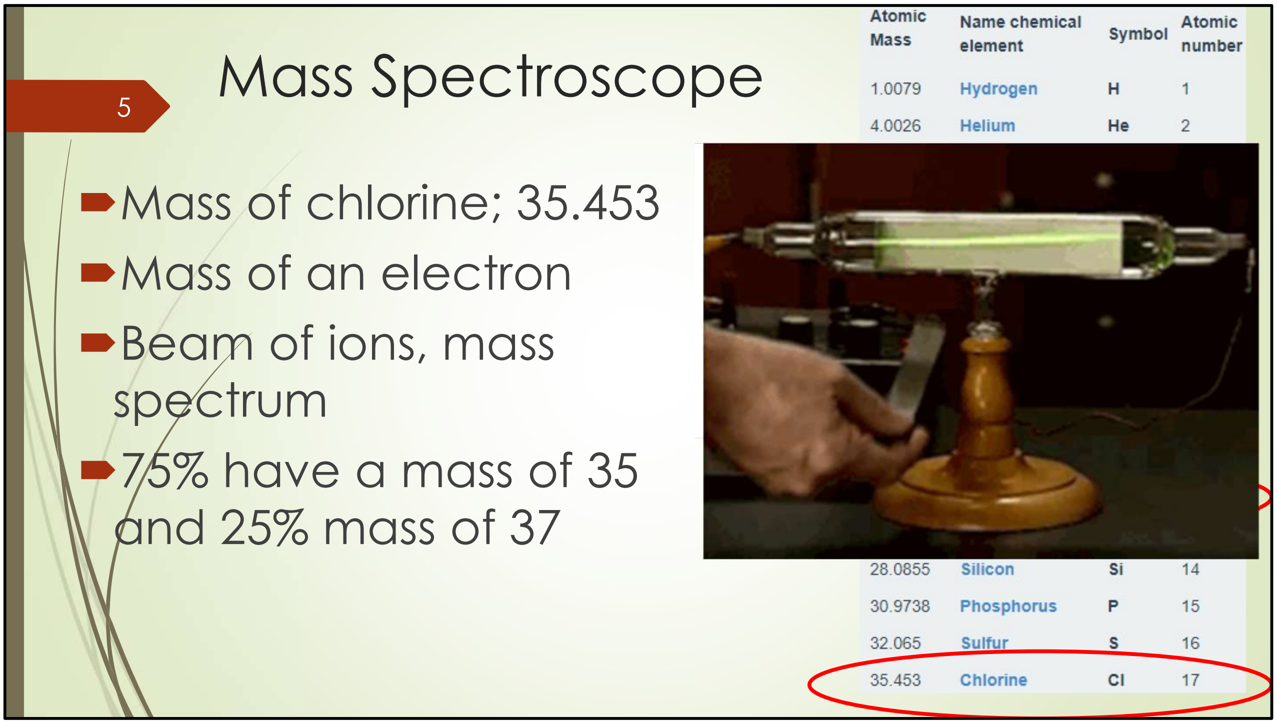
*Recall that there are more than 600 billion trillion hydrogen atoms in one gram of hydrogen, and that atoms are so small we cannot observe them directly.
*Recall that positive charges repel each other.
*Recall that Rutherford determined that *all of an atom's positive charge is contained in a nucleus that was only *1/100,000 of the size of the atom in spite of their mutual repulsion, and *had almost all of the atom's mass.
*Drawings of atoms distort the proportions. *If a hydrogen atom were the size of a football stadium, its nucleus would be the size of a pea. No one has seen a nucleus so its structure must be inferred from other clues.



*Ernest Rutherford named the basic building block of the nucleus a **proton**. The number of protons in the nucleus determines what element the atom is.
*A proton has one positive charge.
*In a neutral atom, each proton attracts a negative electron which fits into an energy layer outside the nucleus. The simplest atom is Hydrogen which can have one proton in the nucleus and one electron outside.
*If the atom has a different number of electrons than protons, it is an ion. An extra electron makes it a negative ion and one too few makes it a positive ion.
*Notation: Atoms are represented in formulas by an abbreviation of their name which is one or two letters with the number of protons in front and below. If the atom is an ion, its charge is shown above and to the right. For example, a positive ion of carbon, that has *six protons and *only five electrons, is shown on the right



*Recall that Avagadro determined that the same volume of two different gasses have the same number of atoms or molecules if the temperature and pressure are the same. This made it possible to compare the masses of individual atoms by weighing samples of the same volume, temperature and pressure.
*If we arbitrarily define the mass of the simplest atom, Hydrogen, as 1 atomic mass unit, and *compare its mass to the atoms with more protons, we get the following table of elements and their masses:*
*Observe that the atomic numbers are integers, and that most of the atomic masses are close to integer.

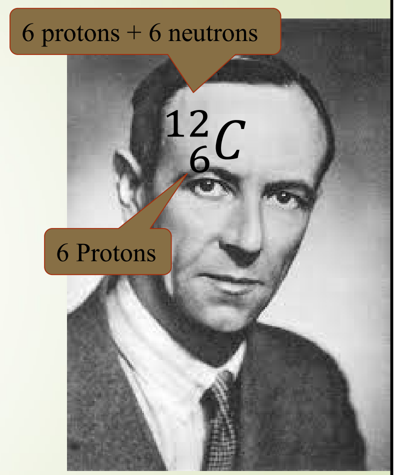


*The twelfth element, magnesium, and the seventeenth element, chlorine, do not obey this pattern. Chlorine is the most different with a mass of about 35 and a half.
*In 1912, J.J. Thomson deflected a beam of electrons in a Crookes tube with a magnetic field to determine the mass of an electron.
*This device was later modified to work with ions. This range of masses, is called the mass spectrum.
*When a sample of chlorine was ionized and sent through a magnetic field, the stream of ions separated into two distinct beams of different intensity. *By measuring the intensity of the two beams, they found that about 3/4 of the chlorine atoms had a mass of 35 and 1/4 had a mass of 37 that produced an average of 35.45

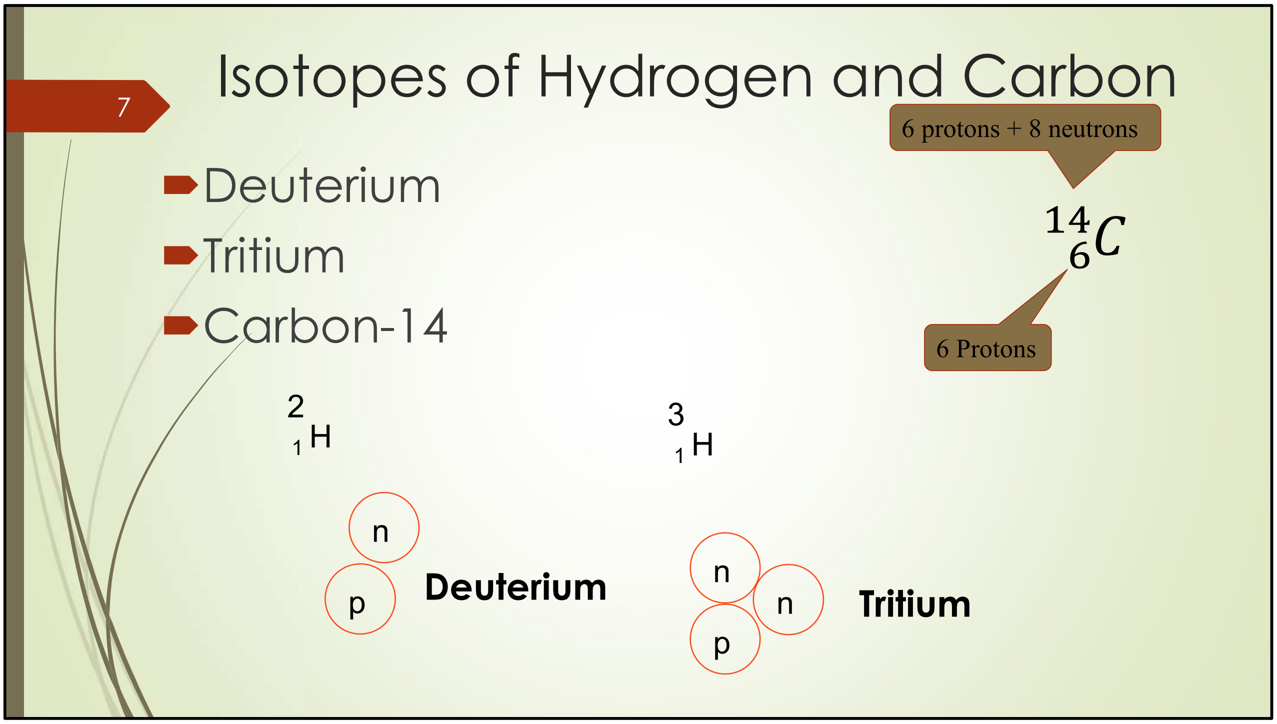
6

Isotopes

- In 1923, Chadwick, **neutron**
- **Isotopes** (same type)
  - Same # of protons
  - Different # of neutrons
- Most elements are mostly one isotope, but not all
- Notation



*In 1923, James Chadwick proposed the existence of another particle in the nucleus that was about the same mass as a proton but is neutral that he named a **neutron.**
*Two atoms might have the *same number of protons, and therefore both be the same element, but they could have *different numbers of neutrons. Because they would be the same type of element, they are **isotopes** of that element.
*Most elements consist of atoms with the same number of neutrons but some, like chlorine, are mixtures.
*Notation of isotopes displays the total number of protons plus neutrons is written in front and above the name of the element. For example, *the 12 indicates the isotope of carbon.

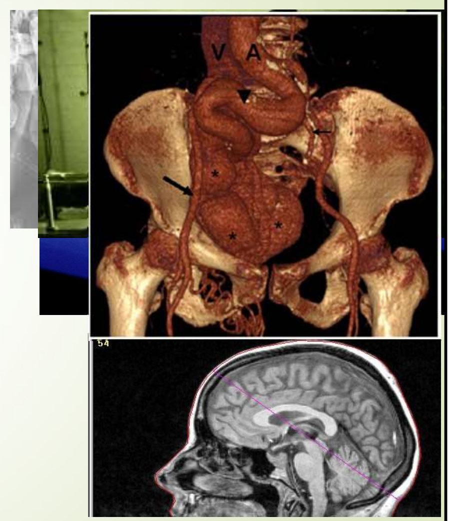


Two isotopes of hydrogen are important enough to have their own names
*If the nucleus of a hydrogen atom also has a neutron, it is called **deuterium****
If the nucleus of a hydrogen atom has two neutrons, it is called **Tritium**
*Another isotope you might have heard of if Carbon-14
*It has six protons, like all other carbon atoms but it has 8 neutrons for a total of 14

8

Röntgen or X-rays

- In 1895, Wilhelm Röntgen, X-rays
- Partially blocked by denser matter
- Shadow photographs show bones and teeth
- Short wavelength, high-energy photons of light
- CT scans

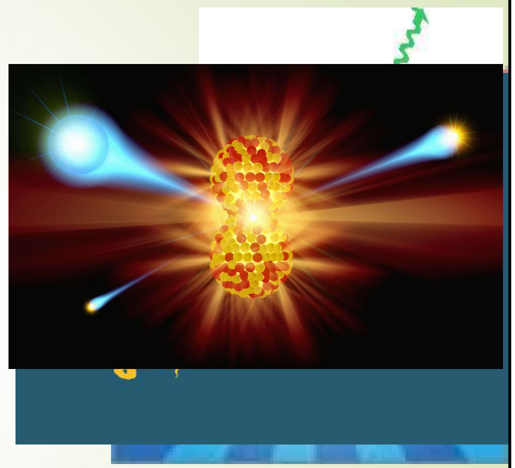


*In 1895, Wilhelm Rontgen was experimenting with a Crookes tube that was powered by a high-voltage Tesla transformer that produced several thousand volts. *He noticed that phosphorescent materials glowed nearby while the tube was operating. He placed opaque objects that would block visible light between the tube and the materials but the unknown rays from the tube when through them. He called the unknown rays, **x-rays**.
*He found that the rays could expose a photographic film and that dense objects would partially block the rays and cast a shadow. He immediately saw the potential of these rays and made the first x-ray image of his wife's hand that showed the bones inside.
*X-rays can show broken bones, and *abnormalities in tooth development like these impacted wisdom teeth.
*X-rays are photons of light but with smaller wavelengths than visible light which makes them more energetic and penetrating. Some countries, like Germany, call them Rontgen rays instead of x-rays.
*Modern X-ray machines emit short pulses that can be combined with digital cameras and computers to make composite images called **computer tomography** or **CT scans**

9

Ionizing Radiation

- Radiate
- Ionizing radiation
- Sources:
  - Electron beams (x-rays)
  - Outer space
  - Sun
  - Nuclei of some isotopes



*To radiate means to spread out from a center. *We often use the word to describe a source of heat.
*Ionizing radiation is a form of energy that can create ions by *knocking an electron from a neutral atom, or by *breaking a large molecule into positive and negative pieces. The infrared heat from a radiator doesn't have that much energy.
*Ionizing radiation can come from a variety of sources, including: *a beam of electrons hitting a metal plate inside a dentist's x-ray machine, *outer space, *the sun or *from the nuclei of some isotopes.

10

Ultraviolet Light (UV)

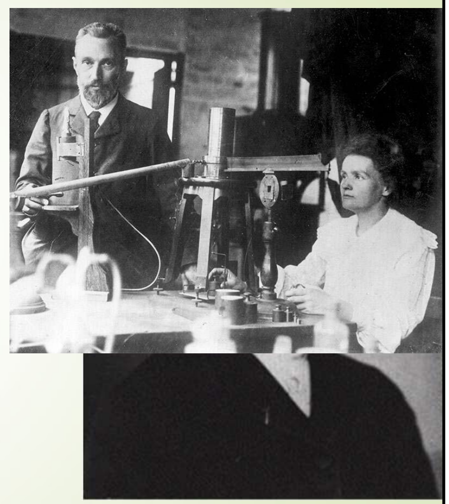
- UVA (315-400 nm)
  - >95% of UV
  - related to skin aging
- UVB (280-315 nm)
  - Makes vitamin D, melanin
  - Can kill cells that must be replaced
  - High levels cause sunburn
  - Mutations of DNA, cancer

Ultraviolet light that is a normal component of sunshine is a form of ionizing radiation. UV light is shorter wavelength than visible light with wavelengths between 280 and 400 billionths of a meter or nanometer. It can be divided into two ranges called UVA and UVB.
**More than 95% of the UV light from the sun at the earth's surface is between 315 and 400 nm. This is called the UVA range. *It is related to skin aging.
*UVB are shorter wavelengths from 280-315 nm that have more energy and penetrate further.
*In modest amounts, our bodies use it to make vitamin D and a dark pigment called melanin.
*UV light can kill healthy cells which are regularly replaced by the body's normal replacement processes that include increased blood flow to the damaged area.
*Too much UV light can produce sunburn and a more severe response. Symptoms include inflamed skin, pain, blisters, fever, nausea, and shedding of dead skin.
*Repeated sunburns are related to incidences of skin cancer due to the ionization and mutation of DNA.
*We balance the risks of UVB with prevention methods like sunscreen and limited exposure so that we can enjoy the sun and outdoor activities.

11

Nuclear Radiation

- Radiation from the nucleus
- In 1896, Henri Becquerel, radiation from Uranium
- Marie and Pierre Curie discovered radium and polonium
- Tumor treatment
- Radioactive



*Energy or particles that come from the nucleus of an atom are called **nuclear radiation**.
*In 1896, Henri Becquerel, noticed that one of the phosphorescent materials he was using to explore the effects of crookes tubes, was able to glow whether the tube was turned on or not. Further experimentation showed that the Uranium used in the phosphors was its own source of radiation.
*Marie Curie and her husband Pierre, were able to detect ionizing radiation from new elements and discovered radium and polonium. He died in a Parisian traffic accident involving a horse-drawn wagon in 1906 at the age of 46. She died of disease related to exposure to toxic chemicals and radiation at the age of 66.
*Marie discovered that radiation from radium could kill tumors and spent much of her time exploring its use as a cancer treatment. Radiation treatment has since saved millions of lives.
*She coined the term **radioactive**.

Types of Nuclear Radiation

12

- 1899, Rutherford, alpha, a beta, β
- Alpha: Helium ion, $^{4}_{2}He^{+2}$
- Beta: **e**$^-$,
- 1900, Vilard: Gamma: γ, photon.
- Neutron, $^{1}_{0}n$

*In 1899, Ernest Rutherford identified two different types of radiation from the nucleus. X-rays were already named so he named the two new types for the first two letters in the Greek alphabet; Alpha and Beta
*By passing them through a mass spectrometer, he found that an alpha particle had a charge of +2 and a mass of 4 amu, *which is the same as a Helium ion.
*Beta particles had the same charge and mass as an electron
*In 1900, Paul Villard discovered photons of light, similar to X-rays that came from the nucleus of radium that could also expose film.
*In 1932, James Chadwick discovered that neutrons could be emitted from the nucleus. Because they are neutral, they were much harder to detect.

Shielding

13

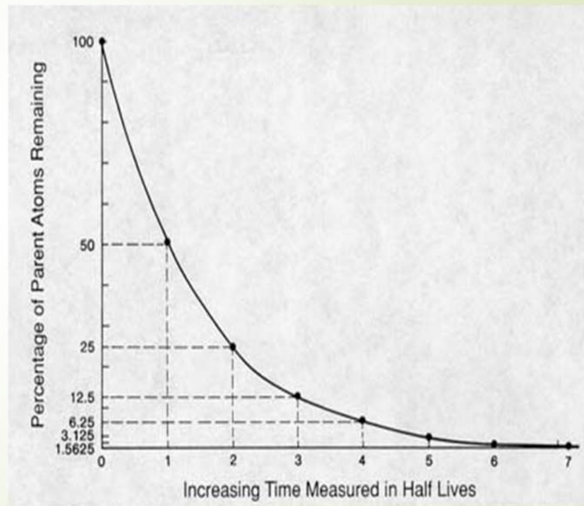
- UVB, << 1mm
- Alpha; 4" air
- Beta; 8 meters of air or 1 centimeter of water
- Gamma: 20-30 meters of air or 14 ft. of water
- Neutrons; >100 meters in air, 14' of water

*Much less than a millimeter of sunscreen will block UVB light (1/2 tsp. for each arm, leg, face, neck)
*A few inches of air or just the thickness of skin will block alpha particles
*Beta particles travel several meters in air but just a few centimeters in water
*Gamma photons travel tens of meters through air and about 14 feet of water
*Neutrons can travel hundreds of meters through air but are stopped by hydrogen-rich materials like water in about 14 feet.
*Nuclear research can be conducted safely at the bottom of a pool of water about 20' deep.

Rate of Emissions

14

- Depends on the Isotope
- Half life
- Exponential decrease
- Five half-lives

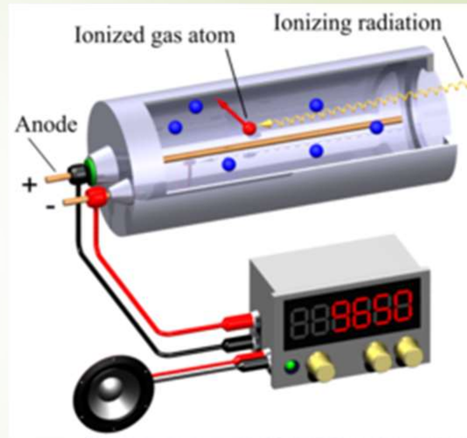


*The type of element is determined by the number of protons in the nucleus but the type of radiation, if any, is determined by the number of neutrons, i.e. which isotope it is.
*If an isotope is radioactive, the rate of emissions decreases with time, but the decrease is not linear. In a given amount of time, half of the atoms will emit radiation. After an equal amount of additional time, half of the rest will emit, and so on. ***
*A chart of the activity shows how emissions decrease with time
*Half life is a statistical description, and it becomes less accurate when the number of isotopes gets low. Generally, it becomes less usable for prediction beyond five half lives.

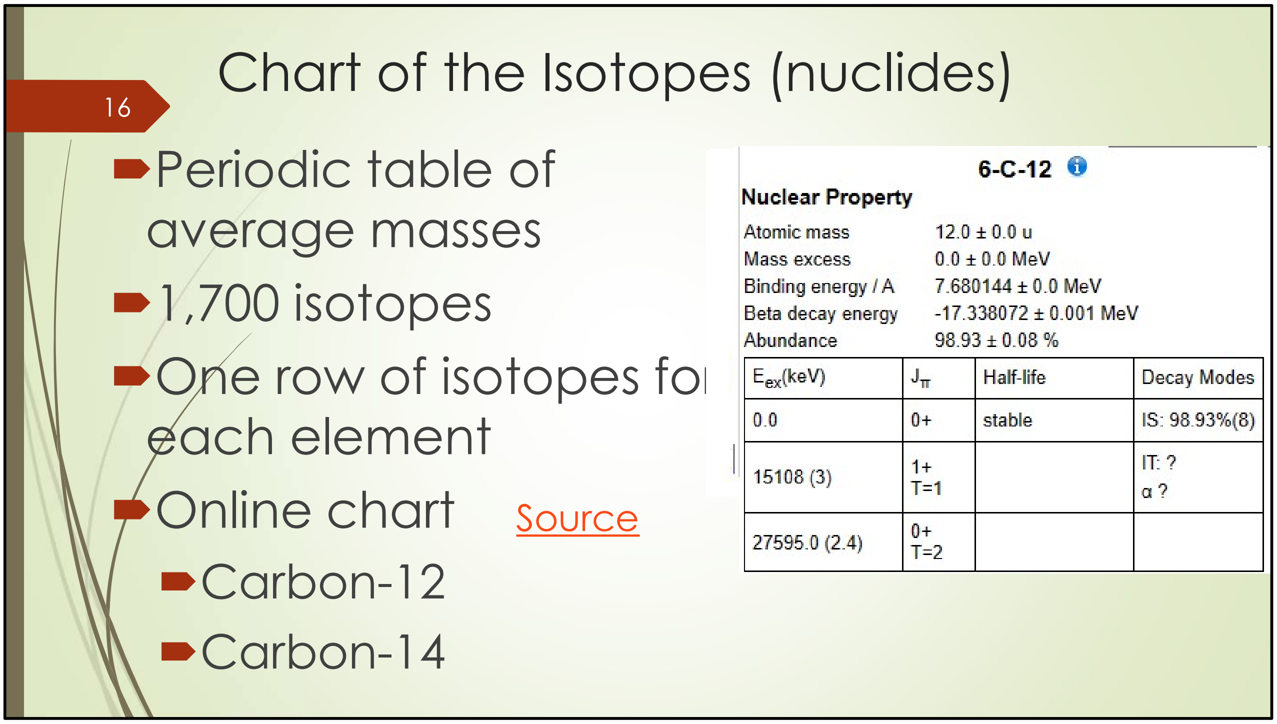
Detecting and Identifying Ionizing Radiation

15

- Photographic film
- Cloud chamber
- Bubble chamber
- 1908, Geiger counter
- Scintillations in crystals



*Like light and x-rays, ionizing radiation will expose photographic film. Film badges can be worn to indicate local exposure
*Ions can form condensation sites in a vapor that is about to condense like alcohol vapor above dry ice. Ionizing radiation leaves a trail of liquid droplets that are visible, *somewhat like the contrail of ice crystals behind a jet aircraft. (demonstration)
*Similarly, ionizing radiation leaves a trail of bubbles in liquids that are about to boil in a bubble chamber. Bubble chambers are often used with magnetic fields that bend the paths of charged particles according to their charge and mass.
*In 1908, Hans Geiger, invented a device called a *Geiger counter that could detect and count radiation particles that passed through a vacuum tube between two charged plates and temporarily created a path for current to flow. (demonstration)
*Radiation can cause flashes of light in certain crystals that can be counted.

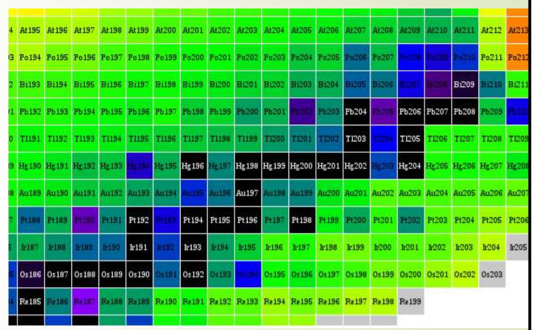


*The modern periodic table lists over 100 elements. The atomic mass number for each of them is an average of the masses of the isotopes of that element that are found in nature.
*Each element can have numerous isotopes and about 1,700 have been identified. A general term for all isotopes is **nuclides**. A chart showing all the nuclides would be hard to put on a single piece of paper.
*Each row of the chart has about a dozen isotopes, each with a different mass, half-life, and mode of decay.
*An online chart is able to zoom in on an area of the chart and clicking one of the isotopes displays a table of information about that isotope including its mass, half-life, and mode of decay. *For example, if you click on the box for Carbon-12, it displays details about that isotope showing that it is stable, with a mass of exactly 12. Due to the importance of organic chemistry, the amu is defined as 1/12 the mass of Carbon-12.
*If you click the box for Carbon-14, it shows that it emits a beta and has a half-life of 5,700 yrs +- 30 yrs.

Structure of the Nucleus

17

- Elements with an even # have more stable isotopes or longer lives
- Small atoms: # of neutrons ~ # of protons
- Large atoms:
  - Atoms larger than Bismuth are not stable
  - # of neutrons ~2.5x # of protons



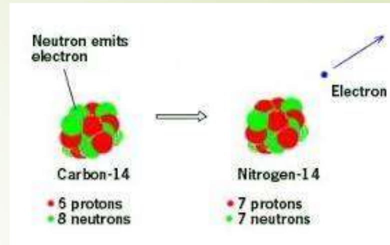
Source

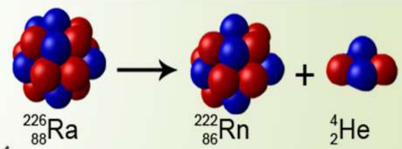
*Isotopes with about the same number of protons and neutrons tend to be more stable in smaller atoms, e.g. He-4 and Carbon-12
*All the atoms with more than 83 protons (Bismuth-83) are radioactive
*Elements with even atomic and mass numbers tend to have longer half-lives than odd numbers, e.g. U-238 (92,238) four billion, vs. U-235 700 million.

Natural Transmutation

18

- Beta
  - Neutron decays into a proton and emits an electron
  - ${}^{14}_{6}C$ ➔ β$^-$ + ${}^{14}_{7}N$
- Alpha
  - Large atoms like Radium-226
  - ${}^{226}_{86}Ra$ ➔ ${}^{4}_{2}He$ + ${}^{222}_{84}Rn$



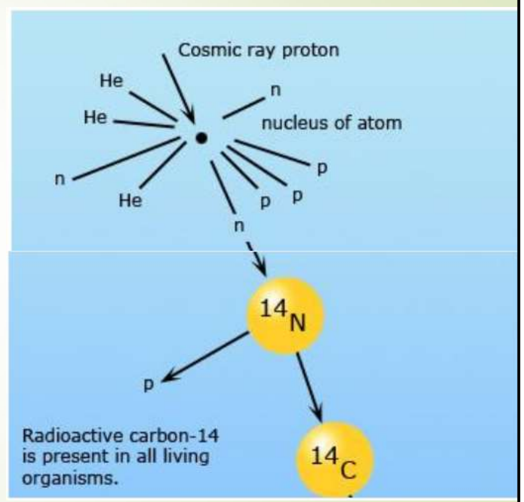


*It was a surprise to identify beta particles as electrons emanating from the nucleus. *A neutron in the nucleus can break apart into a positive proton and a negative electron. The proton stays in the nucleus, changing it into the next higher element, and the electron is emitted.
*For example, Carbon-14, an isotope of carbon, can emit a beta and become Nitrogen-14.
*Large atoms can emit alpha particles that remove two protons and two neutrons from the nucleus.
*For example, Radium-226 can emit an alpha and turn into Radon-222

Cosmic Ray Transmutation

19

- Protons from space
- Neutron knocks a proton out of N-14 to make C-14
- C-14 emits a beta and transmutes back to N-14
- About 1 part per trillion
- 238 betas per second

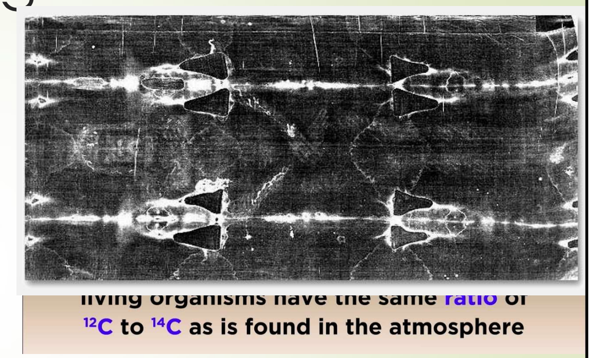


*Cosmic rays are mostly protons arriving from space that have a lot of energy. *They can shatter atoms in the upper atmosphere creating a shower of fragments including free neutrons.
*Most of the earth's atmosphere is Nitrogen. The neutrons are about the same mass as a proton and can knock a proton out of a Nitrogen nucleus while the neutron remains. This transmutes the Nitrogen-14 into Carbon-14.
*Carbon-14 has a half-life of 5730 years. It emits a beta and transmutes back into Nitrogen-14.
*This process of creation and decay balances out at a fairly stable concentration of about 1 C14 per trillion C12 which is enough to *emit about 238 betas per second per kg of carbon.

20

Carbon-14 Dating

- Solar flares, bomb tests, and fossil fuel use
- C-14 absorbed into living plants
- Calibrated against tree-ring data
- Dead Sea Scrolls; 2,100 yrs. old
- Shroud of Turin: 700 yrs. old

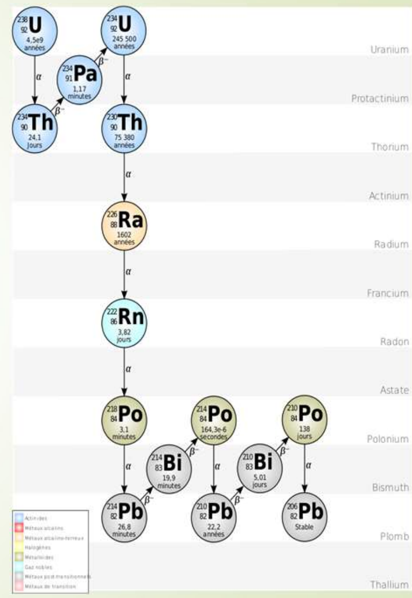


*Factors that can affect the concentration are solar flares of extra protons, nuclear weapons tests that added more C14, burning fossil fuels that have no C14, and slower absorption rates into seawater
*Carbon, in the form of CO2, is absorbed into living plants and turned into hydrocarbons by photosynthesis. After a plant dies, its C14 activity drops with a half-life of about 5,730 years
*C-14 dating can be calibrated by comparing it to tree-ring dating
*C-14 dating method used to date the papyrus in the Dead Sea Scrolls at > 2000 yrs old
*Shroud of Turin only 700 yrs. old

Dating Rocks

21

- C-14 limited to plants and about 28,500 years
- Uranium 238, half-life 4.5 billion years
- Decay chain U-238 to Pb-206
- Oldest rocks about 4 billion years old



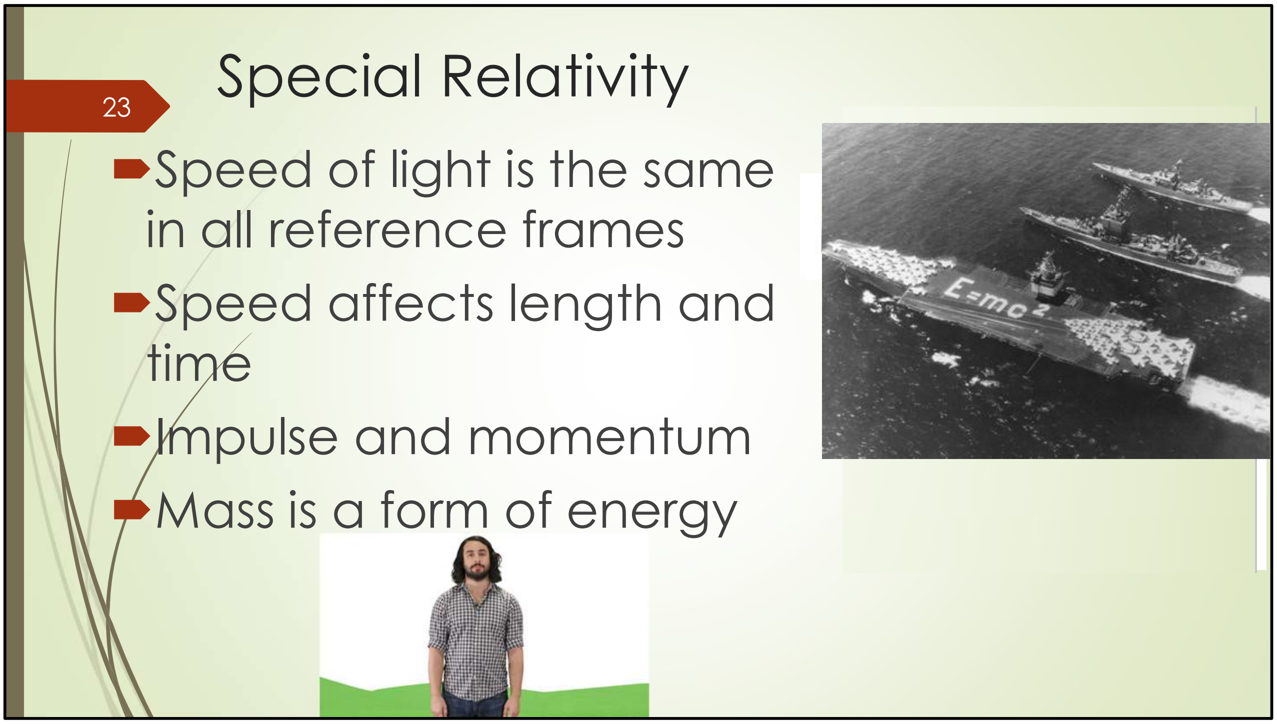
*Carbon-14 dating is only useful for objects that were once living plants or animals that ate them and is only accurate for the most recent 28,500 years. (five half lives at 5700yrs)
*Some isotopes have much longer half-lives. For example, Uranium-238 has a half-life of 4.5 billion years.
*U-238 emits alpha and beta particles, transforming into a sequence of other radioactive isotopes until it finally becomes a stable isotope of lead, Pb-206. Each of these isotopes has a known half life. The age of a rock since it solidified at the earth's surface can be estimated by the ratio of U-238 to Pb-206 or by other similar ratios of long-life radioactive isotopes to their stable products.
*The oldest rocks found on earth are about 4 billion years old.

Nuclear Energy

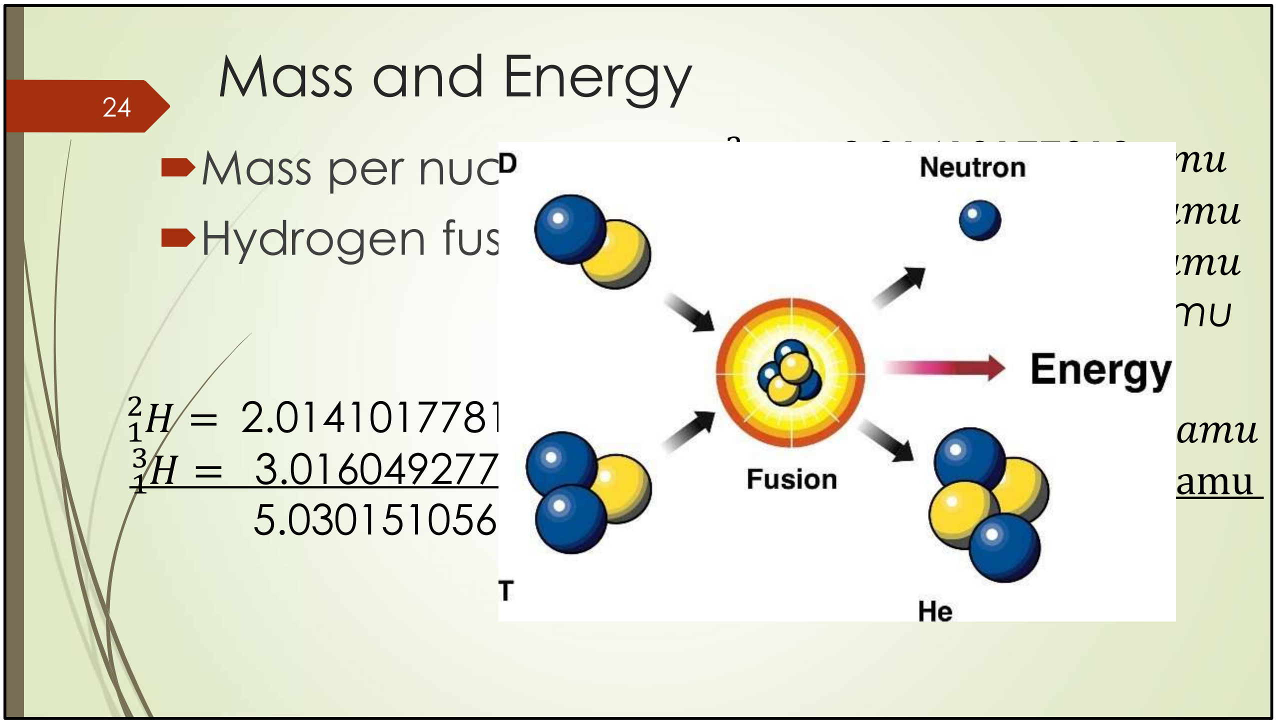
22

- Age of the Sun >4 billion years
- Nuclear radiation
- Where does the energy come from?

*If the earth is at least 4 billion years old, it is likely that the sun is at least that old. If the sun was made of wood or coal, it would burn up all its fuel in a few thousand years.
*Molecules like dynamite only store about 40 electron volts of energy per molecule but nuclear radiation has about 100,000 times more energy.
*The big question at the beginning of the 20th century was what is the source of this energy?



*Albert Einstein identified the source of nuclear energy by explaining why the speed of light is the same regardless of the motion of the frame of reference.
* To get the same speed of light, the measurement of time and/or distance must change.
*Two equations show how the *measured time between two events increases with speed (v) and how the *length of a measurement shortens with speed.
*Recall that impulse causes a change in momentum. Newton thought that impulse always causes a change in speed of a given mass but if there is an upper limit on speed, increased impulse must cause an increase in mass as an object approaches the speed of light.
*Mass is a very condensed form of energy; E=mc2

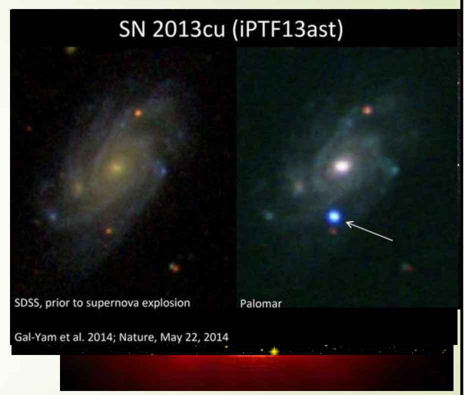


*Mass spectrometers can measure the mass of an ion very accurately. For example, here are the masses of a *two isotopes of hydrogen, a neutron, and helium.
*Scientists proposed that the gravity of the sun was sufficient to press two of the heavier isotopes of hydrogen close enough to make them fuse, (in spite of their mutual repulsion due to having the same charge) to form Helium and emit an extra neutron.
*The sum of the masses of deuterium and tritium is slightly greater than the sum of the masses of Helium and a neutron. This small amount of mass is converted to millions of ev of energy according to Einstein's equation E=mC2. This also explained why Helium could be detected on the sun.

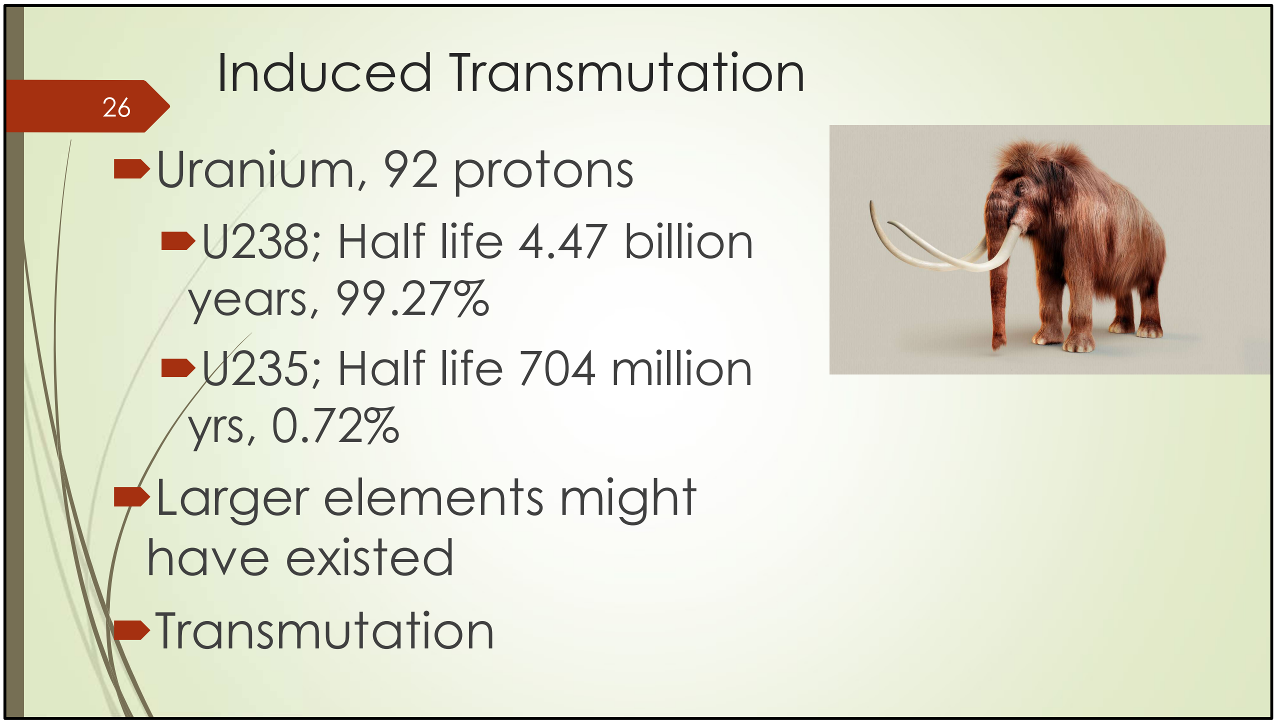
25

Supernovas and Stardust

- Our galaxy, 13.6 billion yrs.
- Sun, 4.6 billion yrs.
- Nova
- Supernova
- Heavy elements blown into space
- Stardust forms new stars and planets



*Evidence indicates that the Milky Way galaxy, of which we are a member, is about three times older than our solar system
*Our sun is capable of fusing hydrogen into Helium, but it doesn't have the size and gravity necessary to fuse larger atoms.
*We think that medium size atoms are fused together in stars that are at least ten times bigger than the sun toward the end of their lives when they collapse in on themselves or draw in a neighboring star and then explode and emit enough light to be visible from earth as if they were new stars or novas.
*The largest atoms are thought to be the result of collisions between much larger stars that also explode and are called supernovas. They can emit as much light as an entire galaxy.
*The explosions of these stars more than 4 billion years ago, scattered heavy elements throughout space as interstellar dust.
*Gravitational attraction is thought to have caused this material to coalesce into new stars and planets such as our solar system. In short, all the larger elements on earth and in our bodies are recycled stardust.



*The largest element found on earth is Uranium. It has 92 protons and comes in two isotopes, *U-238 99.27% with a half life of 4.47 billion years and *U-235 0.72% with a half life of 700 million years.

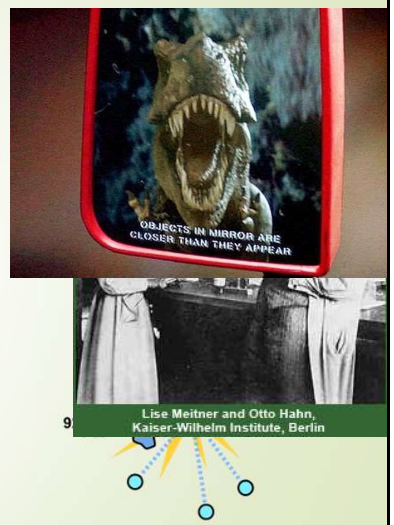
*It is possible that larger elements were present when the earth was formed but they might have had shorter half lives and have become extinct.

*In the 1930s, scientists discovered how to transmute one element into another by bombarding an element with alpha particles, protons, or neutrons. Neutrons were promising because they were not repelled by the positive charge on the nucleus.

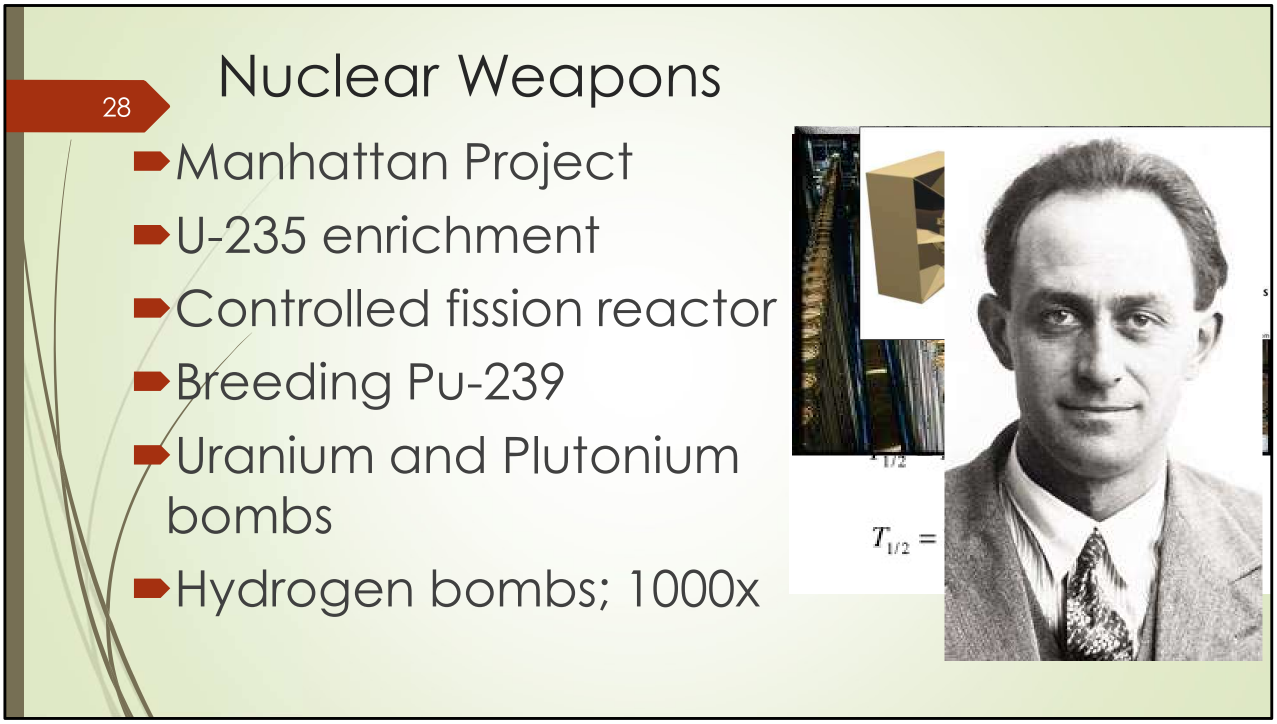
Nuclear Fission

27

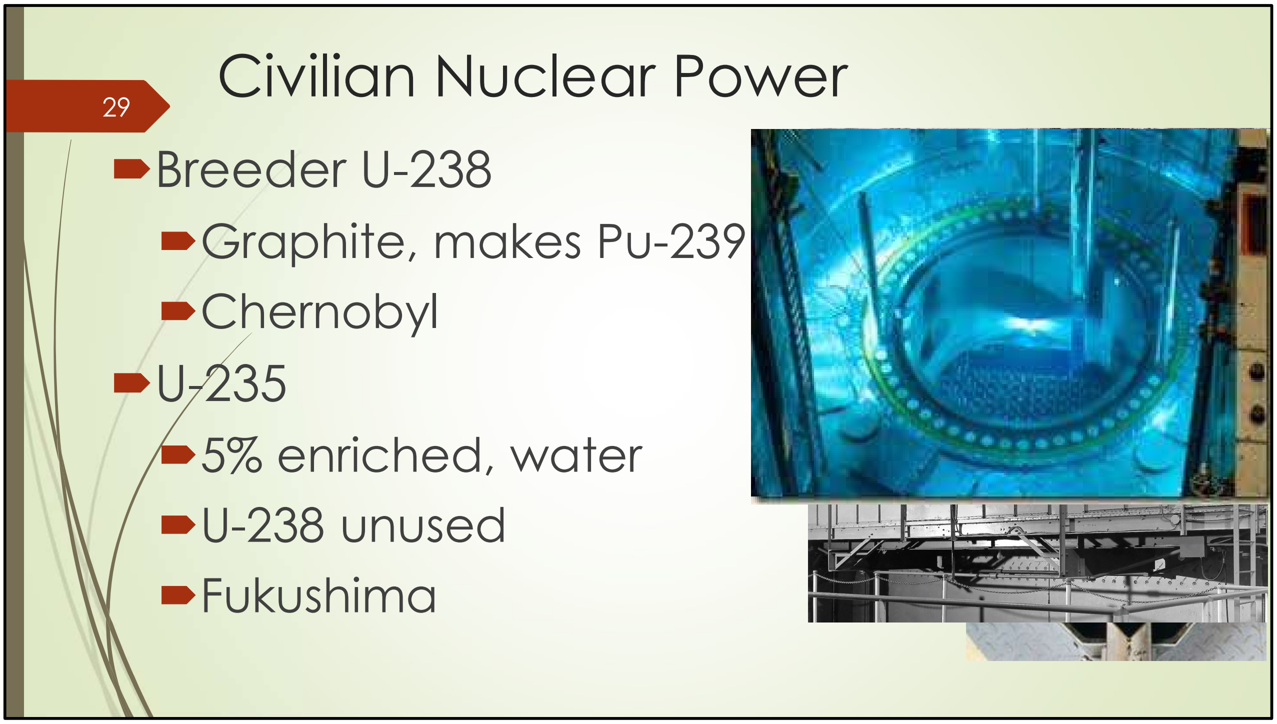
- 1938, Hahn and Meitner
- Produced elements about half the size
- Missing mass becomes energy
- Easier than fusion
- Meitner alerts the world



*In 1938 in Nazi controlled Germany, Otto Hahn and Lisa Meitner were trying to change Uranium atoms into extinct, larger atoms by bombarding them with neutrons and hoping for beta decay once the neutrons were absorbed. *Nazis and reviving extinct elements—what could go wrong?
*The results were not what they expected. Hahn found that his sample of uranium became contaminated with several types of smaller atoms that were about half the size of Uranium.
*Meitner recognized that the neutrons were causing some of the Uranium 235 to split in half and produce even more neutrons making a chain reaction possible. The smaller atoms are called **daughter products**.
*Comparison of the masses before and after the fission showed the products to have less mass which would be converted to energy according to Einstein's equation.
*This method of releasing nuclear energy was much easier to produce than fusion because the neutrons could enter the positive nucleus.
*Lisa Meitner was Jewish. She had already fled Germany, with Hahn's help, and broke the news to the scientific community.



*Einstein was prevailed upon to write a letter to the US president, warning of the possibility of a super bomb in the hands of the Nazis. The president ordered a major effort to develop an atomic bomb called the Manhattan Project.
*To produce a weapon, the concentration of U-235 had to be increased from 0.7% to 80%. Because both isotopes are chemically the same, the small difference in mass between U238 and U235 was used in *centrifuges and *gas diffusion tanks. These methods are slow and costly.
*A lower concentration of U-235 of about 3-5% can be used to create a controlled, self-sustaining fission reaction. The first controlled reactor was built by *Enrico Fermi that used a small amount of enriched uranium *surrounded by blocks of graphite.
*The reactor can be used as a rich source of neutrons to *transmute U238 into Plutonium-239 which fissions as well as U235.
*A bomb can be made from U235 like the one used at Hiroshima, but it is far more productive to use the enriched Uranium to transmute U238 into Plutonium and make a bomb *like the one used at Nagasaki. The Plutonium bomb showed the Japanese that we could make many of them. All of our nuclear weapons use Plutonium.
*If the fission bomb is surrounded by hydrogen, the shock wave of the fission explosion can fuse hydrogen multiplying the energy yield by a factor of a thousand

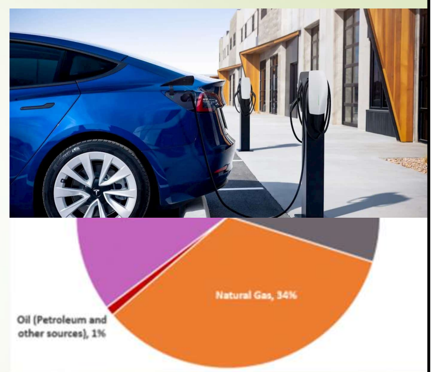


Reactors fueled with Uranium that is enriched to 3-5% U235 can sustain a controlled chain reaction that boils water into steam that generates electricity.
*The US bomb program used reactors that transmuted the U238 into Plutonium239. *Like Fermi's first reactor, they used graphite to enclose the Uranium but had holes through which plugs of Uranium could be inserted and then pushed out the back after some of the U238 had been transmuted into Plutonium.
*The Soviet Union used the graphite design so they could convert the more plentiful U238 into Plutonium 239. *It was this type of reactor that exploded, and the graphite burned at Chernobyl in 1986. The other three similar reactors at the site operated until 2000.
*In 1977, President Carter decided that the US would not use breeder technology in civilian reactors for fear of the proliferation of nuclear weapons that use Plutonium. US designs place the Uranium in *metal fuel rods *under water. When about half of the U235 has fissioned, the fuel rods are replaced and *stored under water. *If the fuel rods are not kept submerged, they can overheat and melt. This happened at Fukishima in 2011 after a tsunami disabled its controls.

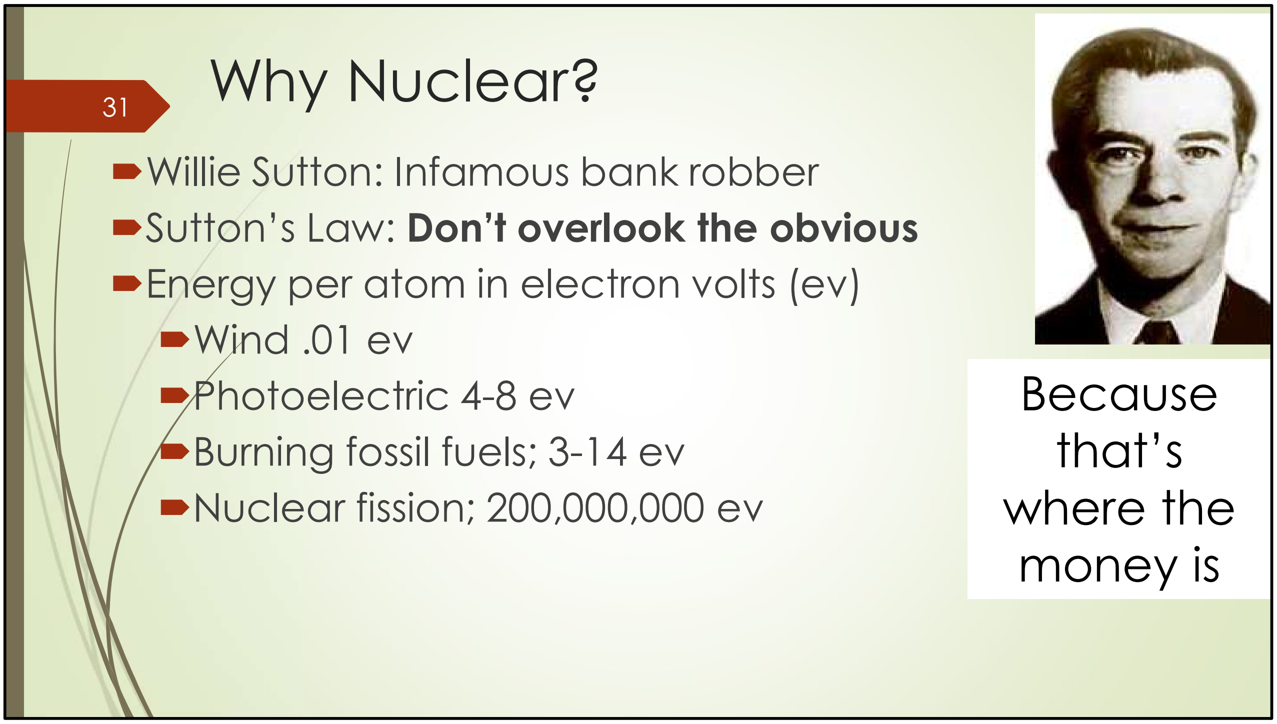
US Electric Energy

30

- No new reactors in US, 20%
- Electric Output; 4 Trillion kwh
- Fossil Fuels: 2.6 trillion kwh
- Switch transportation to electricity; 3 trillion kwh
- Eliminate fossil fuels
  - 2030 Goal: 1.6 trillion kwh
  - 2050 Goal: 4 trillion kwh



*Building civilian nuclear power plants halted after Chernobyl and a much smaller incident at Three-mile island in the U.S. They account for 7% of installed capacity but produce about 20% of US electric power because they can operate continuously at full power.
*The US produces about 4 trillion kwh of electric power each year from fossil fuels, nuclear, hydro, wind, and solar.
*About 2.6 trillion of that is generated by burning coal and natural gas
*If we switch our transportation system from petroleum to electricity, it will take an additional 3 trillion kwh
*To meet our stated goal for reducing carbon emissions for *2030, we need 1.6 trillion kwh of additional clean energy. *To meet the 2050 goal, we need 4 trillion more.



Why should we consider nuclear power?
*Willy Sutton was an infamous bank robber in the 1920s and 30s. He is best known for responding to a question; "Why do you rob banks?" with **Because that's where the money is*. Sutton denied saying it, but the principle behind this alleged reply applies to this problem.* *Let's consider how much energy is available from each source per atom. The unit of energy at this scale is the electron volt or ev. *The energy in each atom of air in the wind is 1/100th of an ev, *The energy from a photon of sunlight hitting an atom in a solar cell is 4 to 8 ev, *the energy released by burning gas or coal is between 3 and 14 ev, *the energy released by splitting an atom of Uranium or Plutonium is 200 million ev. If we follow the Sutton rule, we have to consider nuclear energy.

Annual Energy Output Comparison

32

- Nuclear plant: 8.76 billion kwh per year, (>90% cf) or;
- 1,533 offshore wind turbines (3,000 kw each, 20% cf)
- 1,769 Boeing photocell installations (2,600 kw, 20% cf)

*A nuclear power plant producing a million kilowatts operates almost continuously and generates about 8,760,000,000 kwh a year. To produce the same amount of energy per year would take *1,533 large off-shore wind turbans or *1,769 photocell installations like the one on the roof of the Boeing plant.

33

Why not nuclear?

- Radiation is unnatural, it's a form of pollution
- Power plants might explode
- Nuclear waste will be hazardous for thousands of years: a problem with no solution

If nuclear energy can provide all our energy needs, why don't we use it instead of fossil fuels? There are the four main objections. Let's consider the first three:
*Ionizing radiation is part of nature. *It comes from interstellar space and the sun, and from *rocks in the earth's crust like granite. Together, they are called **background radiation**. *Radioactive C14 is part of ever living plant and animal. Nothing is more "natural" that radioactivity.
*The power plants that had explosions or melt-downs were designed in the 70s when computers used punch cards. New designs are available that encase fuel in ceramics that don't melt or in liquid salt that is already melted at normal atmospheric pressure.
*The three forms of ionizing radiation are alpha, beta, and gamma. They are only dangerous when they come out of a nucleus at high speed. Once they slow down by colliding with shielding, they turn

into an inert gas (helium) or disappear entirely as ordinary electrons and heat. The challenge is to keep fission fragments sequestered behind a few yards of shielding in a form that won't dissolve into ground water or escape into the air until science and technology find a use for them. This can be accomplished by recycling used fuel to remove useful uranium and isolating the fission fragments in glass in a process called **vitrification.**

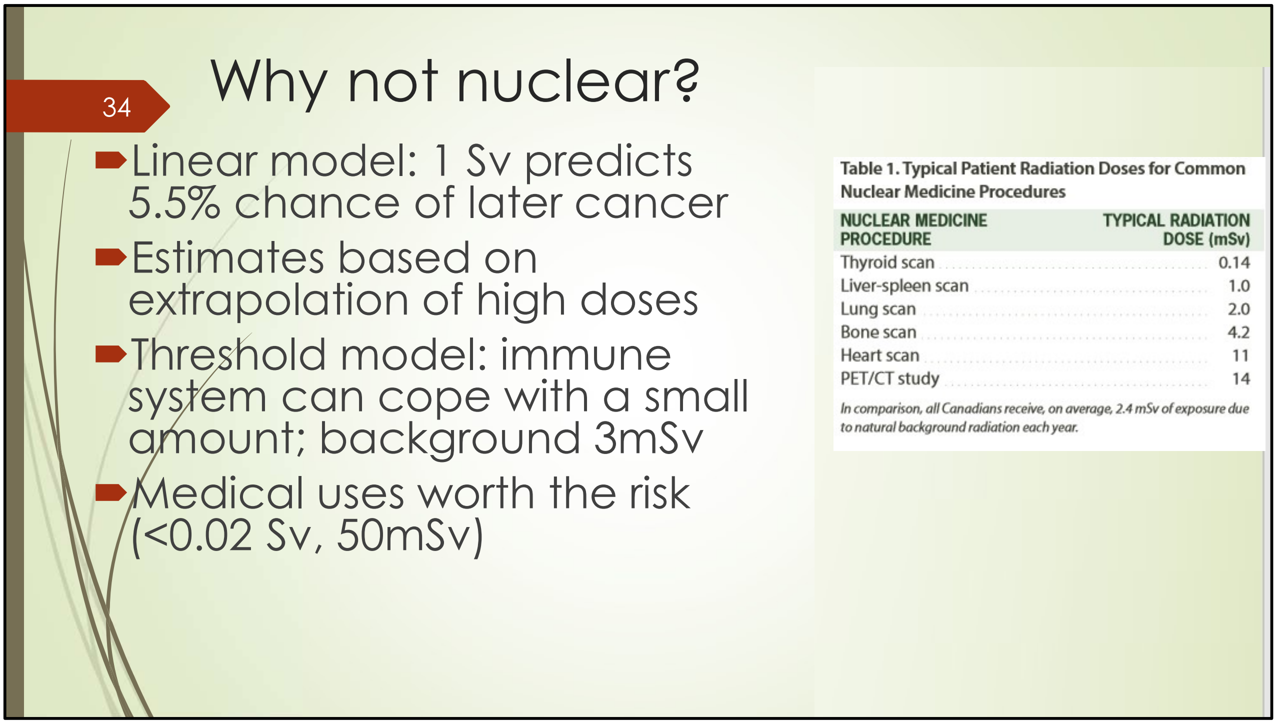


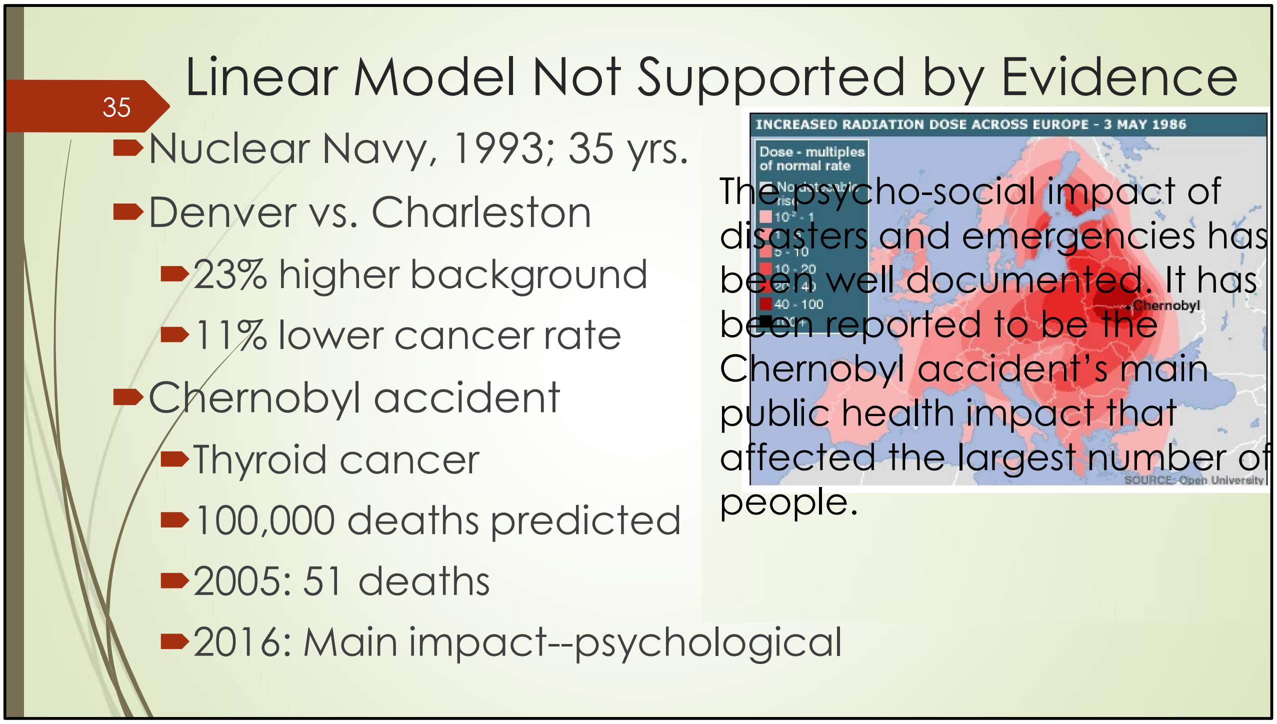
Table 1. Typical Patient Radiation Doses for Common Nuclear Medicine Procedures

NUCLEAR MEDICINE PROCEDURE	TYPICAL RADIATION DOSE (mSv)
Thyroid scan	0.14
Liver-spleen scan	1.0
Lung scan	2.0
Bone scan	4.2
Heart scan	11
PET/CT study	14

In comparison, all Canadians receive, on average, 2.4 mSv of exposure due to natural background radiation each year.

*The most important objection to using nuclear power is the concern that there is no "safe" amount, i.e. even the smallest amount of extra radiation will cause additional cancers sometime later in life. This is called the linear model. A unit of measure is the Gray (1 joule/kg) and an estimate of induced cancer is the Sievert (5.5% of eventually dying of cancer from 1 Gray of absorbed radiation)
*Data was available on the effects of high doses of radiation on the residents of Hiroshima and Nagasaki and its long-term residual effects. Because data was not available on the long-term effect of small additional amounts, the slope of the data was extrapolated to low levels in order to predict the effect on large populations exposed to low amounts of additional radiation.
*The threshold model is used by the government and most medical professionals when dealing with small amounts of chemical toxins. It recognizes that our body's immune system already deals with 3 mSv

of background radiation.
*The medical profession generally uses the linear model, but it also recognizes that the beneficial uses of x-rays and CT scans, isotope scans, PET scans, gamma ray surgery, and radiation treatment outweighs the risk for some patients. Exposures of less than 20 mSv is generally considered worth the slight additional theoretical risk for nuclear diagnostic procedures.



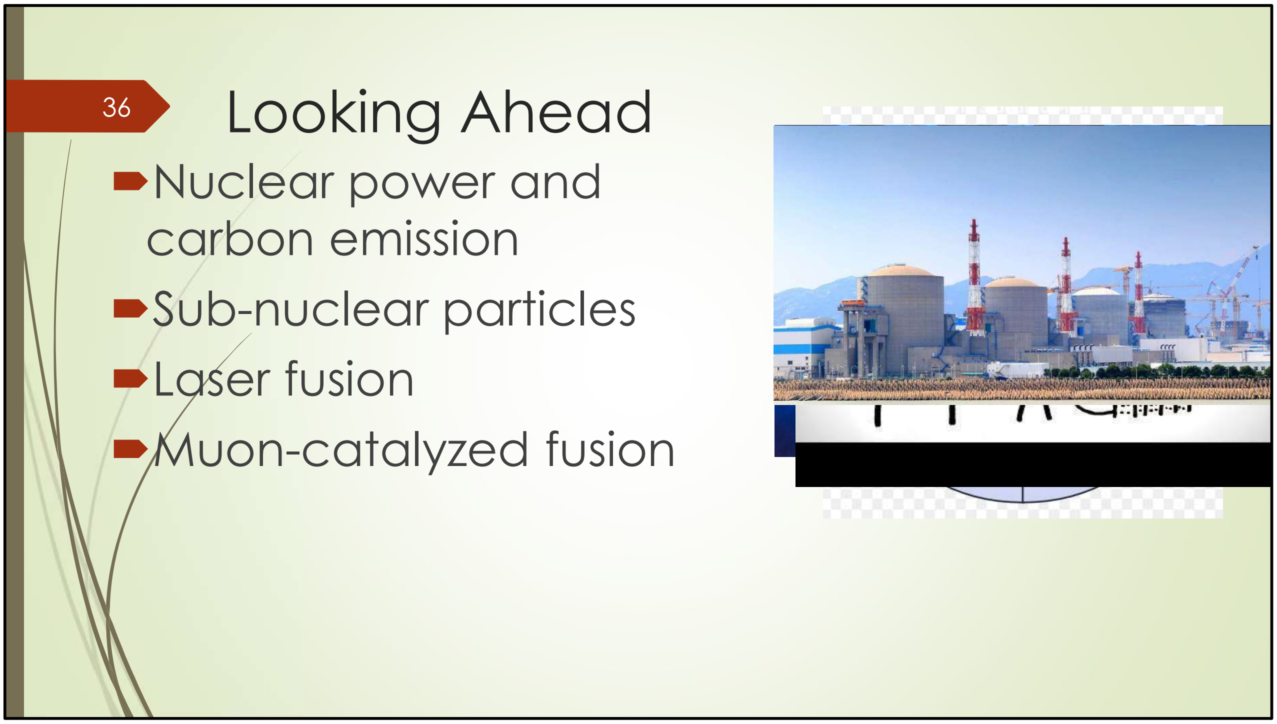
Enough time has passed since the nuclear age began that we can study groups that have been exposed to small additional amounts of radiation.
*Men in the nuclear navy live within a few hundred feet of a nuclear reactor for months at a time. *In 1993, a study of seventy-six thousand submariners found no increase in leukemia, the most likely form of cancer.
*Cities at higher elevations have less atmospheric shielding from space radiation and therefore, higher background levels. A study of cancer rates vs. elevation showed no correlation. For example,
*Denver has 23% higher background radiation than Charleston but
*11% lower cancer rate.
*High doses of radiation killed 31 cleanup workers at Chernobyl within a few months. *Radioactive iodine-131, a fission fragment, spread over a large area. It was was biologically concentrated in milk

from cows that ate grass. *The Soviets did not warn the public in time to avoid drinking milk and the Iodine-131 was further concentrated in the thyroid glands of children causing about 4,000 cases of thyroid cancer but only 9 deaths.

*Groups like Greenpeace used the linear model to predict that 907,000 people would get cancer and 100,000 of them would die. They still stand by that prediction.

*In 2005, the World Health Organization reported that another 19 people who were exposed to high levels had died of cancers bringing the total to 51. Of the 100,000 people living nearby, they predicted that 4,000 of them would die. Of the 5 million exposed to low levels, no measurable increase was expected.

*In 2016, WHO issued another report. The 4000 deaths they expected hadn't happened yet. The report says they will "continue to be investigated". Their conclusion is that the main long-term health effect was psychological, i.e. fear from the predictions of thousands of cancer deaths damaged people's health more than the radiation has.



*China plans to build 150 new nuclear reactors in the next 15 years including $440million to construct a molten-salt reactor that uses Thorium instead of Uranium. They recognize that nuclear power is the only choice that has enough potential to reach carbon reduction goals by 2030 and 2060.
*The nucleus is not as simple as scientists thought in the 1930s. There are about 36 different types of particles in the nucleus.
*Hydrogen fusion induced by laser implosion was first achieved by KMS fusion in Ann Arbor, Mi in 1974. They caused enough fusion to occur to detect high-speed neutrons from the fusion reaction. They used a single laser. They didn't come close to breakeven, but they thought that the science was proven and now it was just a matter of using bigger lasers and investing more money. Fifty years and $3.5 billion later, 192 lasers produced 3 units of energy for 2 units of laser energy hitting the target. This was touted as "breakeven". Now experts are saying that the science is done and its just a matter of investing more money and using bigger lasers. However, it took about 300 units of power to run the lasers, so the fusion actually produced about 1% of the energy needed to power the lasers, not breakeven.
*A new scientific discovery is needed to make fusion practical. One approach is to find a nuclear "catalyst" that will make it easier for two positive nuclei to fuse. A promising approach is called **Muon-catalyzed fusion** but there is a lot more science to do to see if it works.

37

What experiences, insights or questions can you share with us?

References

- UV and cancer: Link
- Chart of the nuclides: Link
- Carbon 14 dating: Link
- US Navy: Link
- Chernobyl: Greenpeace, WHO2005, WHO2016
- China: 150 reactors
- Laser fusion: Link