Nuclear Chemistry

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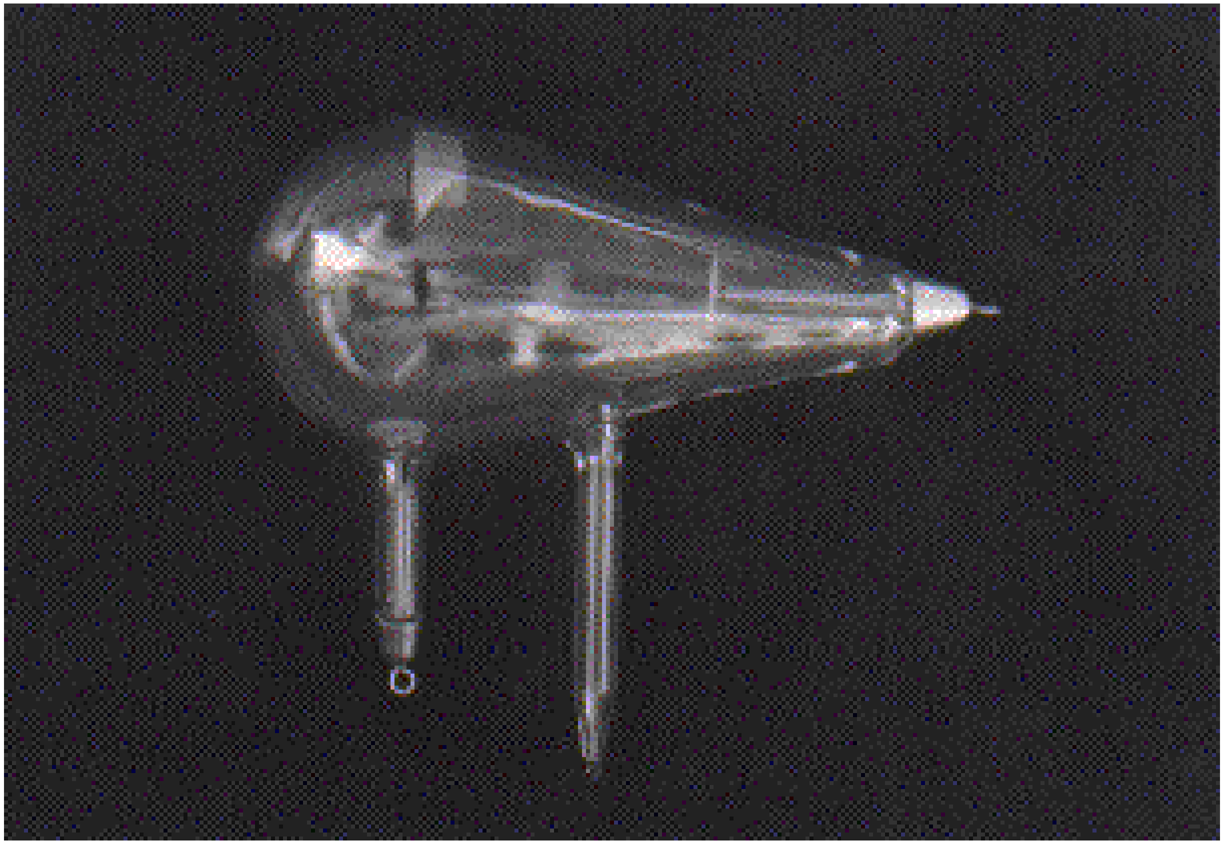
The Discovery of X-Rays and Radioactivity

Wilhelm Conrad Roentgen
1845-1923

In 1895, Roentgen was studying cathode ray tubes, of the type used by J. Plücker (1859), J. W. Hittorf (1869), William Crookes (1875), and E. Goldstein (1886). become well known.

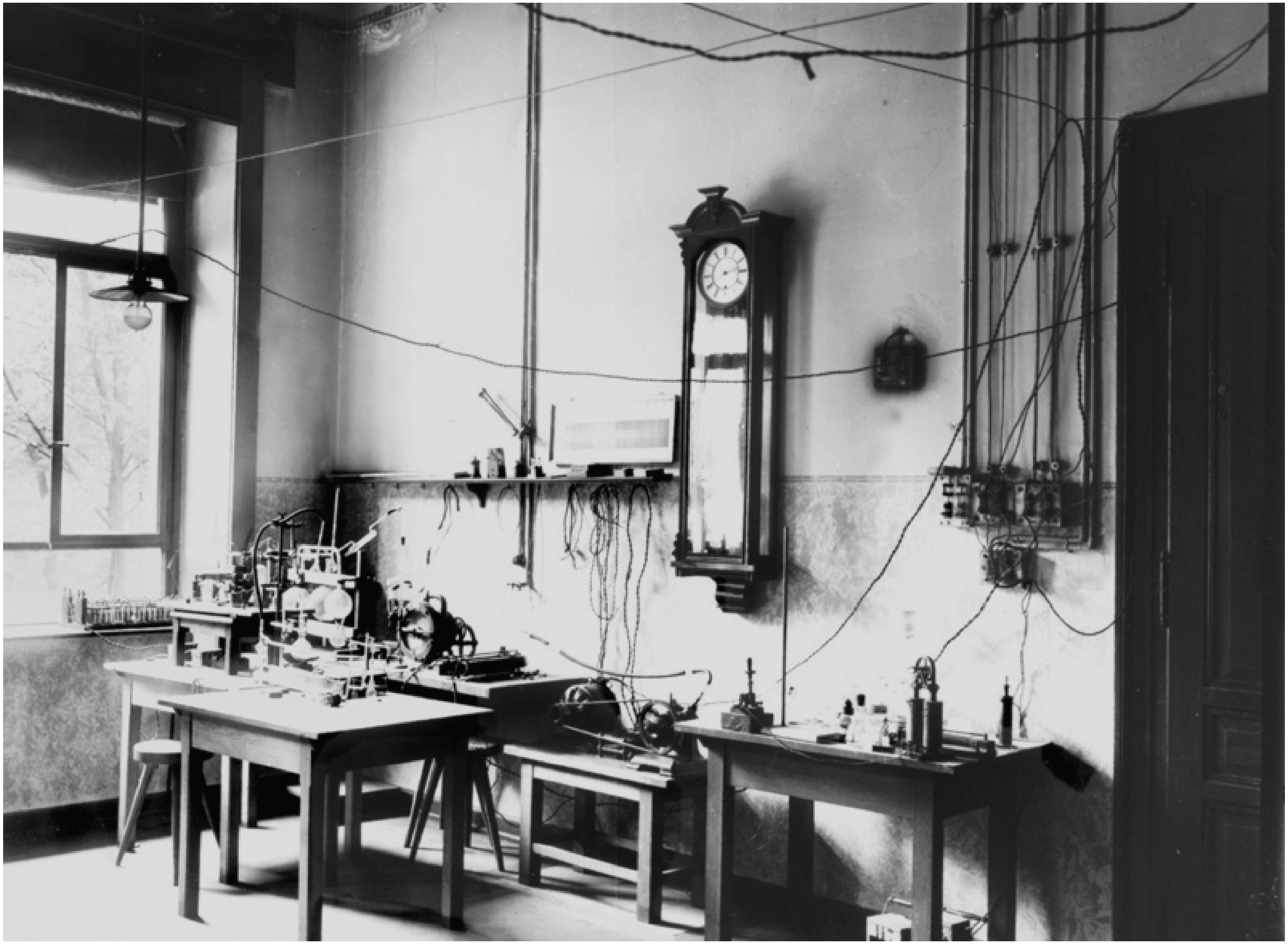


Roentgen's cathode ray tube

Roentgen’s Laboratory

Roentgen's Laboratory

University of Wurzburg, Germany



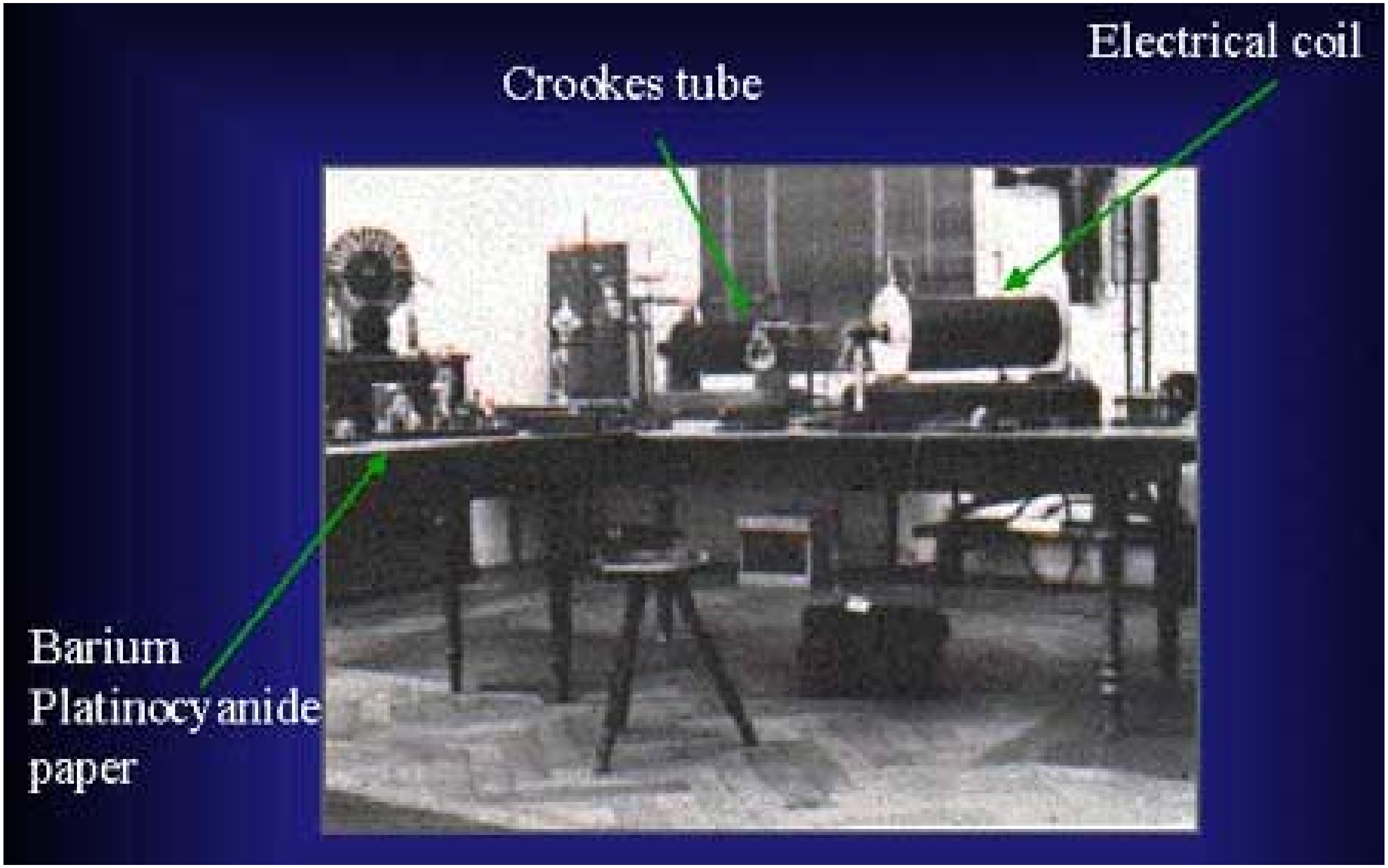
Roentgen’s laboratory (another view)

Roentgen in the laboratory

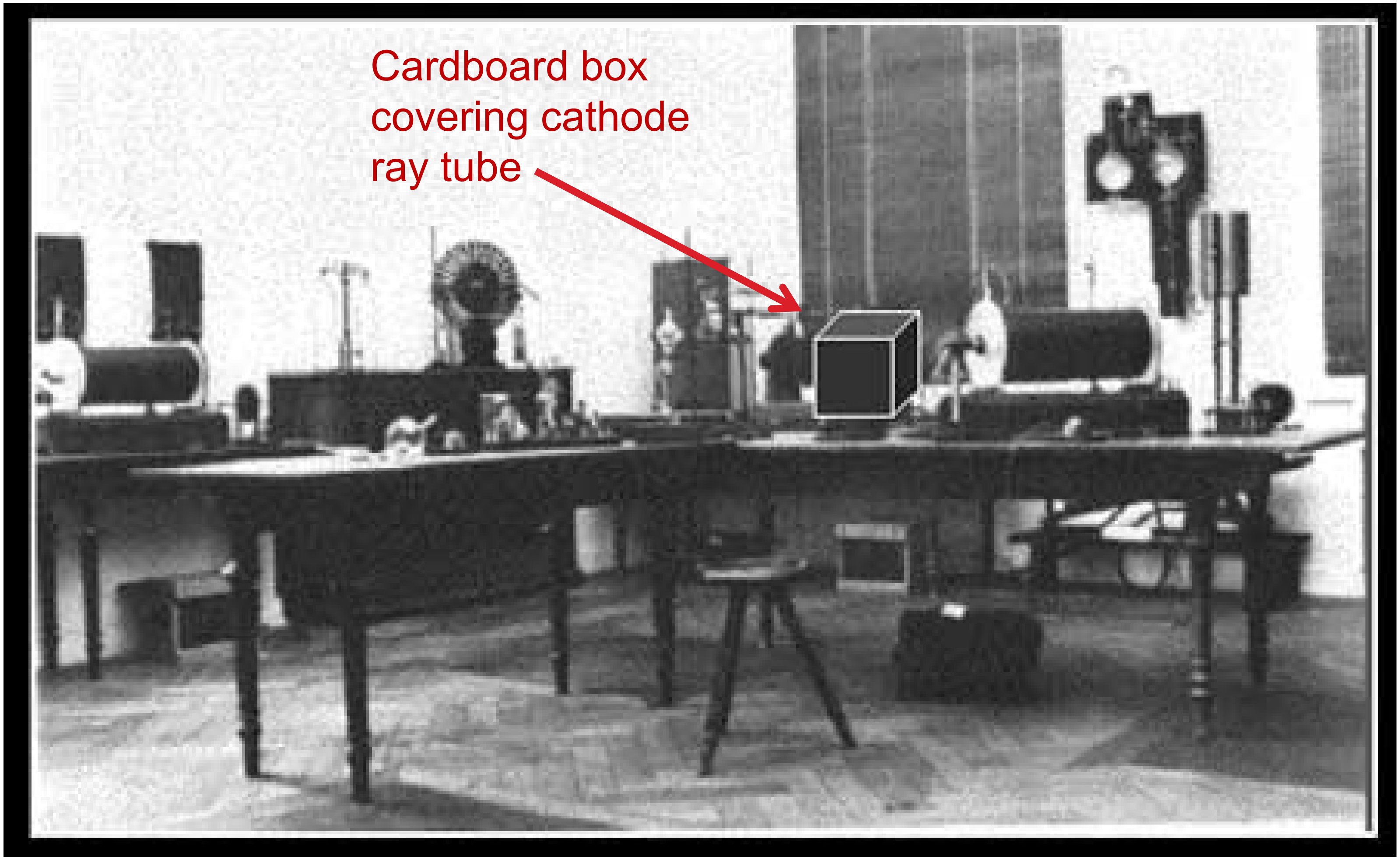
Roentgen noted that barium platinocyanide, painted on a sheet of paper, fluoresced when placed near the cathode ray tube.

barium platinocyanide crystals

a radiographic image produced by sprinkling some barium platinocyanide on photographic film.



The arrangement of apparatus in Roentgen's laboratory



On November 8, 1895, Roentgen had placed a cardboard box, covered with black paper, over the cathode ray tube to better see the glow of the tube. During the experiment, he noticed that the barium platinocyanide was still glowing, even though it was a distance away from the cathode ray tube and not in any direct line of sight of the tube.

Roentgen had his wife, Bertha, place her hand on a photographic plate and exposed it to the rays from the cathode ray tube.
When he developed the plate, he observed the shadows of the bones of her hand and that of the ring she was wearing.

Bertha Rontgen's Hand
8 Nov, 1895

Conducting further experiments, Roentgen concluded that there was a new kind of ray produced by the cathode ray tube that could pass through different objects to differing degrees.

He named these rays X-rays (after “x”, the unknown quantity in mathematical equations).

Roentgen announced his discovery in a paper read before the Würzburg Physical and Medical Society, in December1895.

Roentgen's Observed Properties of X-Rays

1. All bodies are transparent to x-rays, though in very different degrees.
2. Many bodies such as phosphorescent calcium compounds, uranium glass, ordinary glass, rock salt, etc. fluoresce under the influence of x-rays. Of special significance in many respects is the fact that photographic dry plates are sensitive to the x-rays.
3. X-rays cannot be refracted by a prism and they cannot be concentrated by lenses.
4. X-rays cannot be deflected by a magnet,
5. X-rays cannot be regularly reflected by any bodies.
6. X-rays cannot be polarized.
7. X-rays are produced where cathode rays strike the walls of the cathode ray tube or when cathode rays strike a metal surface.

Hand of Albert von Kolliker

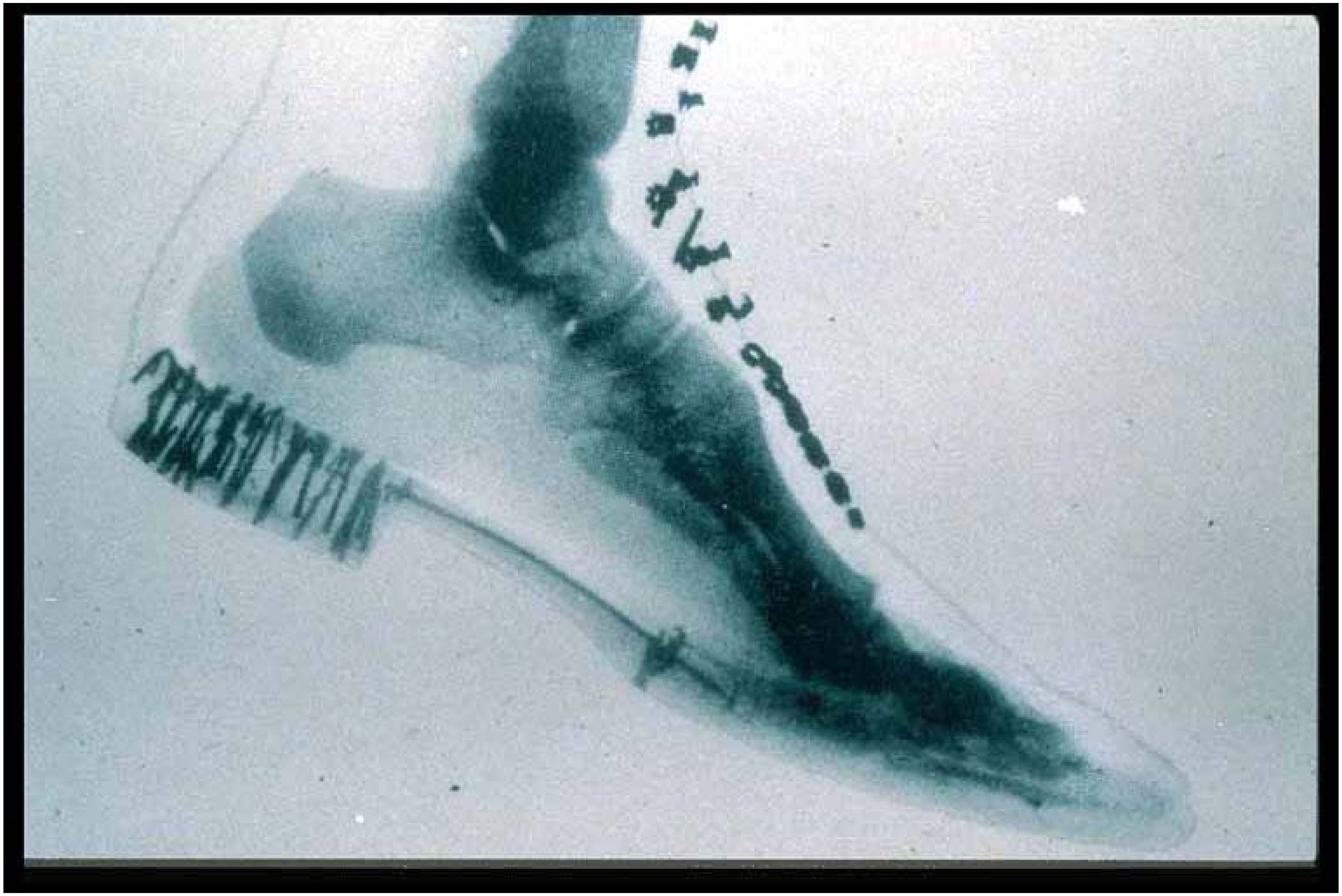
X-ray taken by Roentgen at the first public showing in January 1896

Reference: Conclusion of Wurzburg Physical-Medical Society

X-ray photo of hand of a cadaver made by Mr. Haschek and Dr. Lindenthal, in Professor Franz Exner's physicochemical institute in Vienna. To make the veins visible, the hand was injected with a mixture of lime (calcium oxide), cinnabar (mercury sulfide) and petroleum.

First x-ray in America by Dr. Michael Pupin at Columbia University, early February 1896, to aid in the surgical of more than 40 gunshot pellets embedded in the hand of a New York attorney as a result of a hunting accident

Dr. Michael Pupin
1858 - 1935



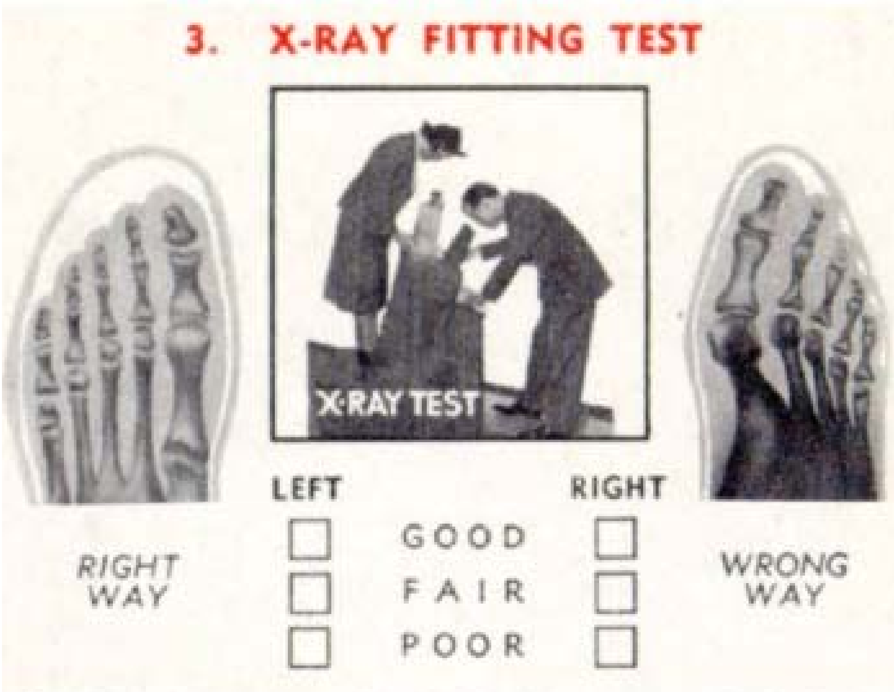
X-ray by Francis Williams - Boston, 1896

Shoe fitting x-ray device

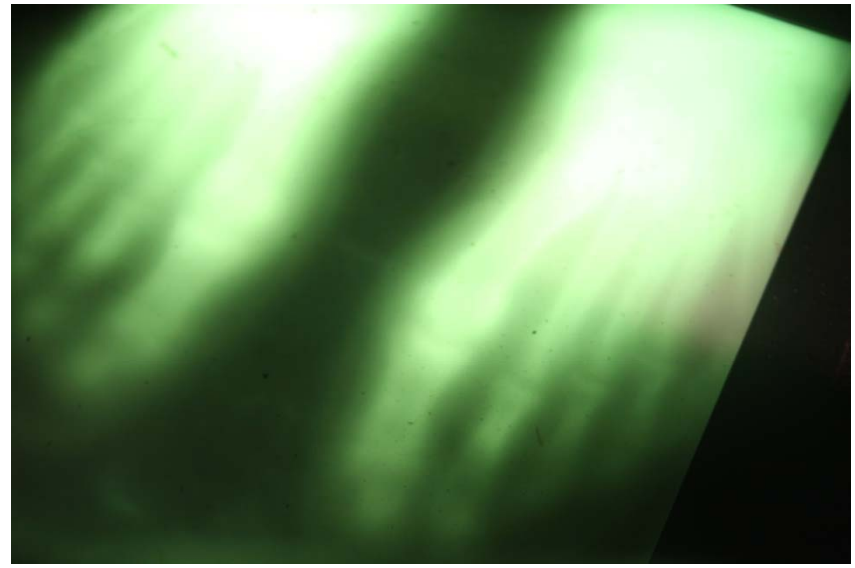
Invented in late 1940's

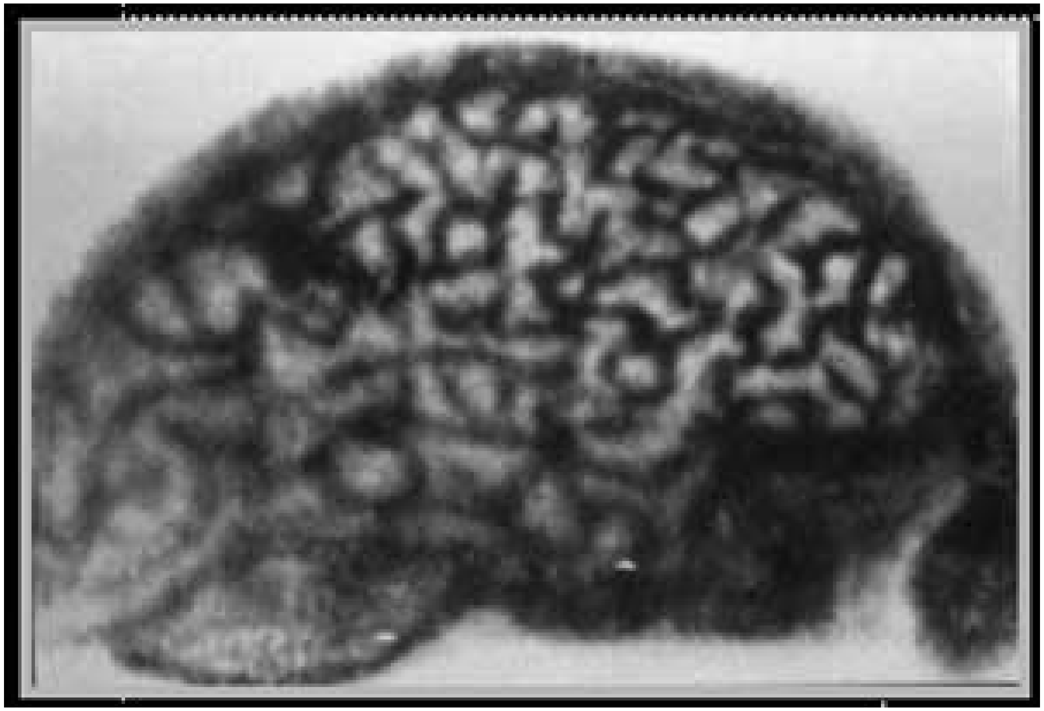
Banned in 1970's

See a video of x-ray shoe fitting on YouTube
http://www.youtube.com/watch?v=wbMN6jueU1A



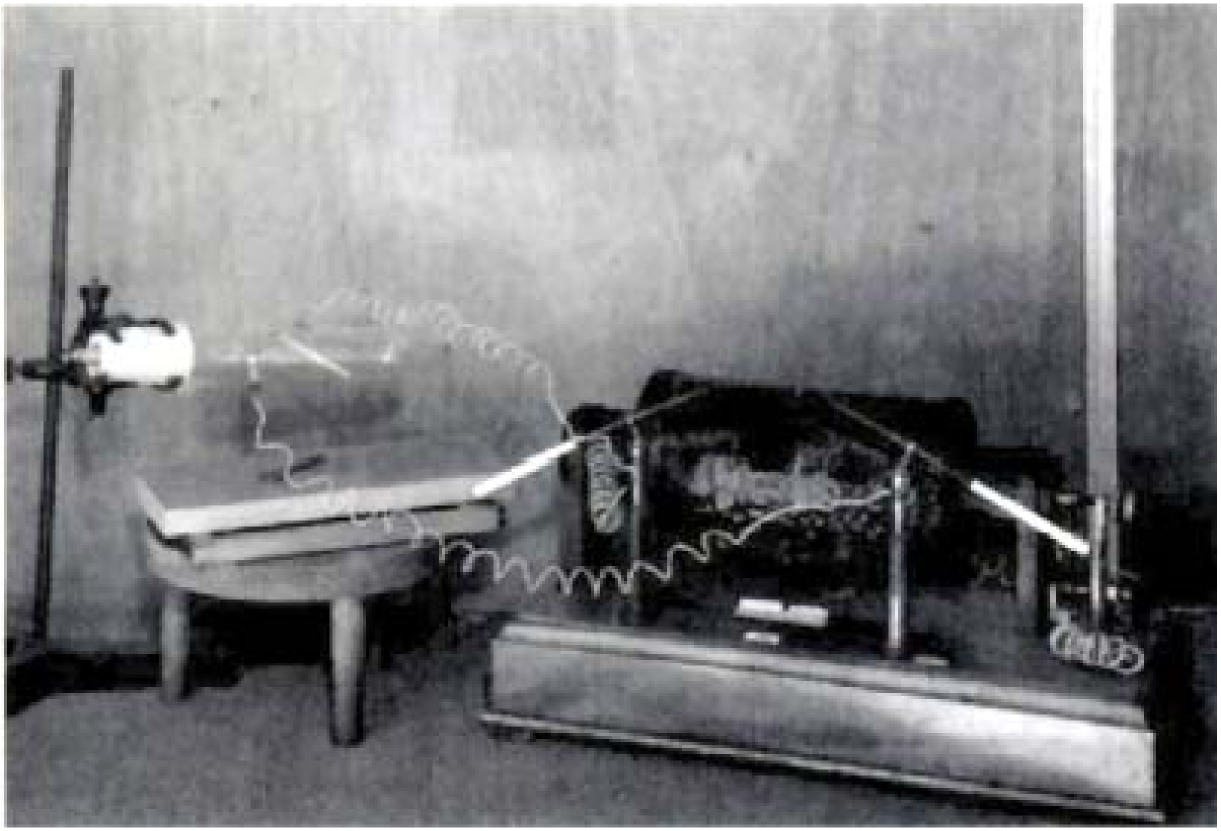
Detail from shoecard possibly distributed by salesmen to their clients, showing both X-ray images of feet in shoes and a fluourscope in use. (Image courtesy of Oak Ridge Associated Universities)



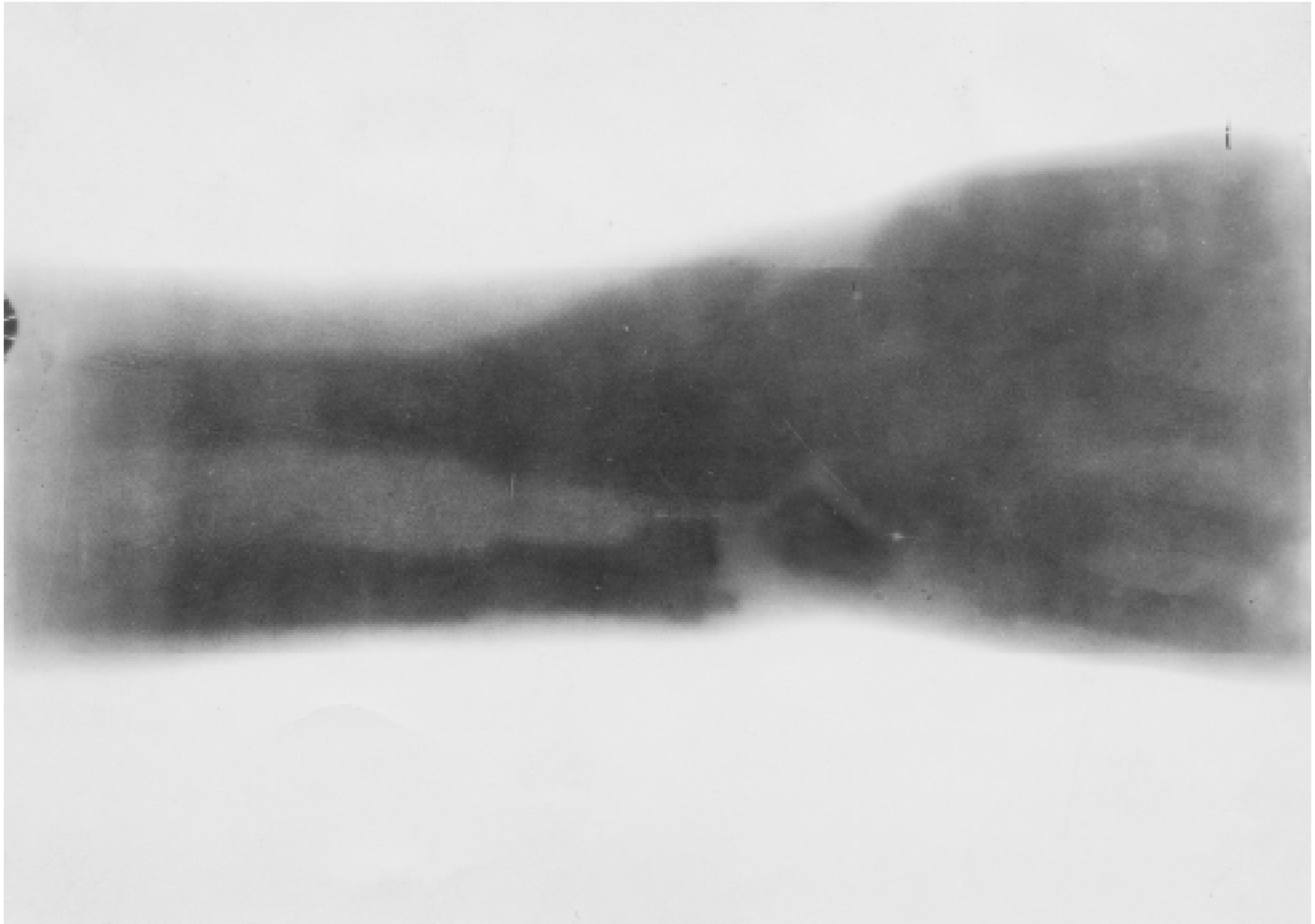


"First radiograph of human brain"
H.A. Falk 1896

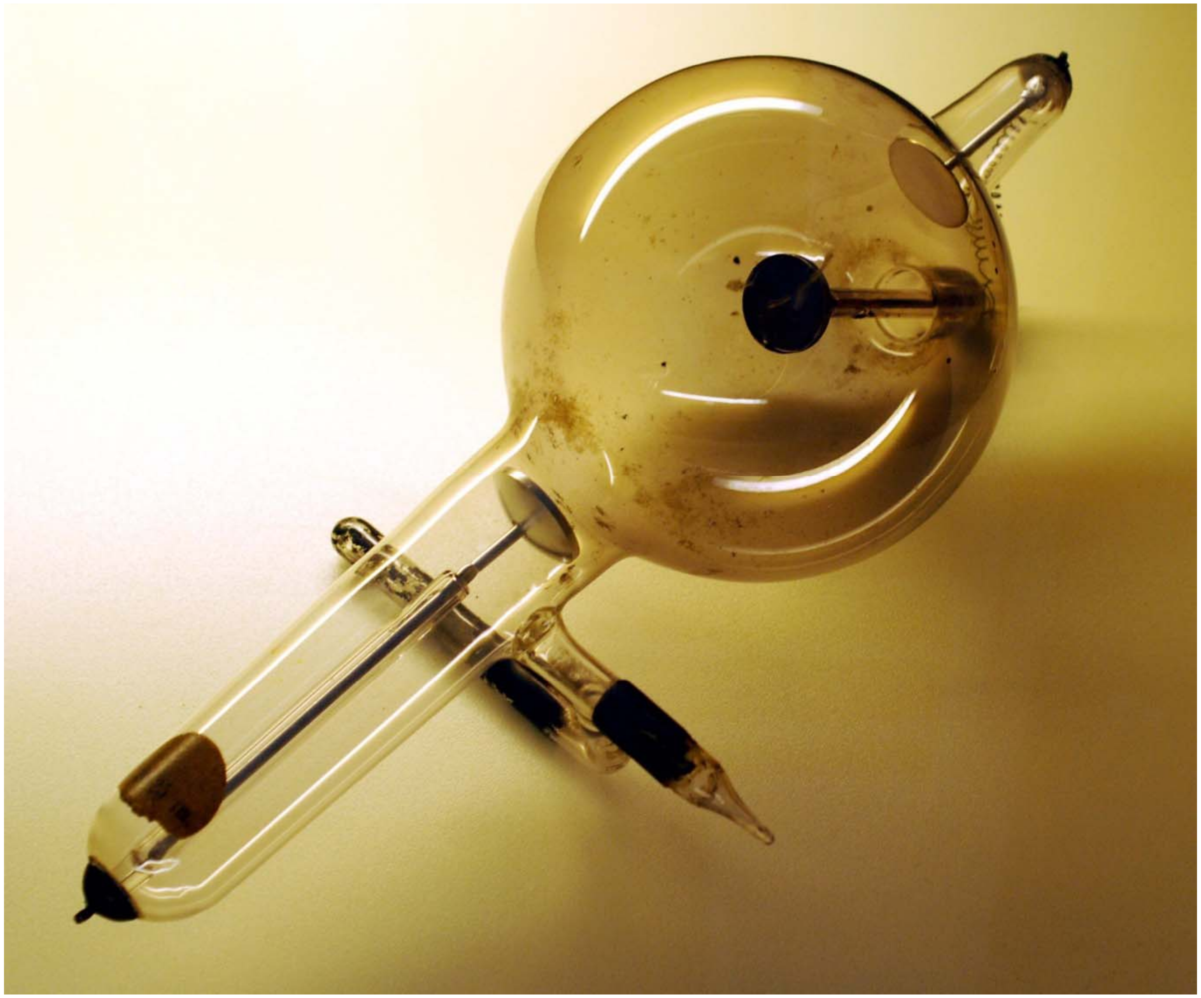
Dr. Edwin Frost (right) and his brother Dr. Gilman Frost (standing) x-ray the fractured arm of a young patient at Dartmouth College, February 3, 1896. Apparatus consists of a battery, a cathode ray tube, and an induction coil. Photographic film is under the boy’s arm. Exposure time was 20 minutes.



Frost’s x-ray tube set-up. This was also known as a Puluj tube, developed by Ivan Puluj as a phosphorescent lamp in 1881. Originally developed as a reading light source, it was later found that the mica plate coated with a phosphorescent material produced a high level of x-rays.



The x-ray of the fractured ulna of 14-year-old Eddie McCarthy at Dartmouth College, February 3, 1896.



An early x-ray tube

The public was fascinated by these “new” x-rays.
It became a novelty to visit an x-ray studio and get an x-ray photograph of one’s hand.

In an x-ray laboratory, a doctor could use a fluorescent screen to view the internal skeleton and organs of a patient. (The x-ray tube is in front of the patient.)

Effect of overexposure to x-rays.

The danger of x-rays was not realized for a number of years.

Roentgen died in 1923 of carcinoma of the intestine. Since Roentgen only worked for a brief time with x-rays, and because he used protective lead shields in his later studies, it is believed his carcinoma was not the result of his work with ionizing radiation.

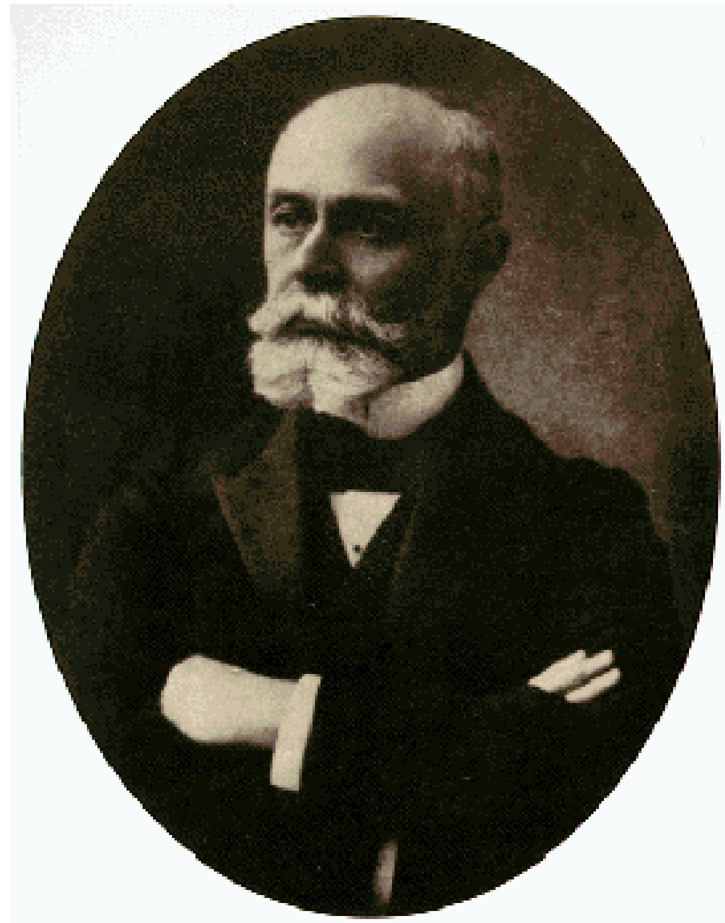
Learning of x-rays, Antoine Henri Becquerel decided to investigate whether there was any connection between X-rays and naturally occurring phosphorescence.

Using uranium salts, which phosphoresce on exposure to sunlight, Becquerel placed them on a photographic plate covered with opaque paper.

When the plate was developed, it was discovered to be fogged.

After storing a prepared photographic plate away from any bright sunlight, Becquerel found that the plate was still fogged.

He concluded some kind of radiation activity was coming from the uranium minerals.



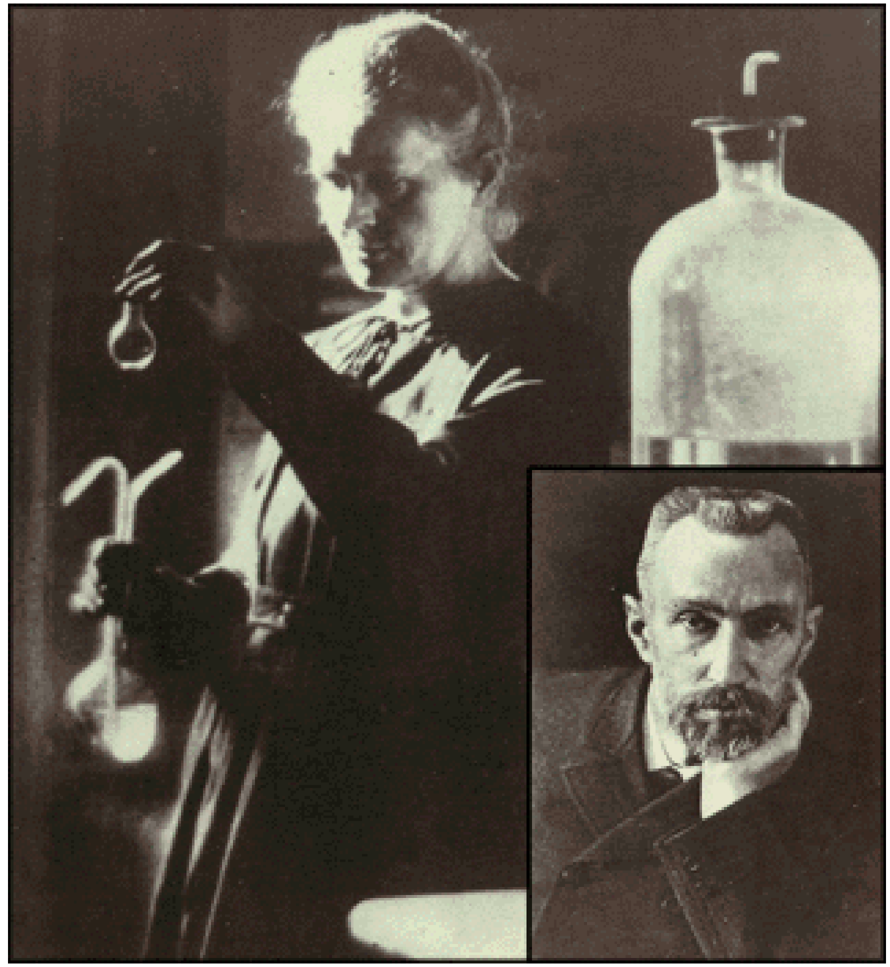
Antoine Henri Becquerel

1852-1908

Becquerel’s photographic plate
with image of
potassium uranyl sulfate

Marie Sklodowska Curie and her husband, Pierre Curie investigated the mineral pitchblende to determine what substance was responsible for the radiation activity.

Obtaining a gift of 100 kg of pitchblende from a mine in Jachymov, Czechoslovakia, they analyzed it to find two new elements, polonium, announced in July 1898, and radium, announced on December 26, 1898.

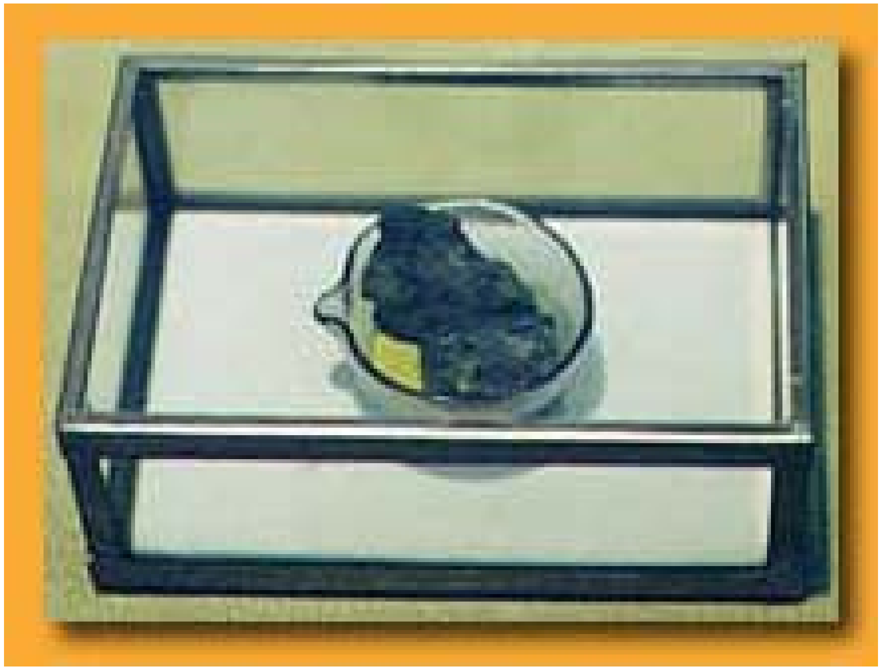


Marie Sklodowska Curie
with inset photo of Pierre Curie
Pierre Curie (1859-1906)
Marie Curie (1867-1934)

The lab where Marie Curie isolated radium.
She referred to it as the “miserable old shed”.

The courtyard where Marie and her assistant did chemical treatments that emitted noxious gases.

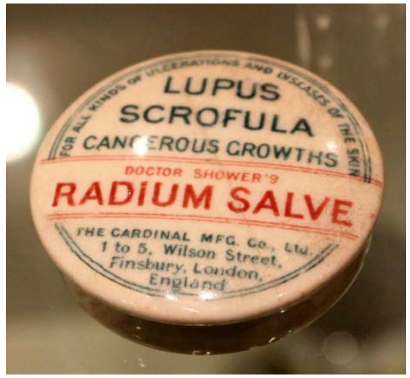
Electroscope used to measure radioactivity
developed by Pierre Curie and his brother

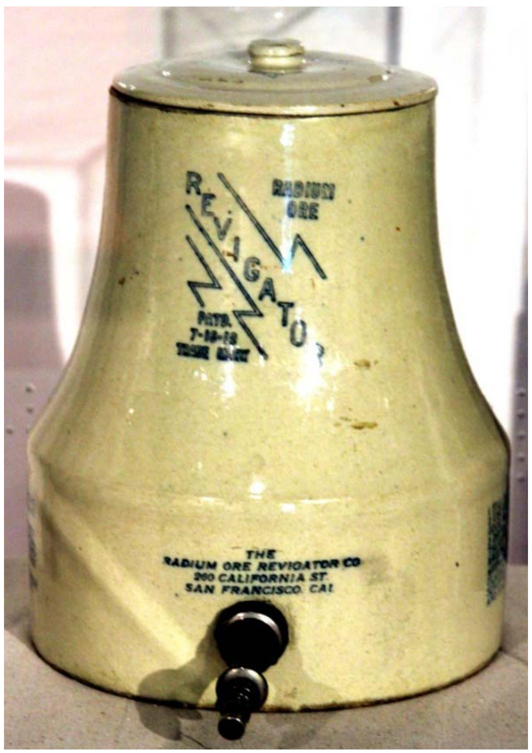


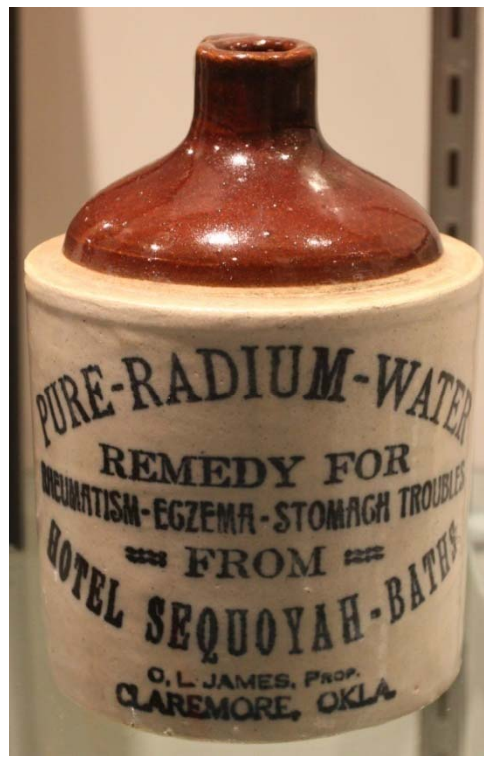
A pitchblende sample used by the Curies that led to the discovery of radium and polonium.

Radium bromide
Shown in the dark

Radium – The Miracle



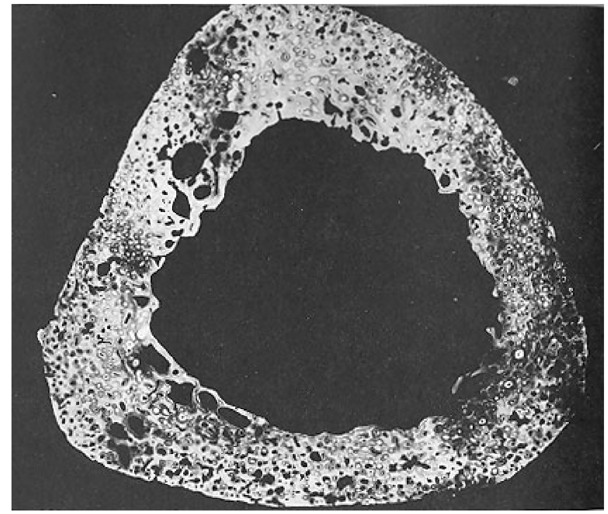


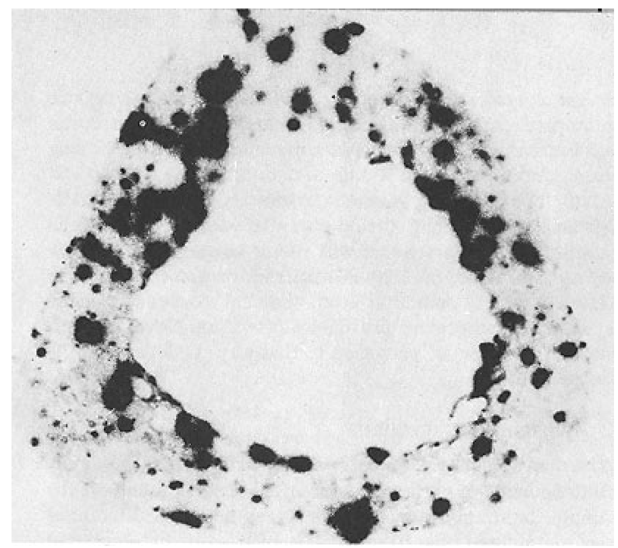


Radium Palace - Jachymov

Radium for Clocks and Watches

Radium for Clocks and Watches





Above: Radium watch dial painters used thin bristled brushes to paint the numbers and hands on clocks and watches. To keep the tip of the brush sharp, they would touch the brush to their tongue.

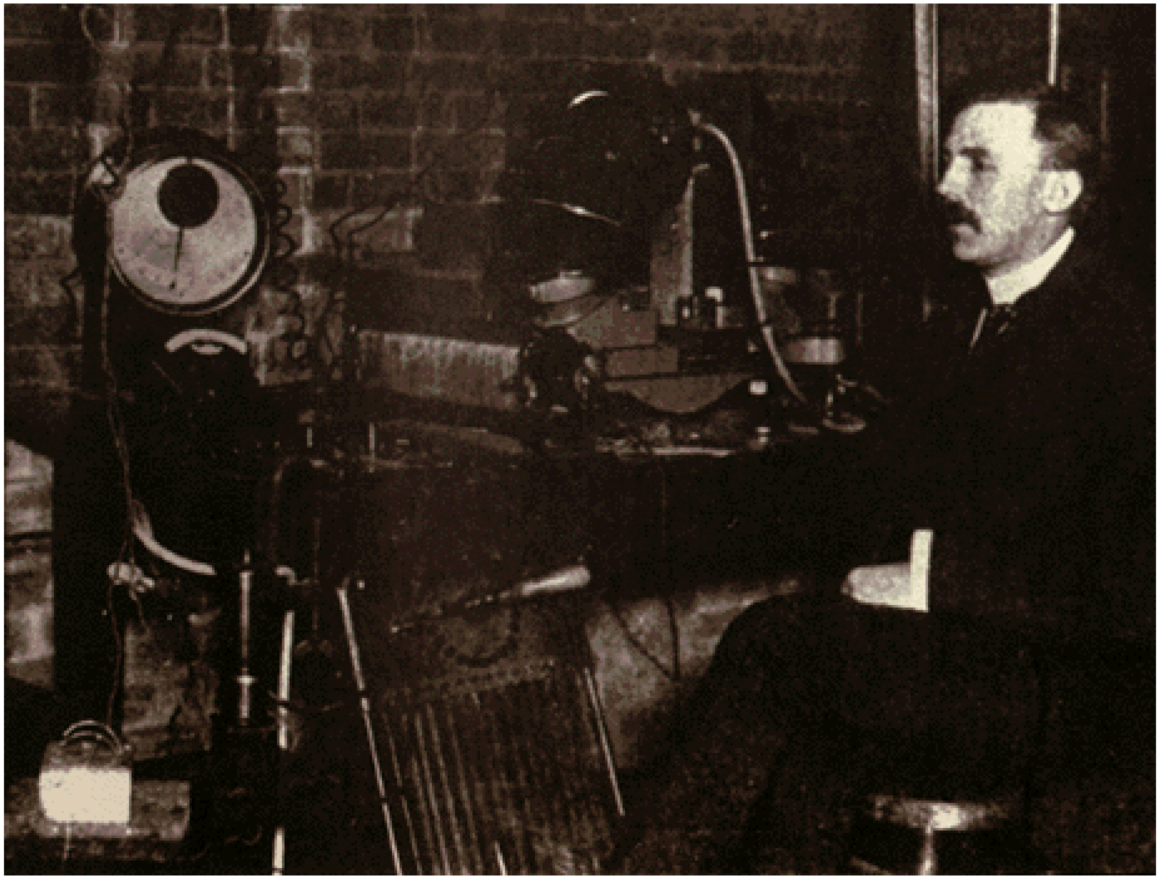
Top right: A section of bone from a radium watch-dial painter. Darken areas are damaged bone.

Bottom right: An autoradiograph of the same section of bone held against photographic film

Radiation Rage

Orange Fiesta ware

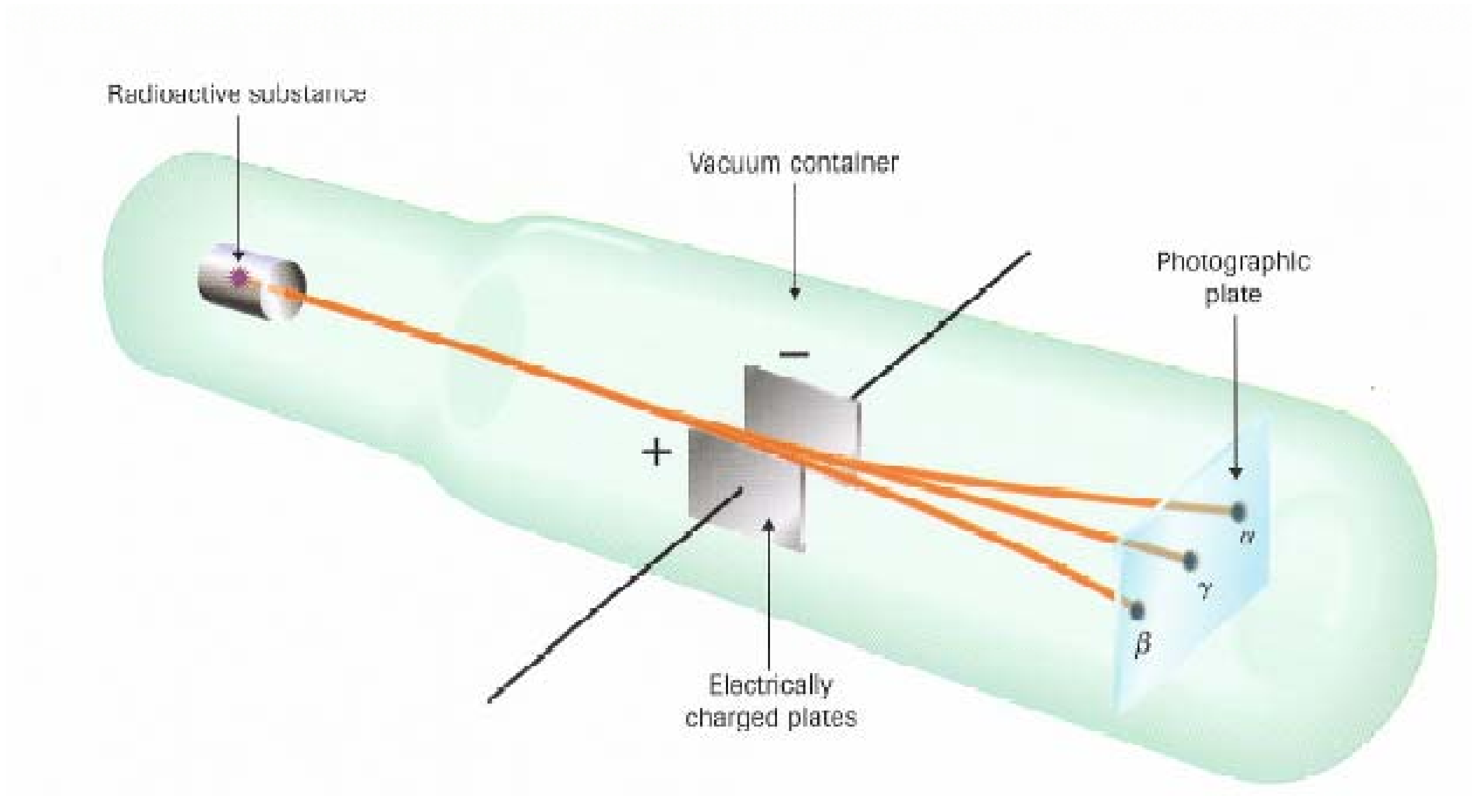
Uranium glass



Ernest Rutherford

In his lab at McGill University, 1903

1871-1937



Rutherford's experiment identifying α, β, and γ particles

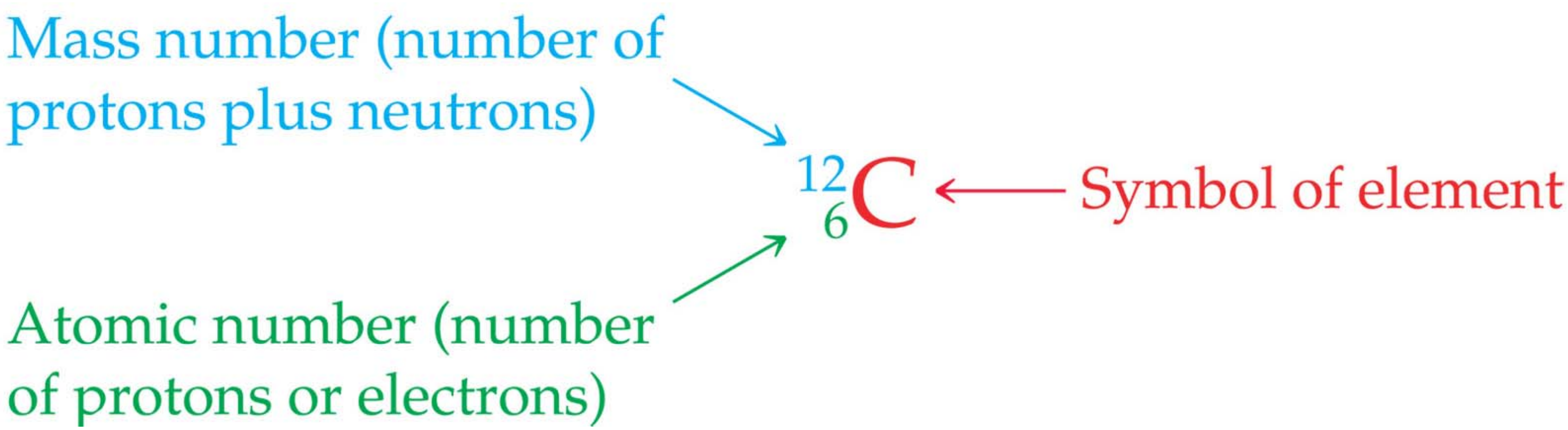
In 1898, using metallic uranium or an ore of uranium, Rutherford showed that the radiation could be split into three pieces which he called alpha, beta, and gamma.

The Nucleus

And

Nuclear Radiation

The Nucleus



- Remember that the nucleus is comprised of the two **nucleons (i.e., nuclear particles)**, protons and neutrons.
- The number of protons is the atomic number.
- The number of protons and neutrons together is effectively the mass of the atom.

Isotopes

- Not all atoms of the same element have the same mass due to different numbers of neutrons in those atoms.
- They all have the same number of protons.
- There are three naturally occurring isotopes of uranium:
  - Uranium-234
  - Uranium-235
  - Uranium-238

Isotopes

- The three naturally occurring isotopes of uranium:
  - Uranium-234
    - Contains 92 protons and 142 neutrons
  - Uranium-235
    - Contains 92 protons and 143 neutrons
  - Uranium-238
    - Contains 92 protons and 146 neutrons

Radioactivity

- It is not uncommon for some nuclides of an element to be unstable, or **radioactive**.
- We refer to these as **radionuclides**.
- There are several ways radionuclides can decay into a different nuclide.

Particles from Radioactive Decay

α-particle: **consist of $^{4}_{2}He^{2+}$ ions**

Penetration: stopped by a piece of paper

β-particle: **consist of electrons**

Penetration: a few mm into human skin

γ-rays: **high energy x-rays**

Penetration: stopped by metals (depends on energy of rays and thickness of metals)

Types of Radioactive Decay

Alpha Decay:

Loss of an α-particle (a helium nucleus)

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

$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

Note that the 2+ charge of the α-particle is not shown

Beta Decay:

Loss of a β-particle (a high energy electron)

$$^{0}_{-1}\beta \quad \text{or} \quad ^{0}_{-1}\text{e}$$

$$^{131}_{53}\text{I} \longrightarrow \, ^{131}_{54}\text{Xe} + \, ^{0}_{-1}\text{e}$$

Mechanism of β decay:

$$^{1}_{0}n \rightarrow \, ^{1}_{1}p + \, ^{0}_{-1}e$$

a neutron decays into a proton and an electron

Positron Emission:

Loss of a positron (a particle that has the same mass as but opposite charge than an electron)

$${}^{0}_{1}e$$

$${}^{11}_{6}C \longrightarrow {}^{11}_{5}B + {}^{0}_{1}e$$

Mechanism of positron emission:

$${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}e$$

A proton decays into a neutron and a positive electron

Gamma Emission:

Loss of a γ-ray (high-energy radiation that almost always accompanies the loss of a nuclear particle)

$$^{0}_{0}\gamma$$

Electron Capture (K-Capture)

Addition of an electron to a proton in the nucleus

- As a result, a proton is transformed into a neutron.

$$ {}^{1}_{1}p + {}^{0}_{-1}e \longrightarrow {}^{1}_{0}n $$

How to Solve a Nuclear Equation

Example: Solve the following nuclear equation:

$$^{226}_{88}\text{Ra} \rightarrow {}^{4}_{2}\text{He} + ?$$

In a nuclear reaction, there is always a release of energy resulting in a slight mass defect (i.e., a loss of mass). Since the loss of mass is very small, we will assume there is no loss of mass or charge.

Therefore, **the sum of the masses on the left side of the equation must equal the sum of the masses on the right side. The same is true for the charges.**

Ra-226 lost an alpha particle, with a charge of 2 and a mass of 4. The resulting daughter has the formula:

$$^{A}_{Z}\text{X}$$

where: A = the mass number
Z = the atomic number

A = 226 – 4 = 222
Z = 88 – 2 = 86

How to Solve a Nuclear Equation

On the periodic table, the element with an atomic number of 86 is Rn. Thus, the daughter is:

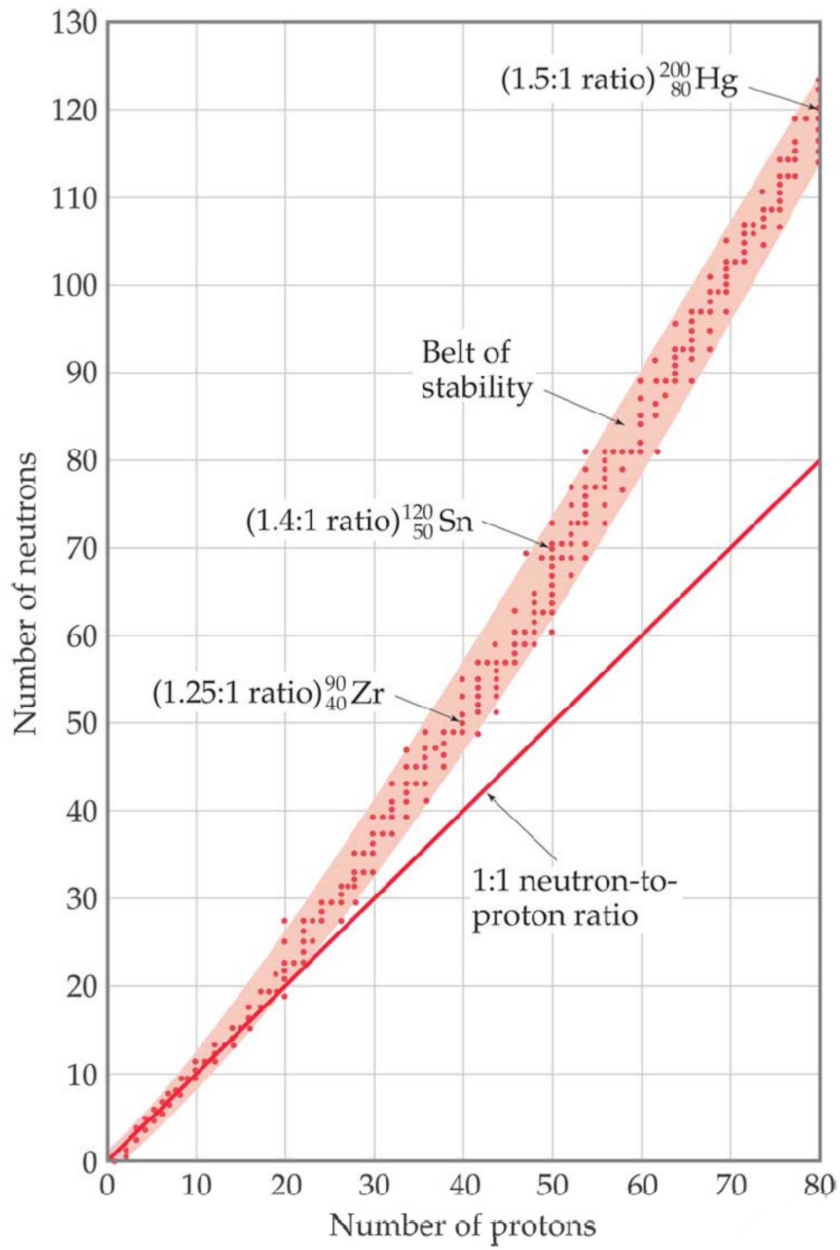
$$^{222}_{86}\text{Rn}$$

The completed nuclear equation is

$$^{226}_{88}\text{Ra} \rightarrow {}^{4}_{2}\text{He} + {}^{222}_{86}\text{Rn}$$

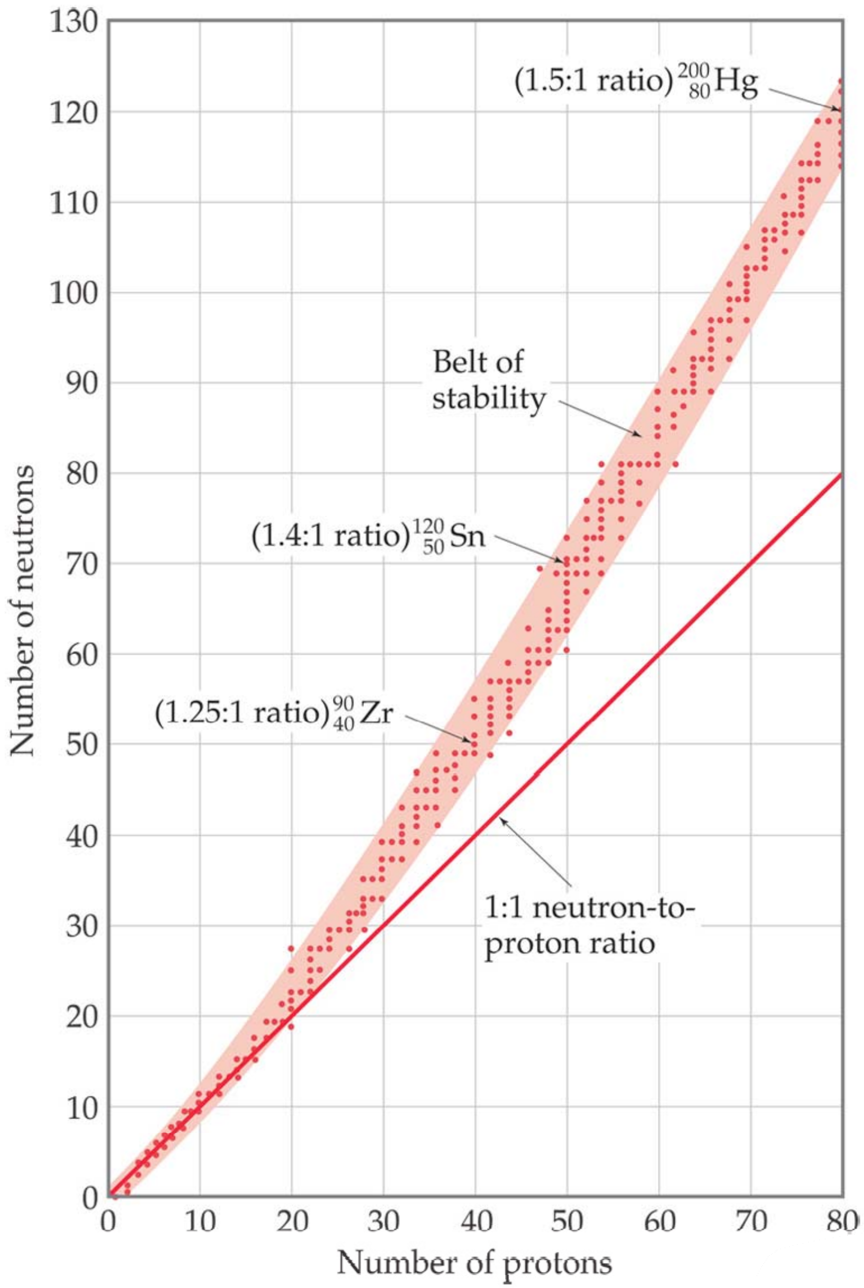
Neutron-Proton Ratios

- Any element with more than one proton (i.e., anything but hydrogen) will have repulsions between the protons in the nucleus.
- A **strong nuclear force** helps keep the nucleus from flying apart.



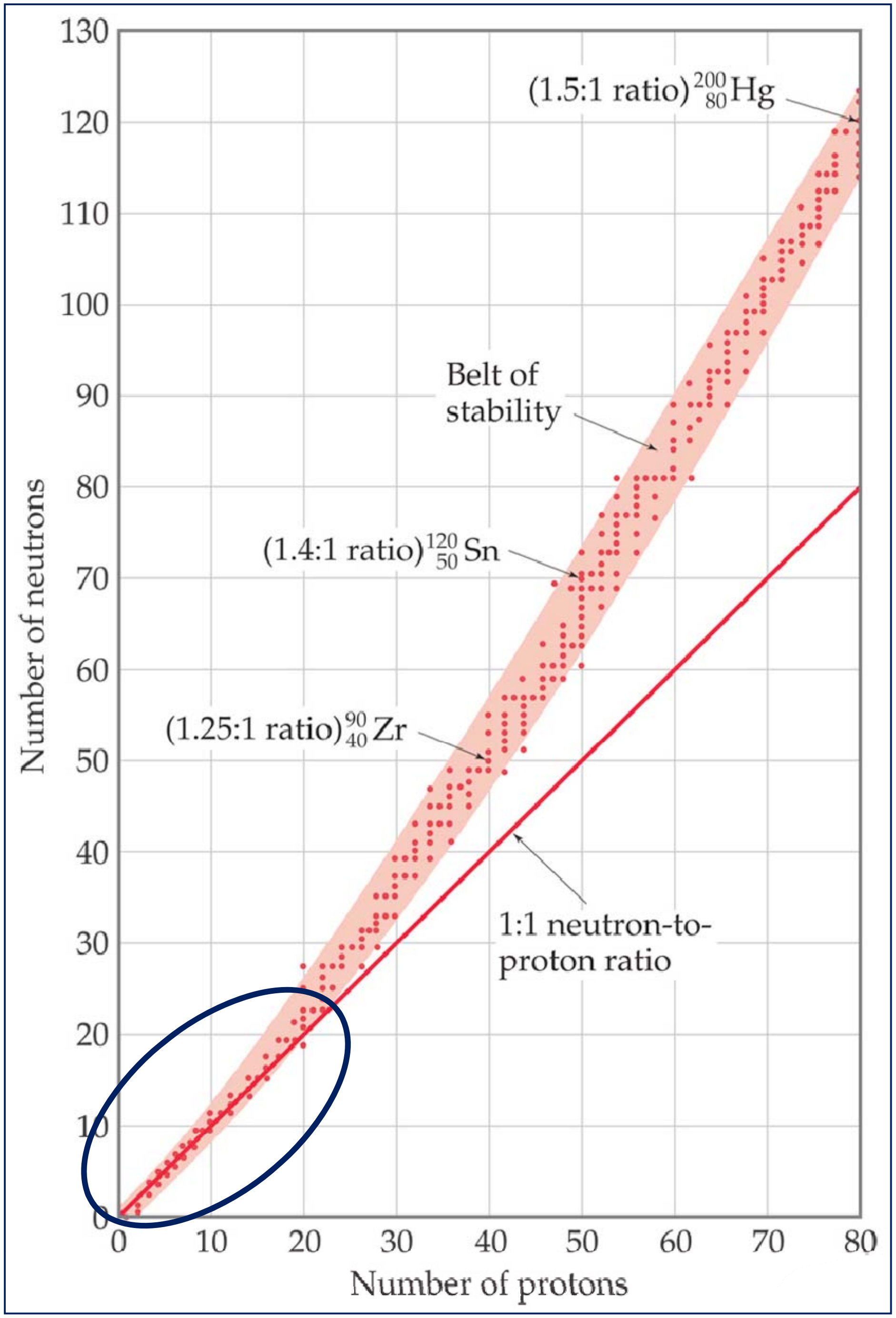
Neutron-Proton Ratios

- Neutrons play a key role stabilizing the nucleus. (think of neutrons as sort of a nuclear "glue")
- Therefore, the ratio of neutrons to protons is an important factor.



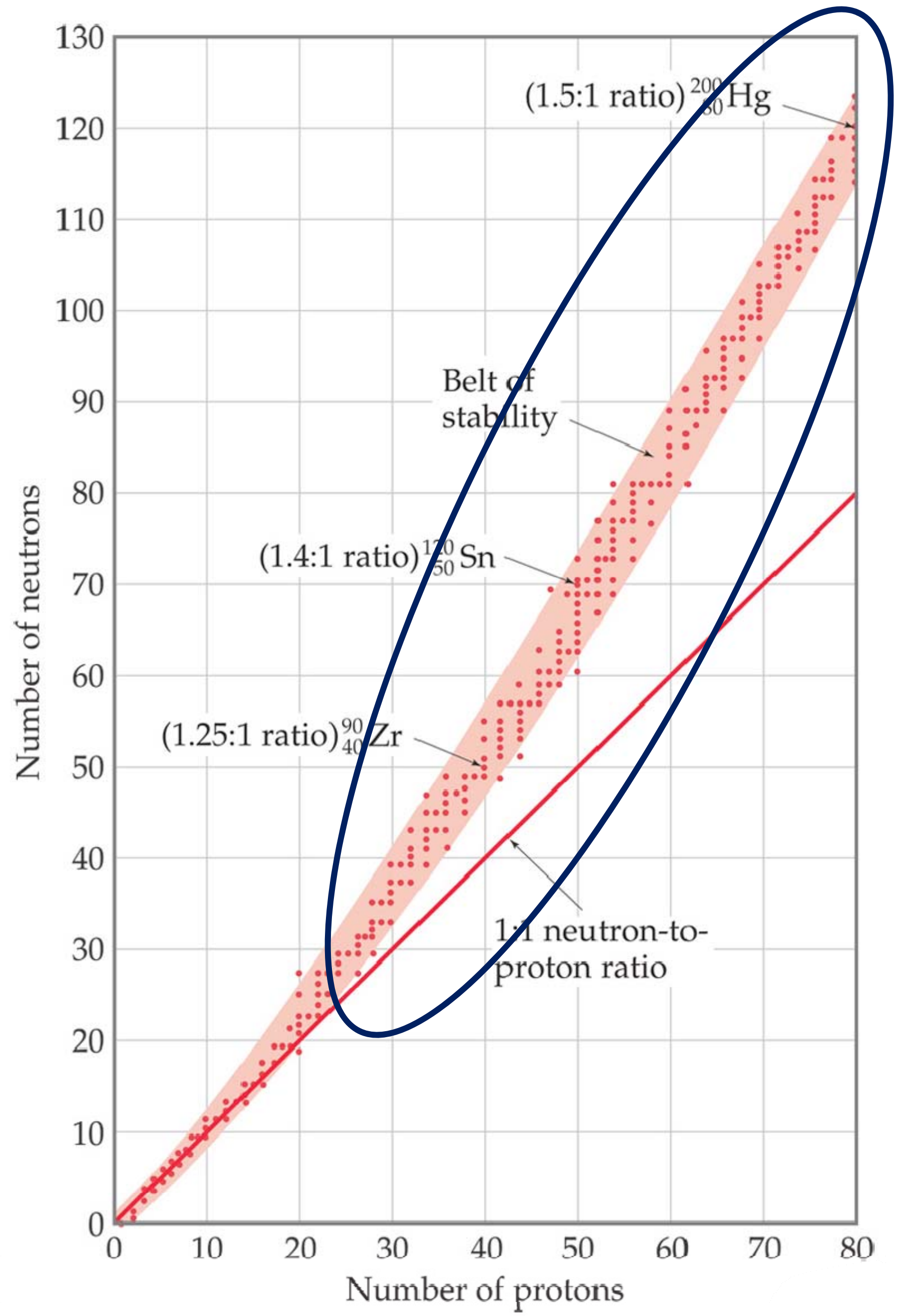
Neutron-Proton Ratios

For smaller nuclei ($Z \leq 20$) stable nuclei have a neutron-to-proton ratio close to 1:1.



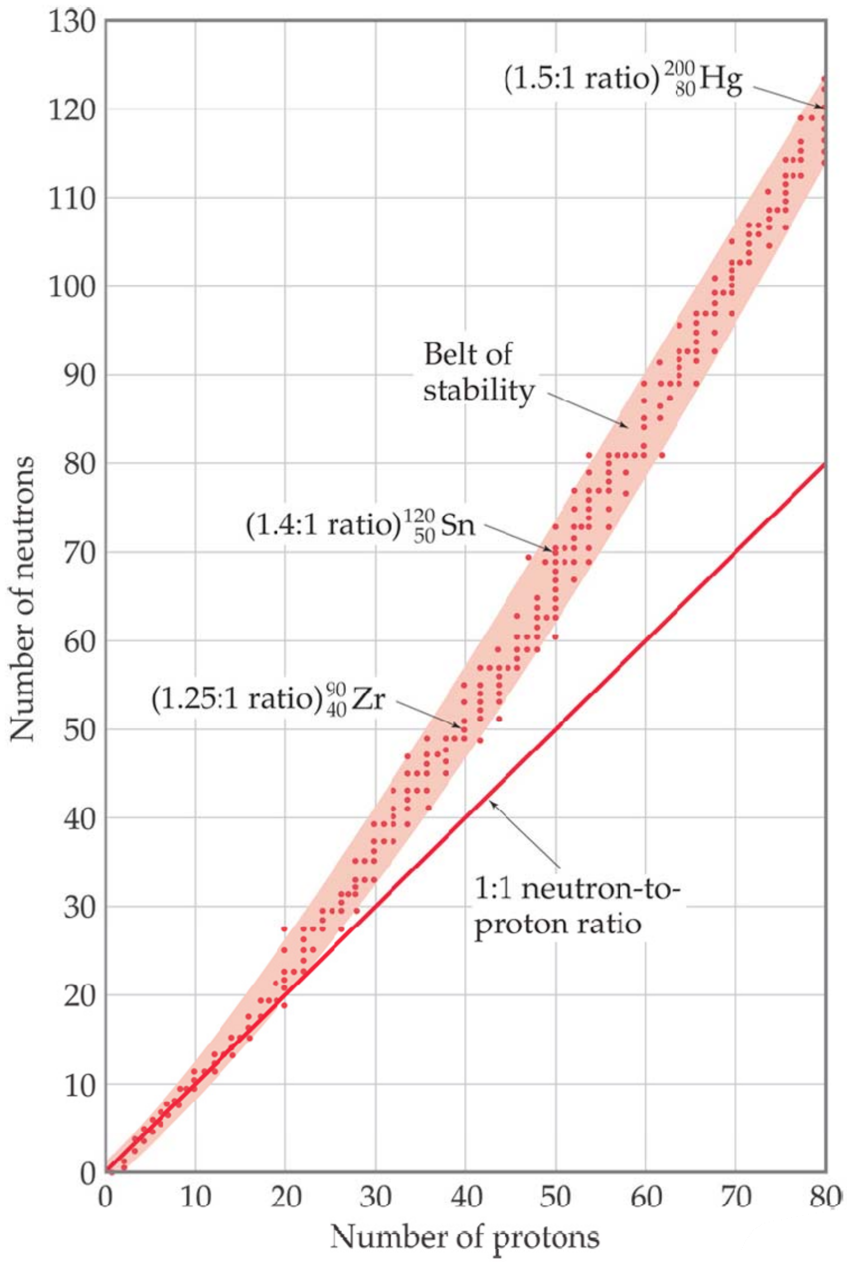
Neutron-Proton Ratios

As nuclei get larger, it takes a greater number of neutrons to stabilize the nucleus.



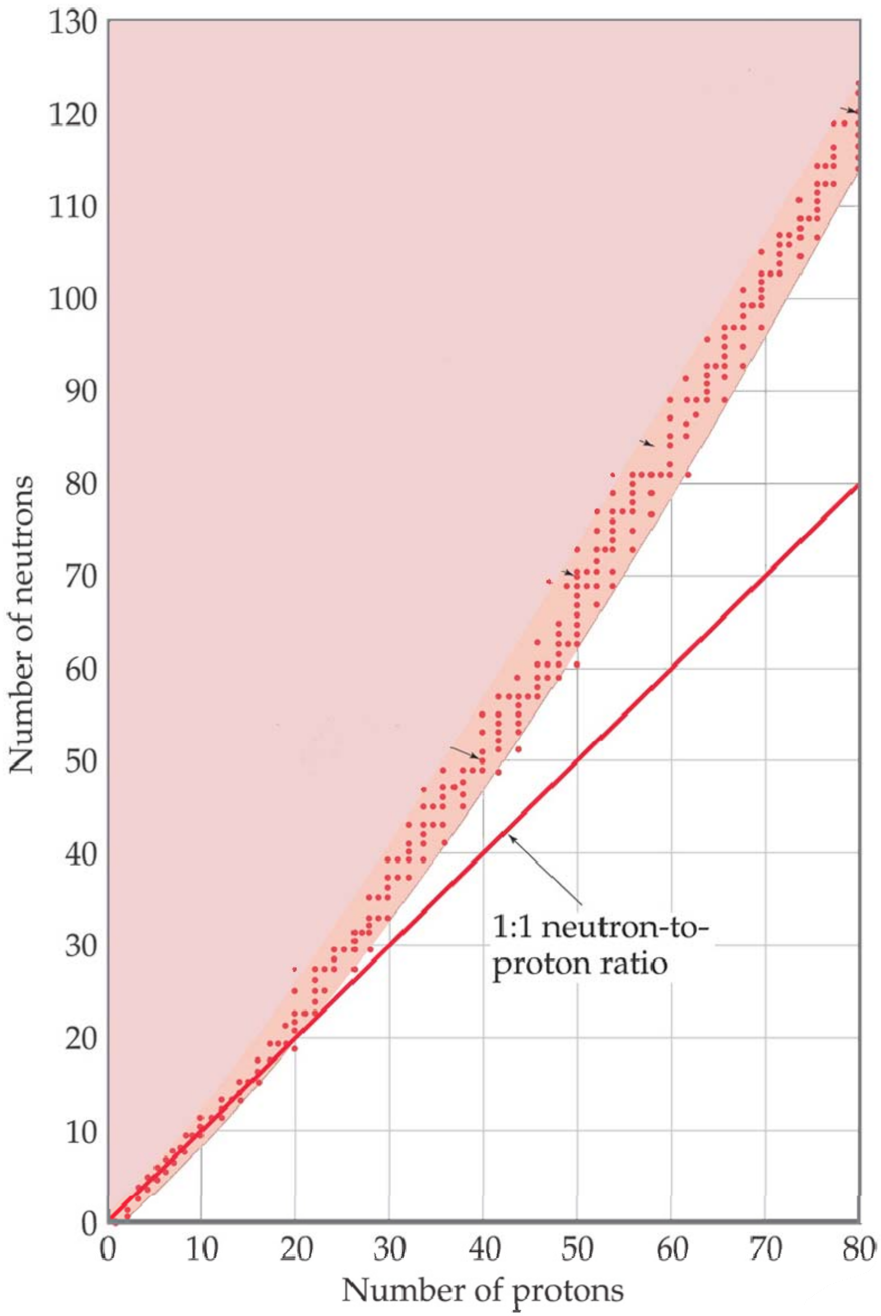
Stable Nuclei

The shaded region in the figure shows what nuclides would be stable, the so-called **belt of stability**.



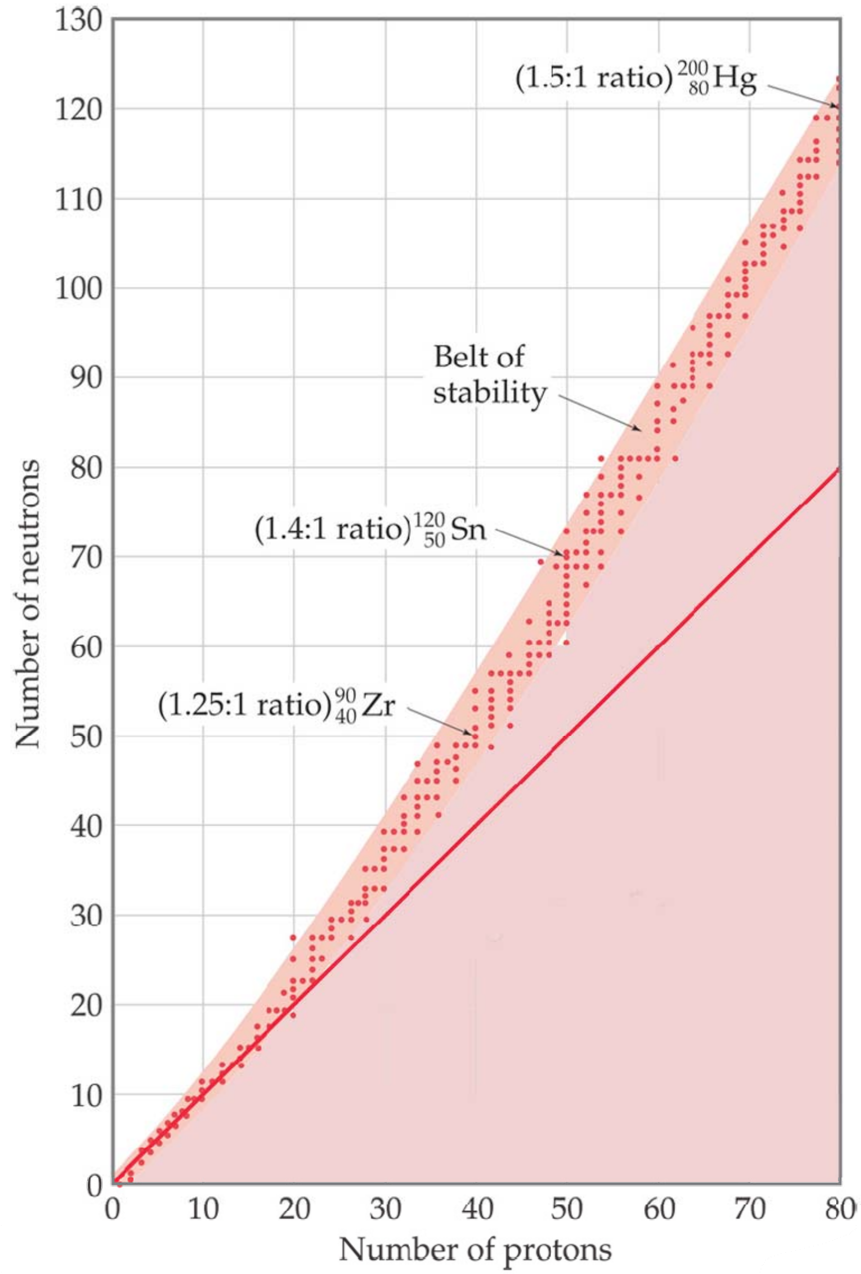
Stable Nuclei

- Nuclei above this belt have too many neutrons.
- They tend to decay by emitting **beta particles.**



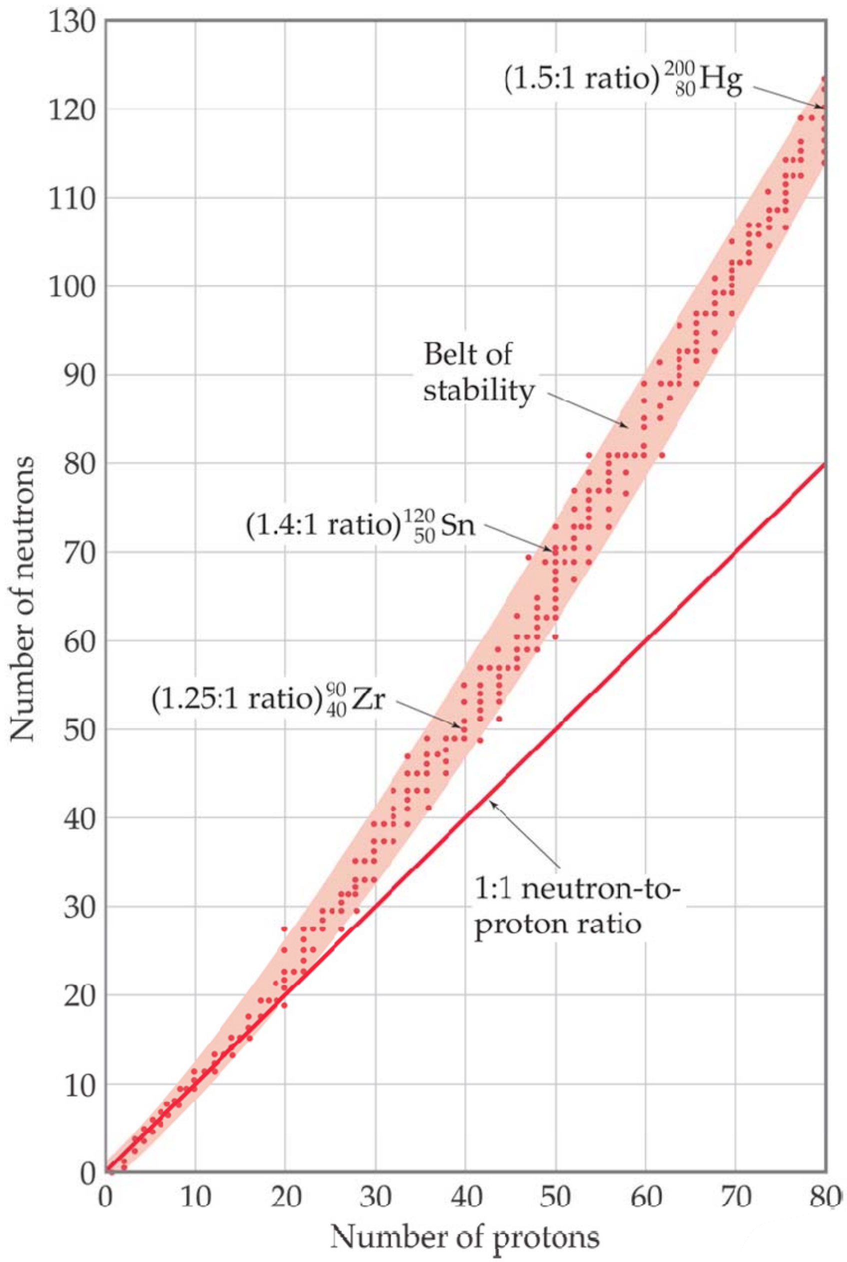
Stable Nuclei

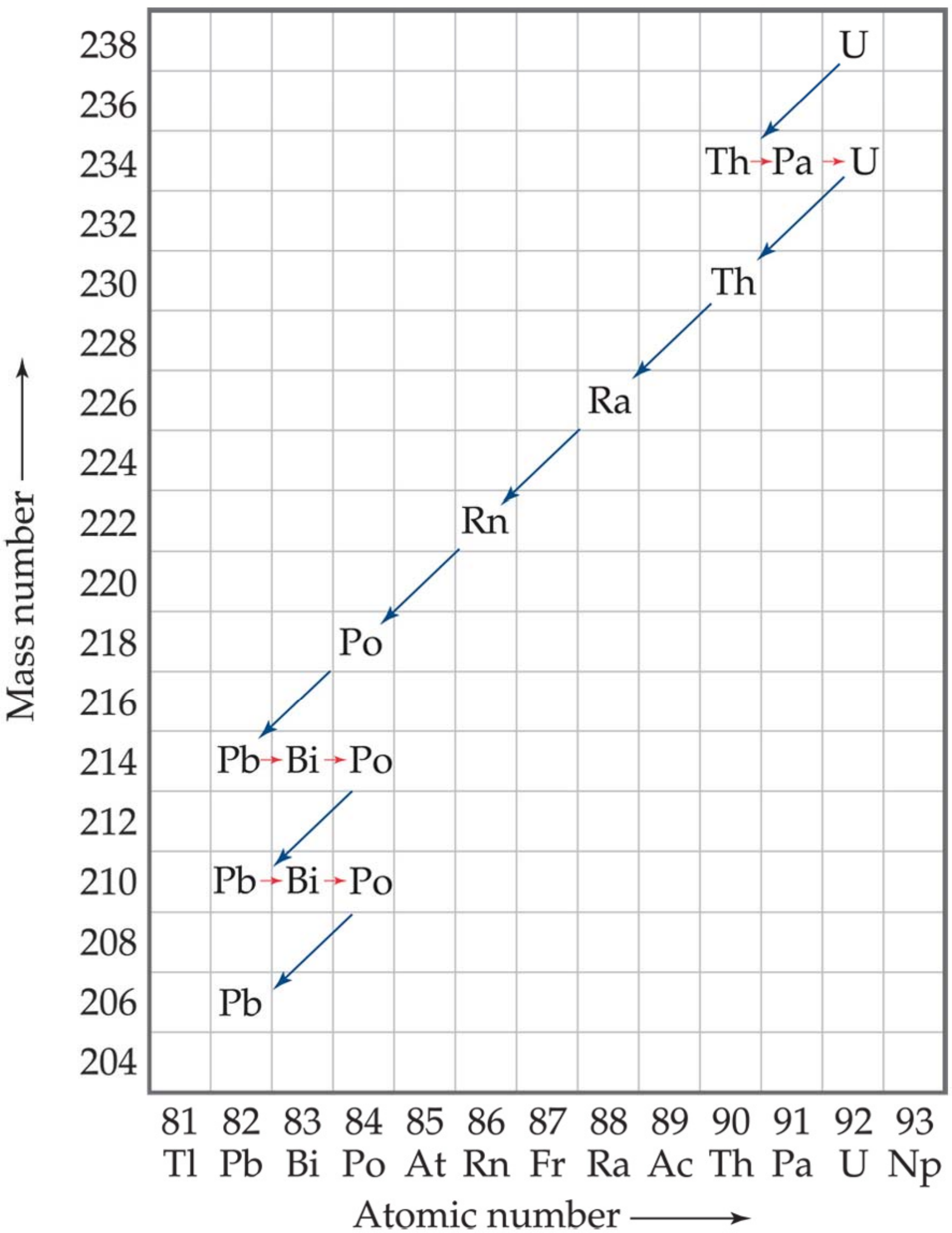
- Nuclei below the belt have too many protons.
- They tend to become more stable by **positron emission or electron capture.**



Stable Nuclei

- Note that the graph does not go beyond elements with 80 protons.
- There are no stable nuclei with an atomic number greater than 83.
- These nuclei tend to decay by alpha emission.

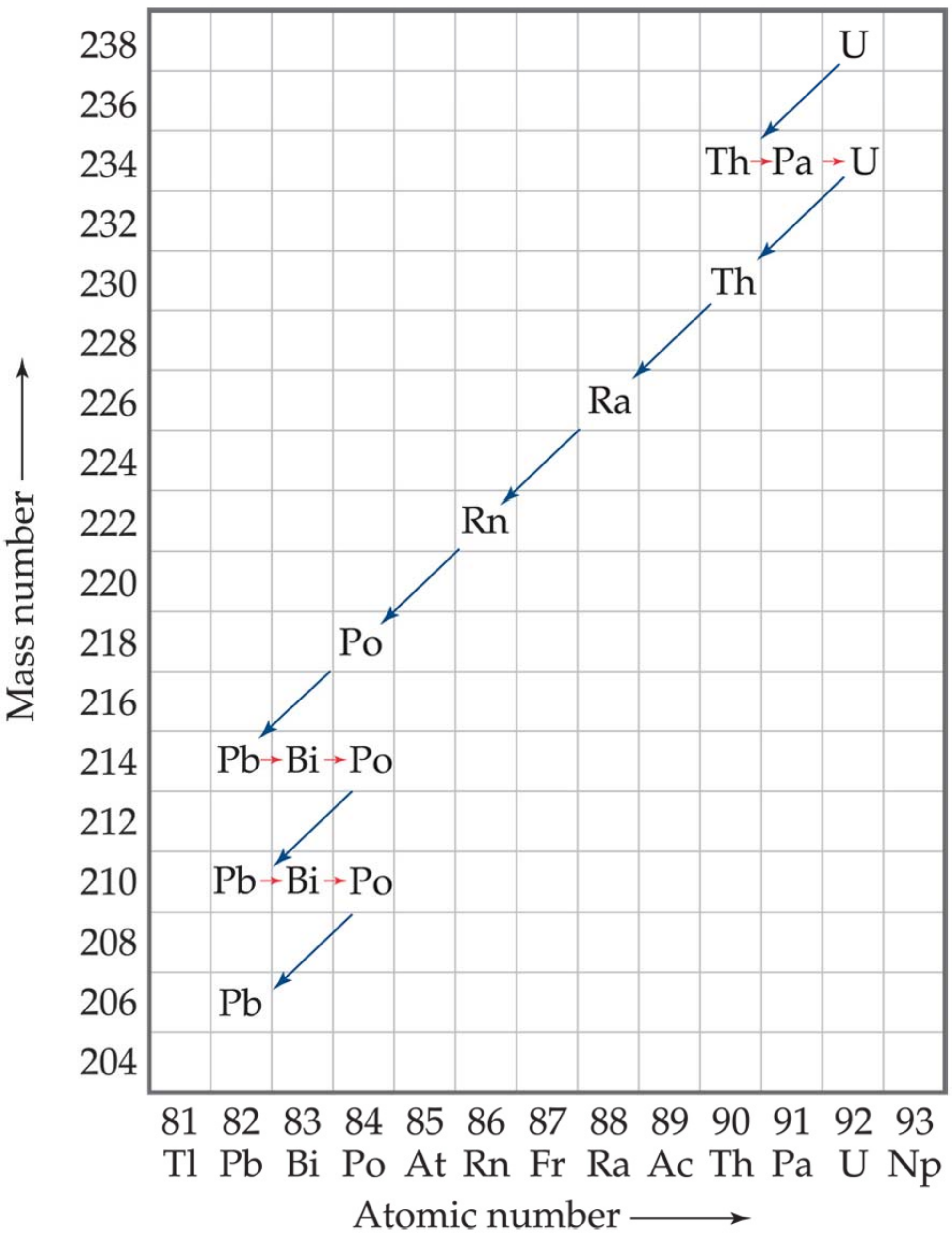




Radioactive Series

- Large radioactive nuclei cannot stabilize by undergoing only one nuclear transformation.
- They undergo a series of decays until they form a stable nuclide (often a nuclide of lead – but not all lead nuclei are stable).

Radioactive Series



View radioactive series at http://www.ead.anl.gov/pub/doc/NaturalDecaySeries.pdf

(static series)

and

http://www.eserc.stonybrook.edu/ProjectJava/Radiation/

(animated series)

Some Trends

Number of Stable Isotopes	Protons	Neutrons
157	Even	Even
53	Even	Odd
50	Odd	Even
5	Odd	Odd

Nuclei with 2, 8, 20, 28, 50, or 82 protons or 2, 8, 20, 28, 50, 82, or 126 neutrons tend to be more stable than nuclides with a different number of nucleons.

Some Trends

Number of Stable Isotopes	Protons	Neutrons
157	Even	Even
53	Even	Odd
50	Odd	Even
5	Odd	Odd

Nuclei with an even number of protons and neutrons tend to be more stable than nuclides that have odd numbers of these nucleons.

Artificial Transmutation

Nuclear transformations can be induced by accelerating a particle and colliding it with the nuclide.

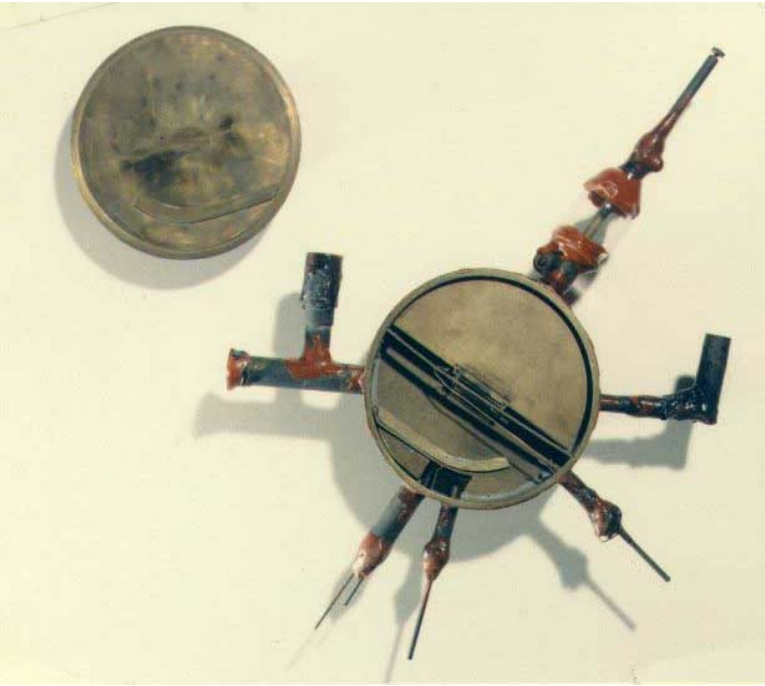
In 1919 Ernest Rutherford became the first person to transmute one element into another by bombarding nitrogen with *α*-particles.

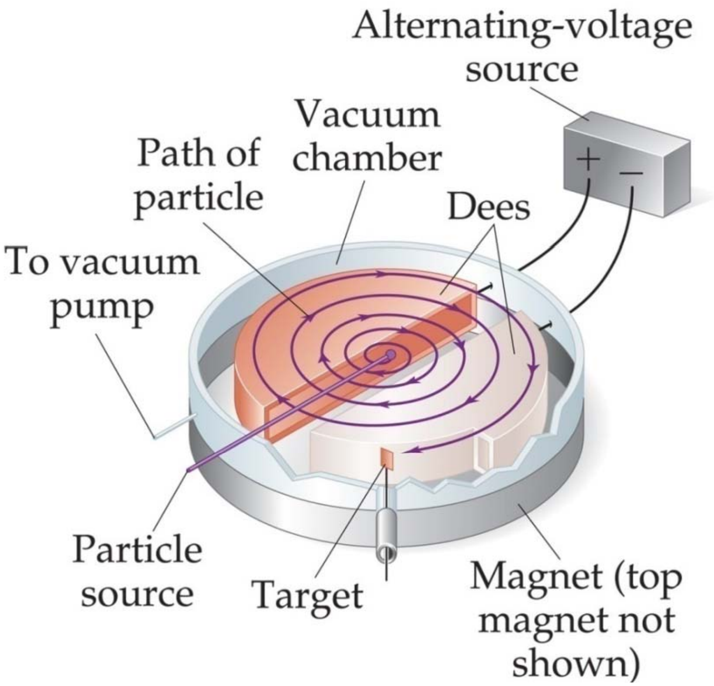
$$^{14}_{7}\mathrm{N} + ^{4}_{2}\mathrm{He} \rightarrow ^{17}_{8}\mathrm{O} + ^{1}_{1}p$$

Particle Accelerators

Today, particle accelerators are used to transmute elements into new elements as well as to probe the nature of the atom.

One of the earliest particle accelerators was the cyclotron, developed by Ernest O. Lawrence in 1929.

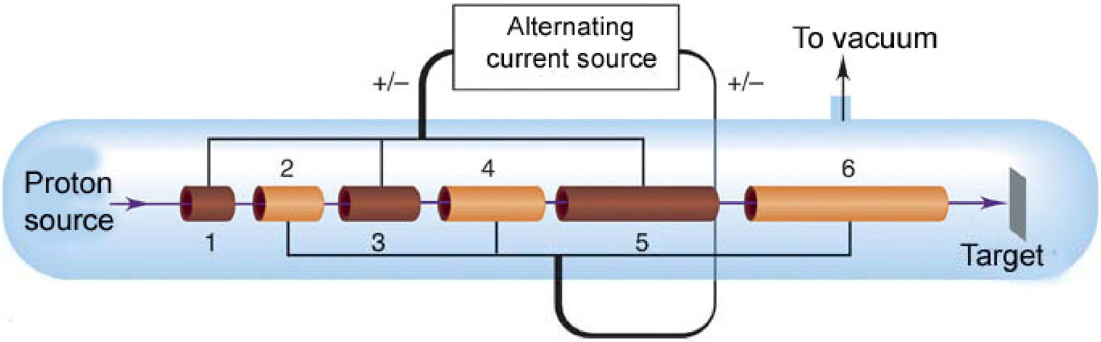




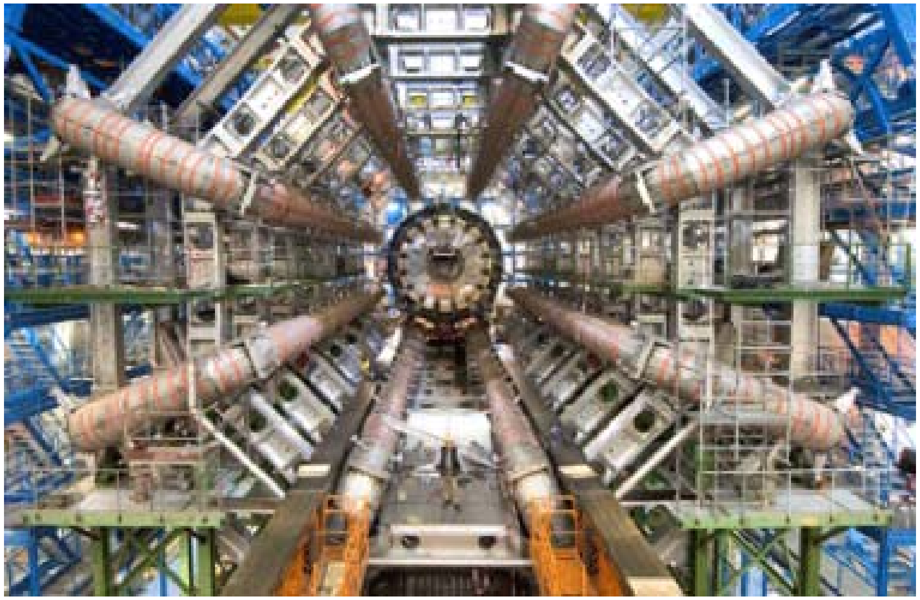
Modern Particle Accelerators

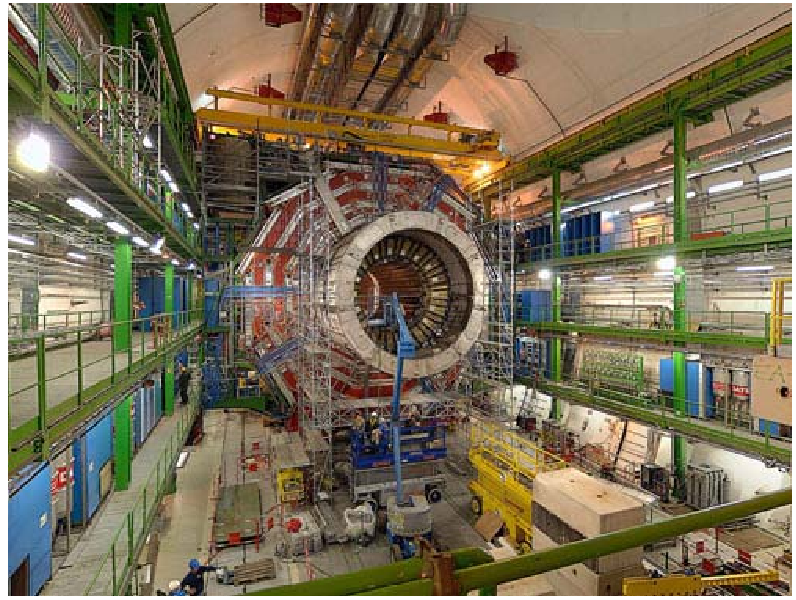
Both linear and circular particle accelerators. Circular particle accelerators need less space, but may have circular tracks with radii that are miles long.

Inside a linear particle accelerator



Inside a circular particle accelerator





Nuclear reactions using neutrons can be used to make isotopes used in medical studies or therapy:

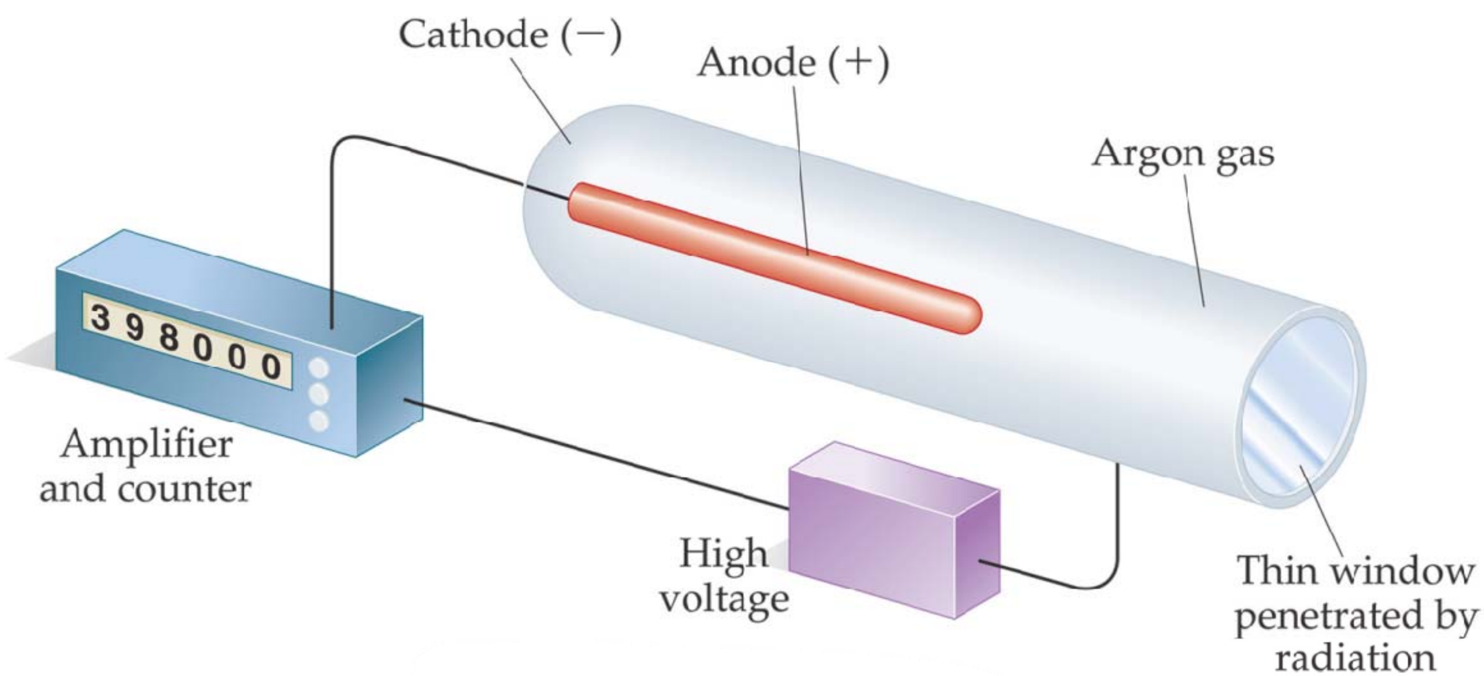
$$^{31}_{15}\mathrm{P} + {}^{1}_{0}n \rightarrow {}^{32}_{15}\mathrm{P} + \gamma$$

Using particle accelerators, new elements, such as the transuranium elements, can be synthesized:

$$^{238}_{92}\mathrm{U} + {}^{12}_{6}\mathrm{C} \rightarrow {}^{246}_{98}\mathrm{Cf} + 4\,{}^{1}_{0}n$$

Measuring Radioactivity

- A **Geiger counter** is used to measure the amount of activity present in a radioactive sample.
- The ionizing radiation creates ions, which create a current that is detected by the instrument.



Kinetics of Radioactive Decay

- Nuclear transmutation is a first-order process.
- The kinetics of a first-order process, is given by the equation:

$$\ln \frac{N_t}{N_0} = -kt$$

Where: N_0 = initial concentration
N_t = concentration at time, t
k = the specific rate constant

Kinetics of Radioactive Decay

- **The half-life (the time it takes for half of the atoms present to decay) is:**

$$\frac{0.693}{k} = t_{1/2}$$

Where: N_t = ½

N_0 = 1

and ln 0.5 = -0.693

- **Comparing the amount of a radioactive nuclide present at a given point in time with the amount normally present, one can find the age of an object.**

Radiocarbon dating

In the upper atmosphere, solar radiation interacts with atoms in the air to produce neutrons.

Some neutrons collide with nitrogen-14 atoms resulting in the formation of carbon 14.

$$^{14}_{7}\mathrm{N} + ^{1}_{0}n \rightarrow ^{14}_{6}\mathrm{C} + ^{1}_{1}\mathrm{H}$$

The carbon-14 is breathed, and consumed by all living organisms. So, all living things contain a level of carbon-14.

When the organism dies, the carbon-14 is no longer replenished and decays.

The age of the organism is determined by the amount of carbon-14 still remaining in its remains.

Kinetics of Radioactive Decay

A wooden object from an archeological site is subjected to radiocarbon dating. The activity of the sample that is due to ^{14}C is measured to be 11.6 disintegrations per second. The activity of a carbon sample of equal mass from fresh wood is 15.2 disintegrations per second. The half-life of ^{14}C is 5715 yr. What is the age of the archeological sample?

Kinetics of Radioactive Decay

First, we need to determine the rate constant, *k*, for the process.

$$\frac{0.693}{k} = t_{1/2}$$

$t_{1/2}$ = half-life
k = *specific rate constant*

$$\frac{0.693}{k} = 5715 \text{ yr}$$

$$\frac{0.693}{5715 \text{ yr}} = k$$

$$1.21 \times 10^{-4} \text{ yr}^{-1} = k$$

Kinetics of Radioactive Decay

Using the rate constant, we can determine *t*:

$$\ln \frac{N_t}{N_0} = -kt$$

$$\ln \frac{11.6}{15.2} = -(1.21 \times 10^{-4}\ \text{yr}^{-1})\ t$$

$$\ln 0.763 = -(1.21 \times 10^{-4}\ \text{yr}^{-1})\ t$$

$$6310\ \text{yr} = t$$

Half-life

When the age of a sample is greater than the half-life, quantities of radioactive materials can be calculated directly using the half-life of the isotope.

Example:

Iodine-131 has a half life of 8 days. 12.0 mg of $^{131}_{53}I$ **is administered to a patient for a thyroid study. How much is left in the body after 32 days?**

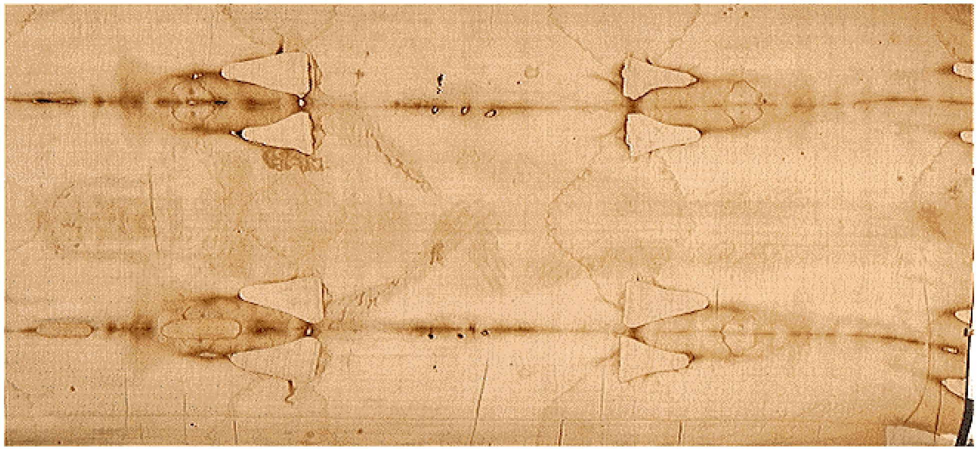
Time, days	Amount of I-131
0	12.0 mg
8	6.0 mg
16	3.0 mg
24	1.5 mg
32	0.75 mg

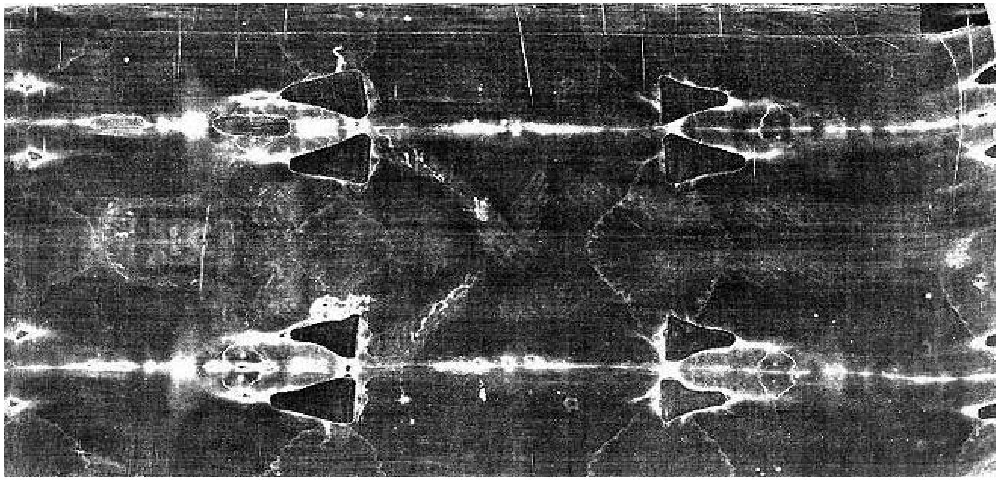
Half-lives of some radioactive isotopes

Name	Symbol	Half-life	Decays by
Tritium	${}^{3}_{1}H$	12.26 years	Beta
Carbon-14	${}^{14}_{6}C$	5730 years	Beta
Phosphorus-32	${}^{32}_{15}P$	14.3 days	Beta
Potassium-40	${}^{40}_{19}K$	1.28×10^{9} years	Beta + gamma
Chromium-51	${}^{51}_{24}Cr$	27.7 days	Electron capture + gamma
Iron-59	${}^{59}_{26}Fe$	44.5 days	Beta + gamma
Cobalt-60	${}^{60}_{27}Co$	5.2 years	Gamma
Iodine-131	${}^{131}_{53}I$	8 days	Beta + gamma

Radiocarbon Dating and the Shroud of Turin

www.shroud.com





Energy in Nuclear Reactions

- There is a tremendous amount of energy stored in the nuclei of atoms.
- Einstein's famous equation, $E = mc^2$, relates directly to the calculation of this energy.

Energy in Nuclear Reactions

- In normal chemical reactions, the amount of mass converted to energy is minimal.
- In a nuclear reaction, the mass converted to energy is many thousands of times greater.
- The amount of mass converted to energy is referred to as the **mass defect**

Energy in Nuclear Reactions

For example, the mass change for the decay of 1 mole of uranium-238 is −0.0046 g.

The change in energy, ΔE, is then

$$\Delta E = (\Delta m)\, c^2$$

$$= (-4.6 \times 10^{-6}\ \text{kg})(3.00 \times 10^{8}\ \text{m/s})^2$$

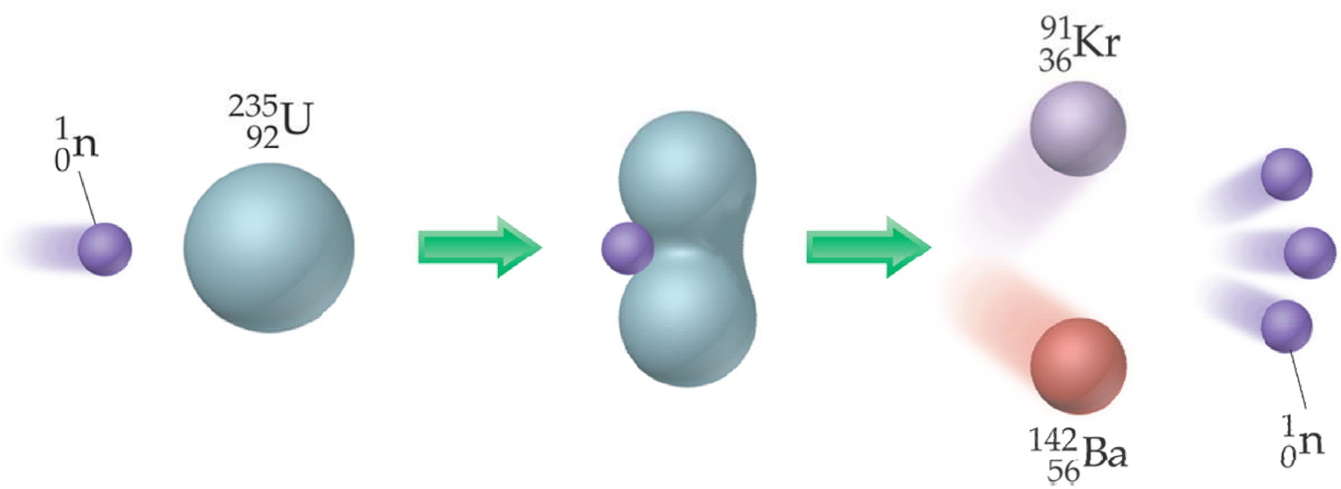
$$= -4.1 \times 10^{11}\ \text{J}$$

Nuclear Fission

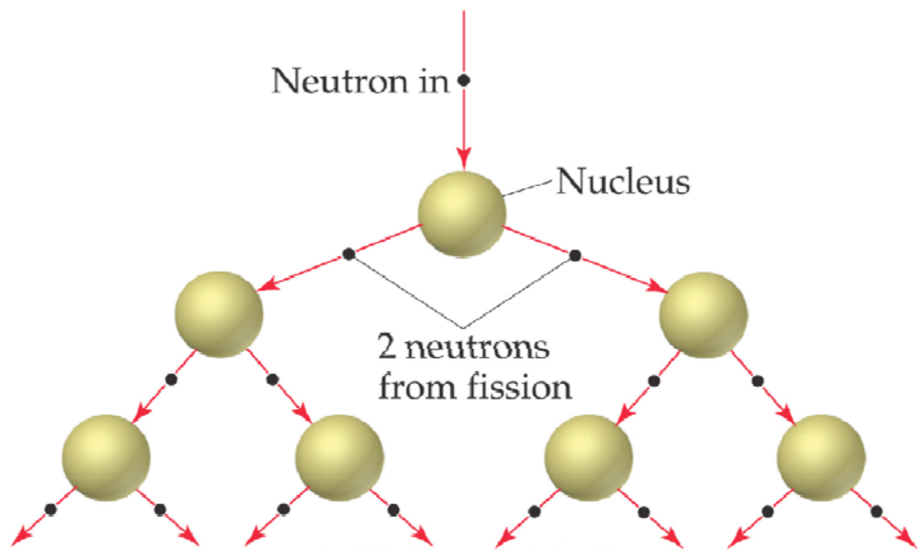
- How does one tap all that energy?
- Nuclear fission is the type of reaction carried out in nuclear reactors.

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{137}_{52}Te + ^{97}_{40}Zr + 2\,^{1}_{0}n$$

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3\,^{1}_{0}n$$

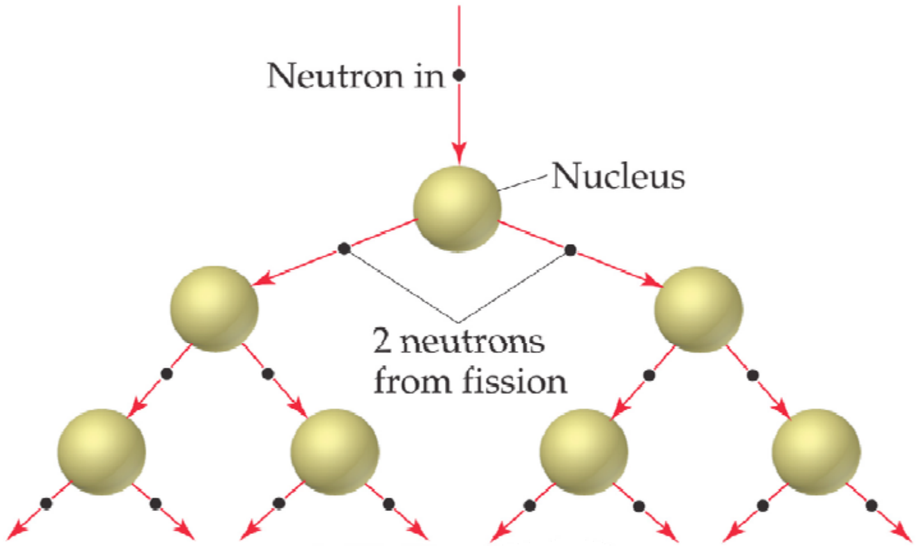


Nuclear Fission



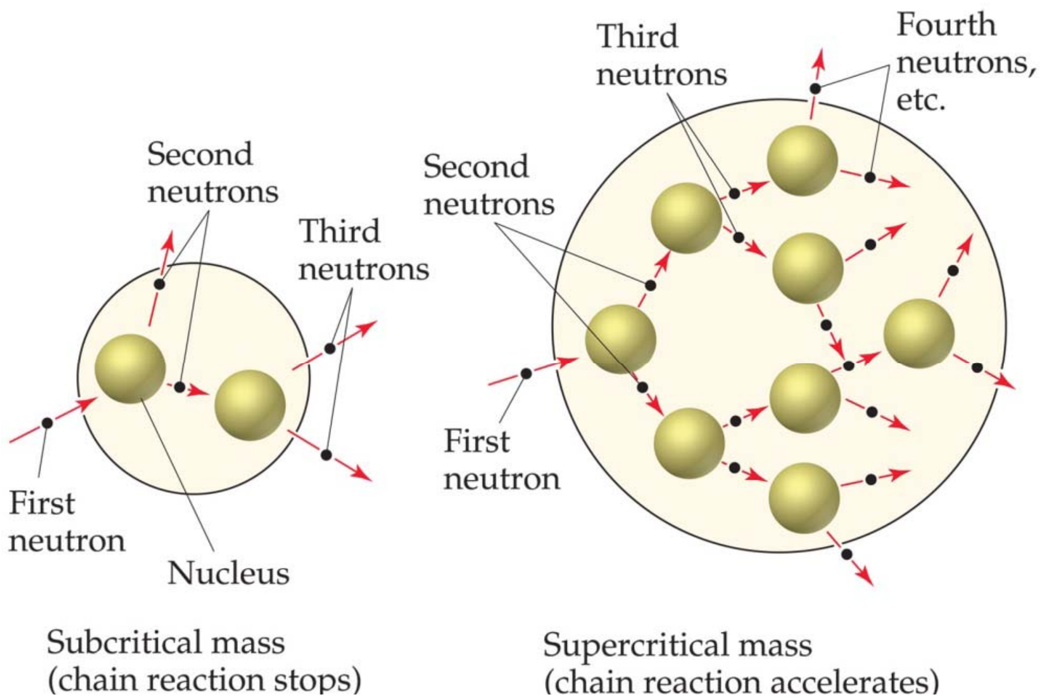
- Bombardment of the radioactive nuclide with a neutron starts the process.
- Neutrons released in the transmutation strike other nuclei, causing their decay and the production of more neutrons.

Nuclear Fission



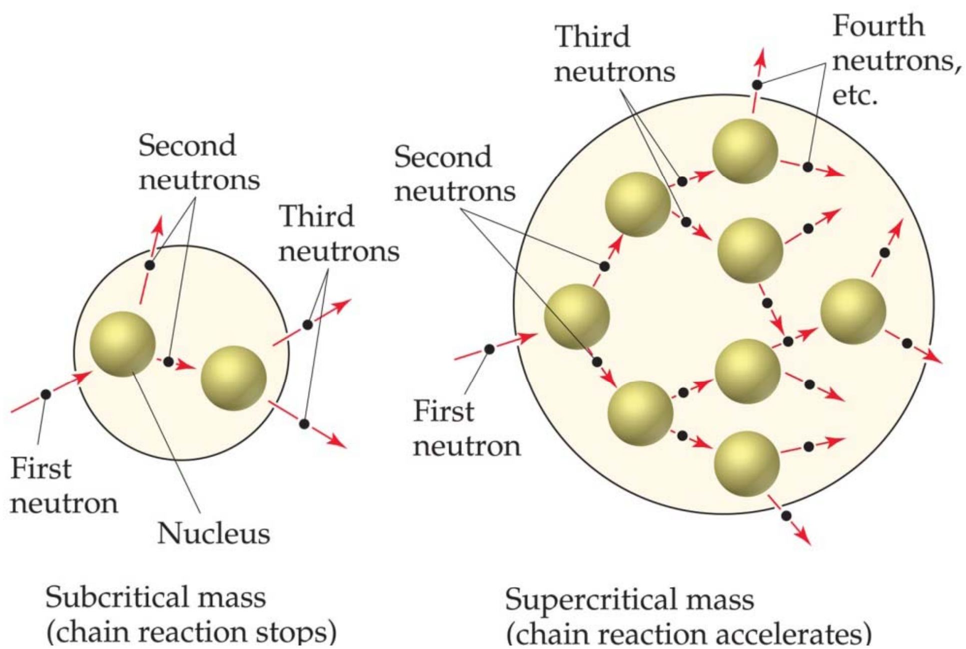
This process continues in what we call a nuclear chain reaction.

Nuclear Fission



If there are not enough radioactive nuclides in the path of the ejected neutrons, the chain reaction will die out.

Nuclear Fission

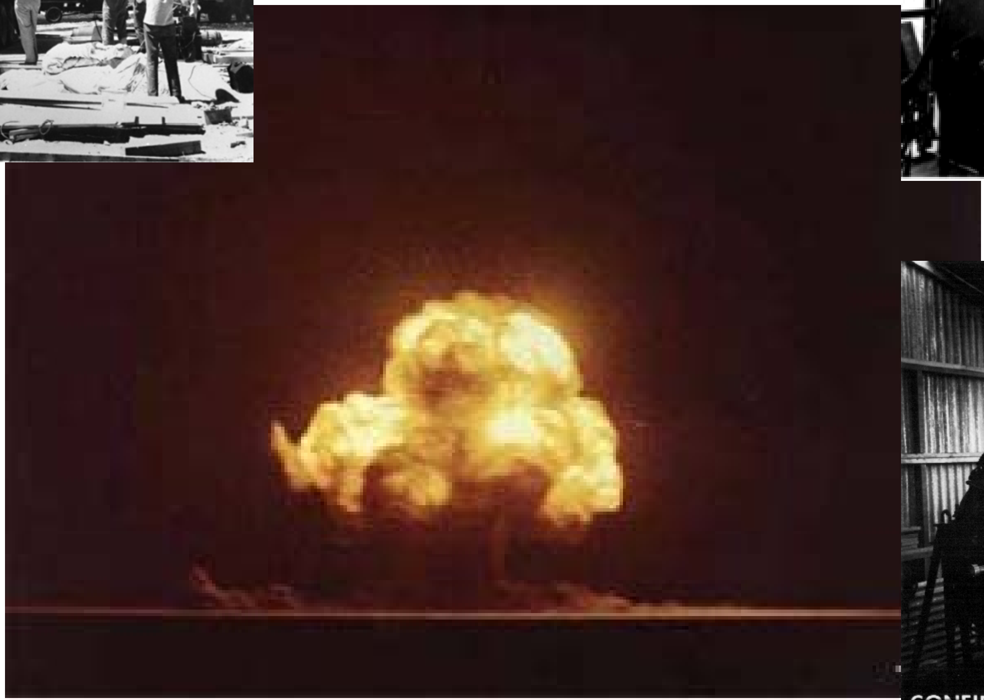


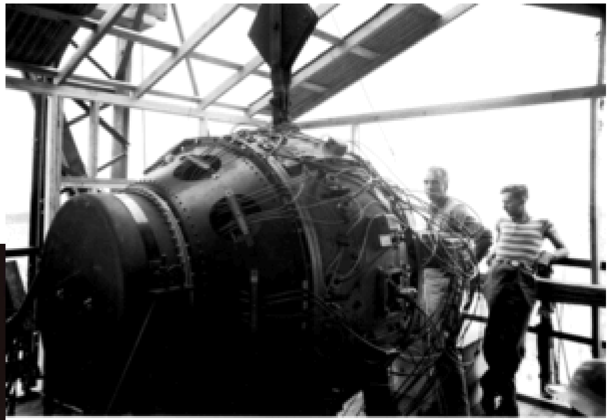
Therefore, there must be a certain minimum amount of fissionable material present for the chain reaction to be sustained. This is called the Critical Mass

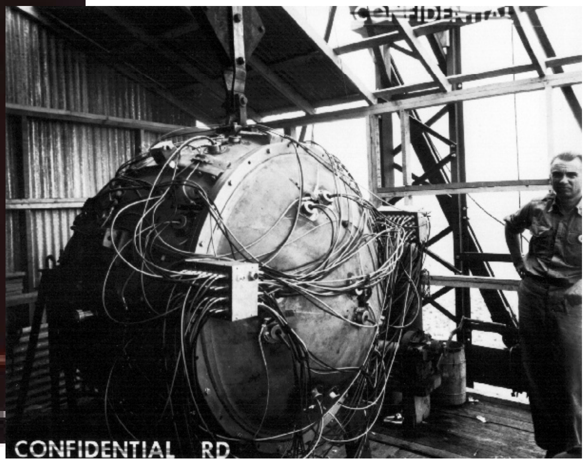
That is, there must be a high probability of the neutron hitting another fissionable nucleus.

Nuclear Weapons

The Trinity test – White Sands Missile Range, Alamogordo, NM, July 16, 1945

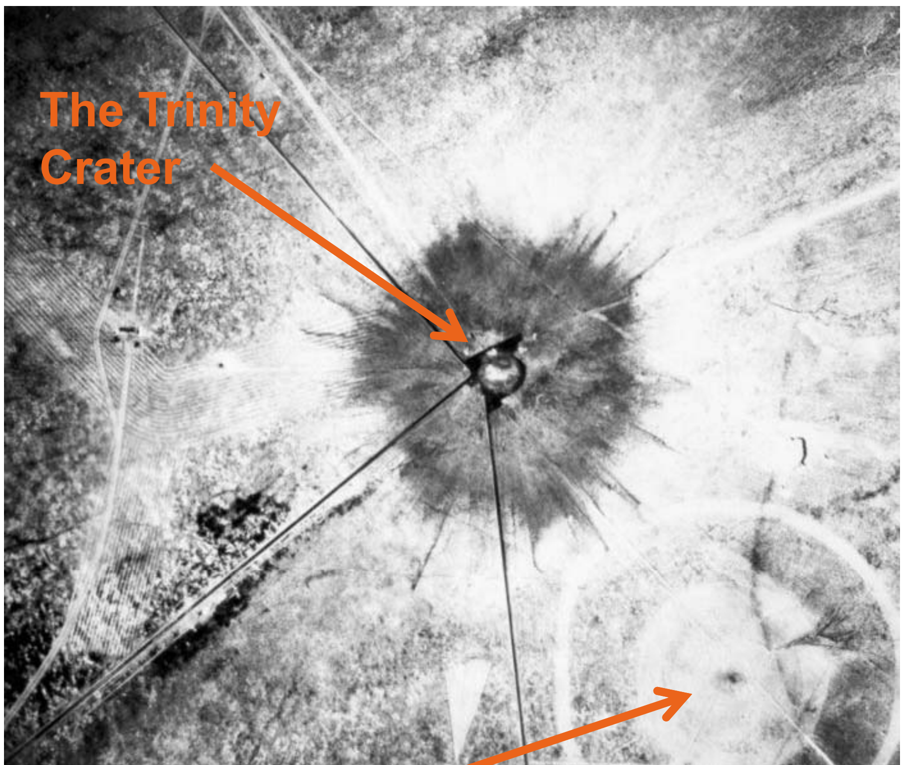






Nuclear Weapons

The Trinity test – White Sands Missile Range, Alamogordo, NM, July 16, 1945



Crater from "100 Ton Test"

108 tons of TNT blown up to calibrate instruments for Trinity test

Ground indentation after the test

Nuclear Weapons

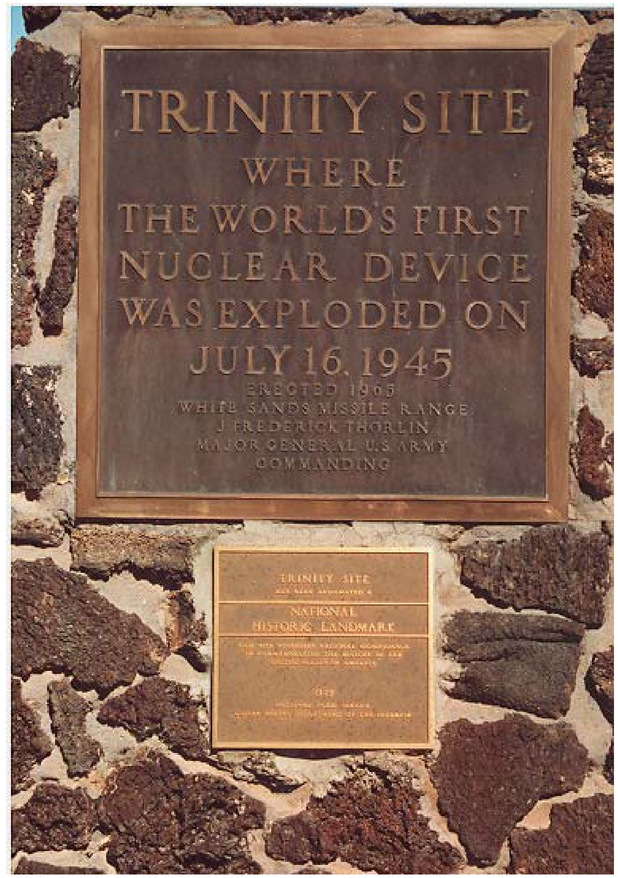
The Trinity test – White Sands Missile Range, Alamogordo, NM, July 16, 1945

The remains of the tower after the test (left) and today (right)

Nuclear Weapons

The Trinity test – White Sands Missile Range, Alamogordo, NM, July 16, 1945

The Trinity monument



Nuclear Weapons

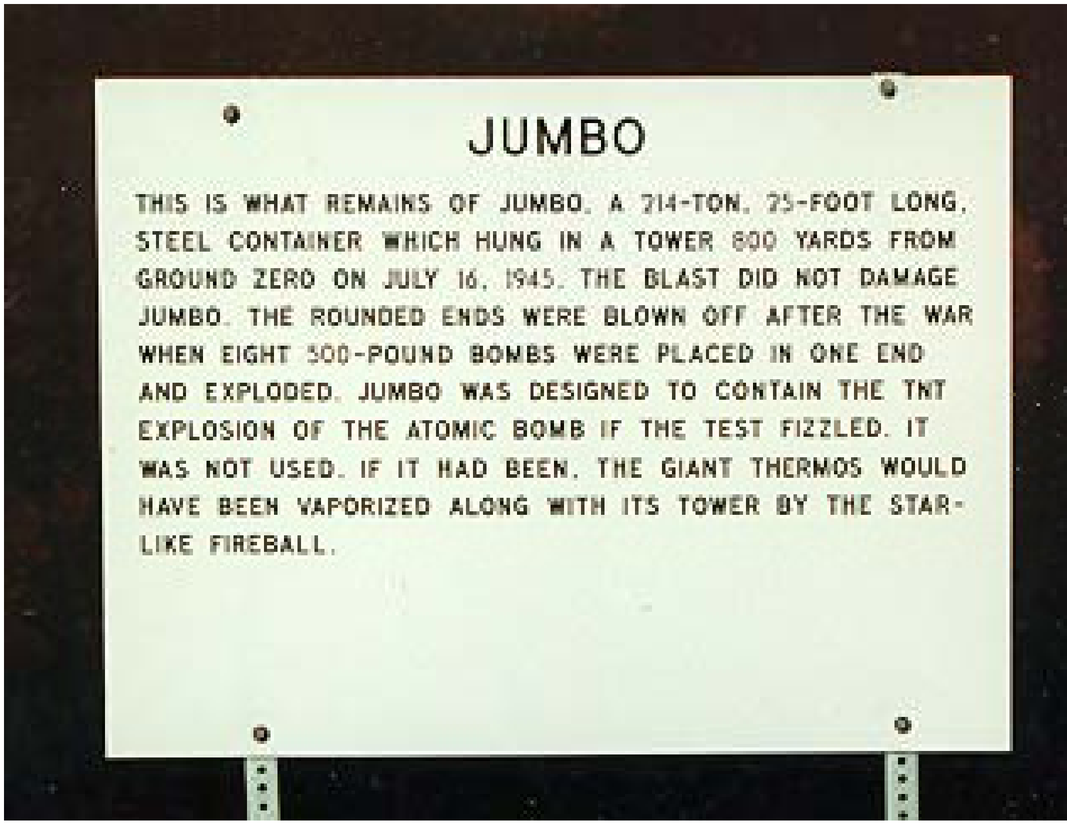
The Trinity Test – White Sands Missile Range
Alamogordo, NM, July 16, 1945

Trinitite: Scattered pieces on the ground at the Trinity site (left)
Samples from the site taken in 1945 with lead box (right)

Nuclear Weapons

The Trinity Test – White Sands Missile Range

Alamogordo, NM, July 16, 1945



Nuclear Weapons

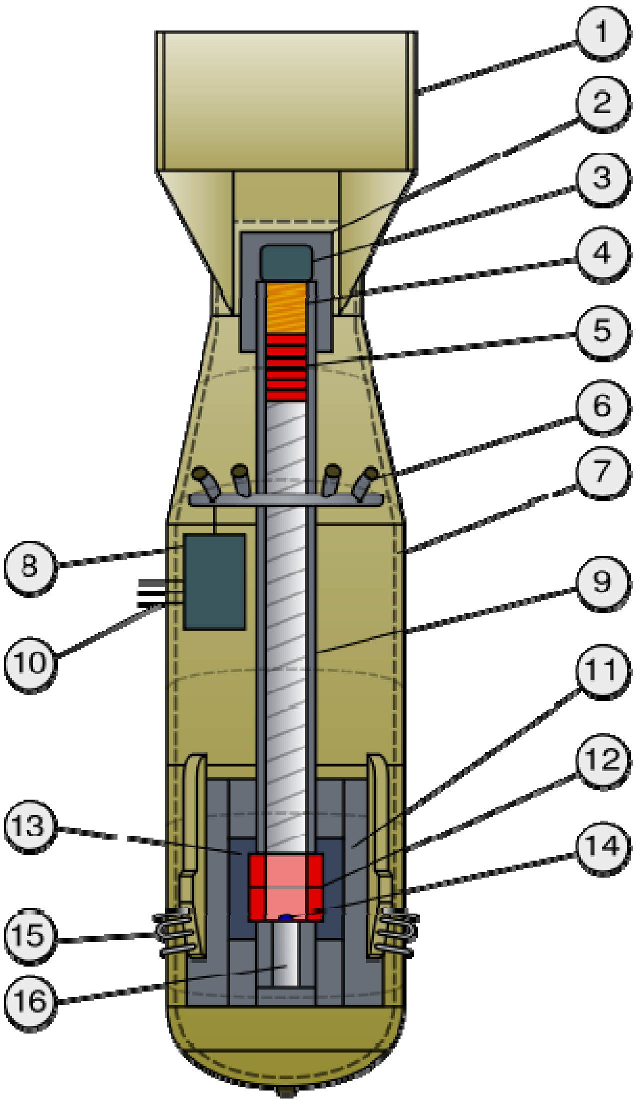
Little Boy Specifications

Length: 120.0 inches (10 feet / 3.0 meters)

Diameter: 28.0 inches (71.1 cm)

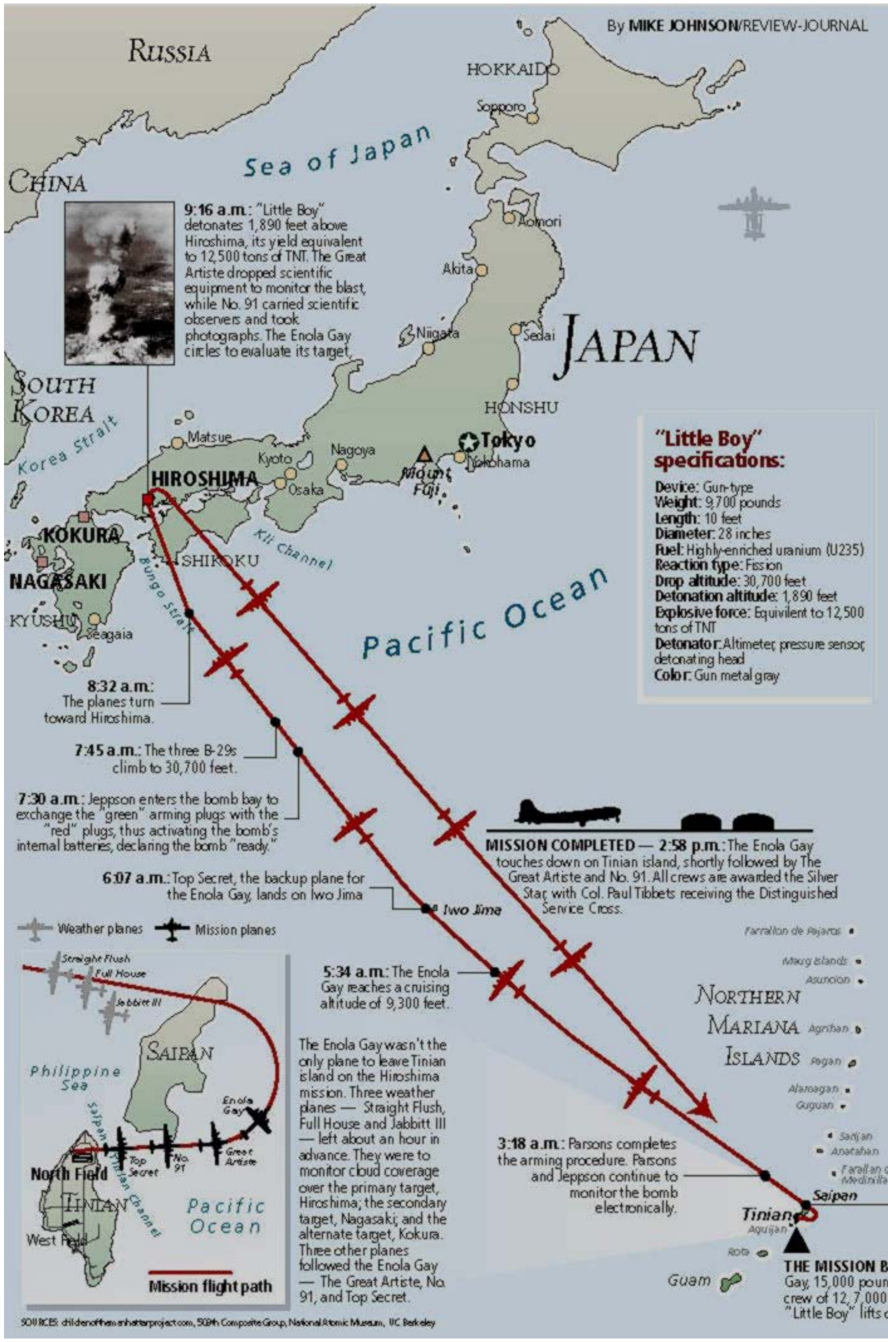
Weight: 9,700 lbs (4,400 kg)

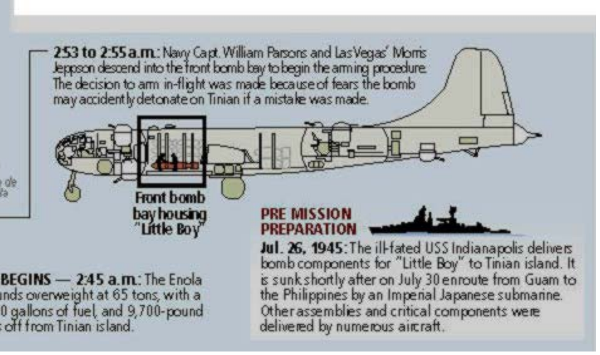
Yield: 15 kilotons (+/- 20%)



1. Box tail fins
2. Steel gun breech assembly
3. Detonator
4. Cordite (conventional) explosives
5. Uranium-235 "projectile", six rings (26 kg) in a thin can of steel
6. Baro sensing ports and manifold
7. Bomb casing wall
8. Arming and fusing equipment
9. Gun barrel, steel, around 10 cm diameter, 200 cm length
10. Arming wires
11. Tamper assembly, steel
12. Uranium-235 "target", two rings (38 kg)
13. Tamper/reflector assembly, tungsten carbide
14. Neutron initiator
15. *Archie* fuzing radar antennas
16. Recess for the boron safety plug (not shown) to be ejected into

The Enola Gay and "Little Boy": Mission over Hiroshima, August 6, 1945

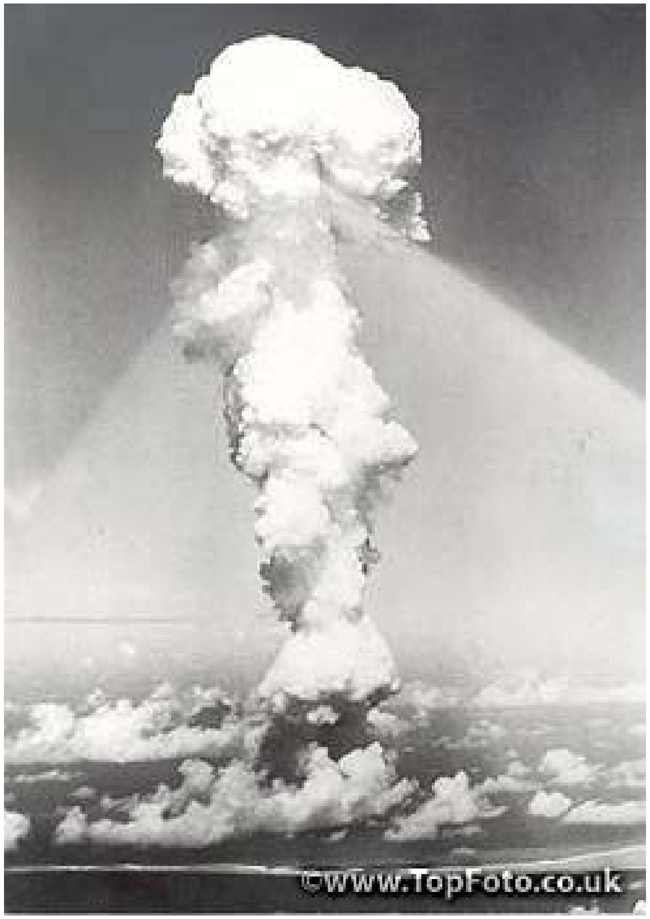


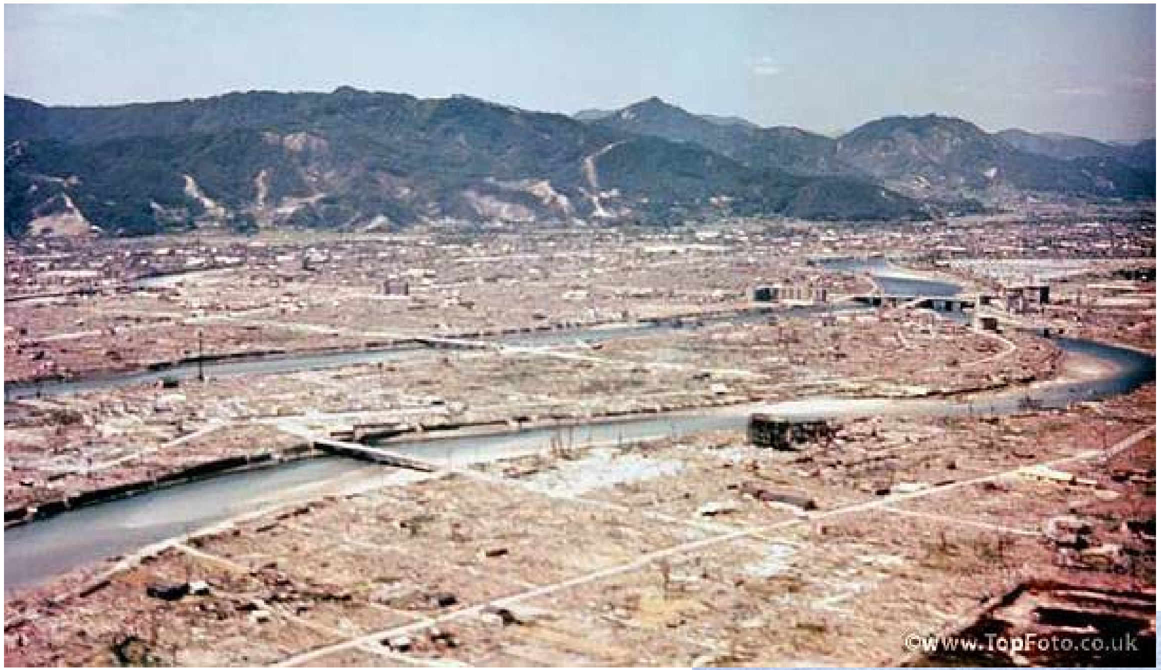


The Enola Gay

The Smithsonian National Air and Space Museum's
Steven F. Udvar-Hazy Center

Hiroshima, August 6, 1945





Hiroshima, August 6, 1945

Nuclear Weapons

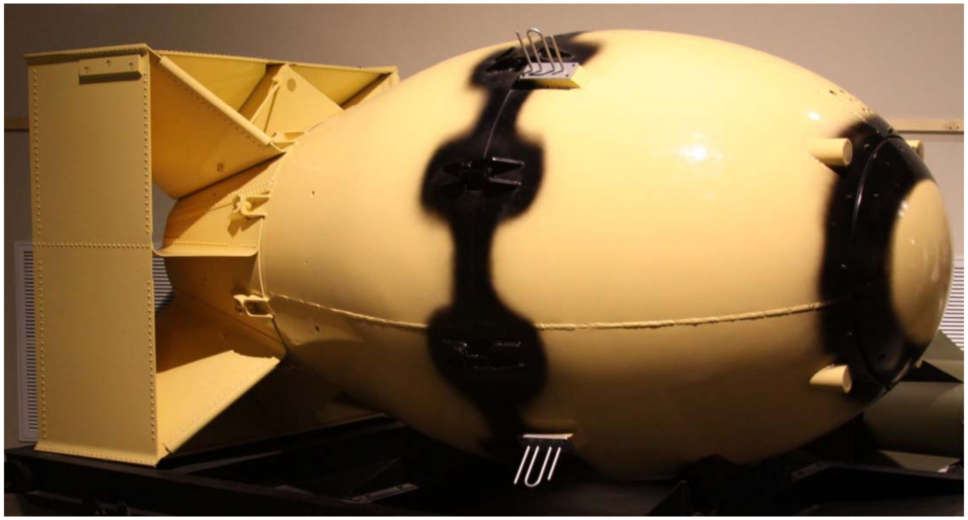
Fat Man Specifications

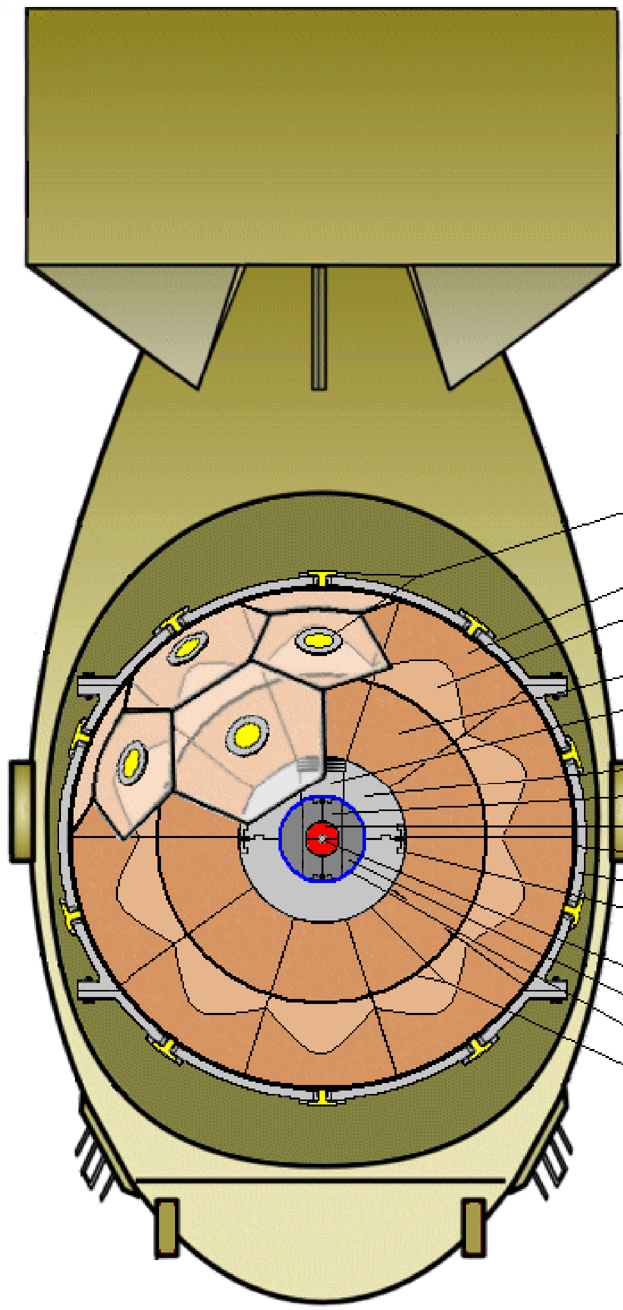
Length: 128.375 inches (10 feet 8 inches / 3.25 meters)

Diameter: 60.25 inches (5 feet / 1.5 meters)

Weight: 10,265 lbs (4,656 kg)

Yield: 21 kilotons (+/- 10%)



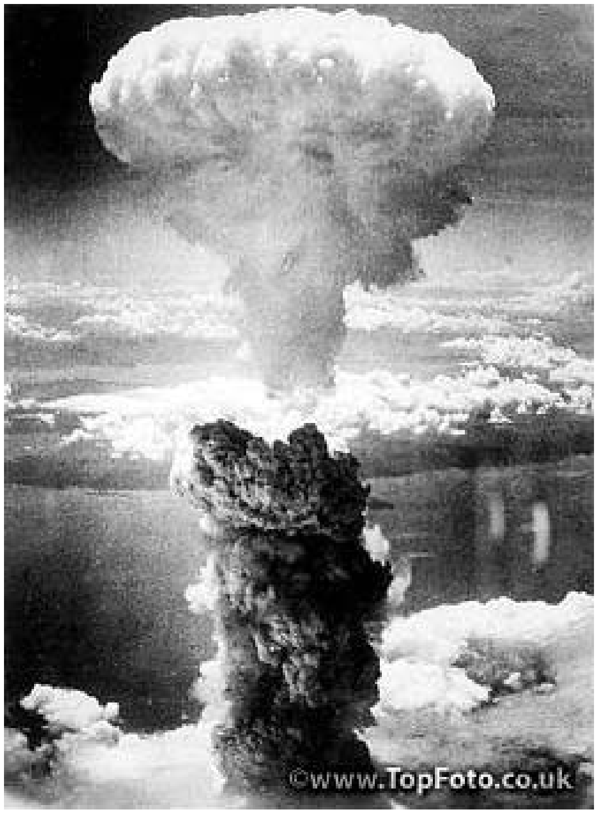


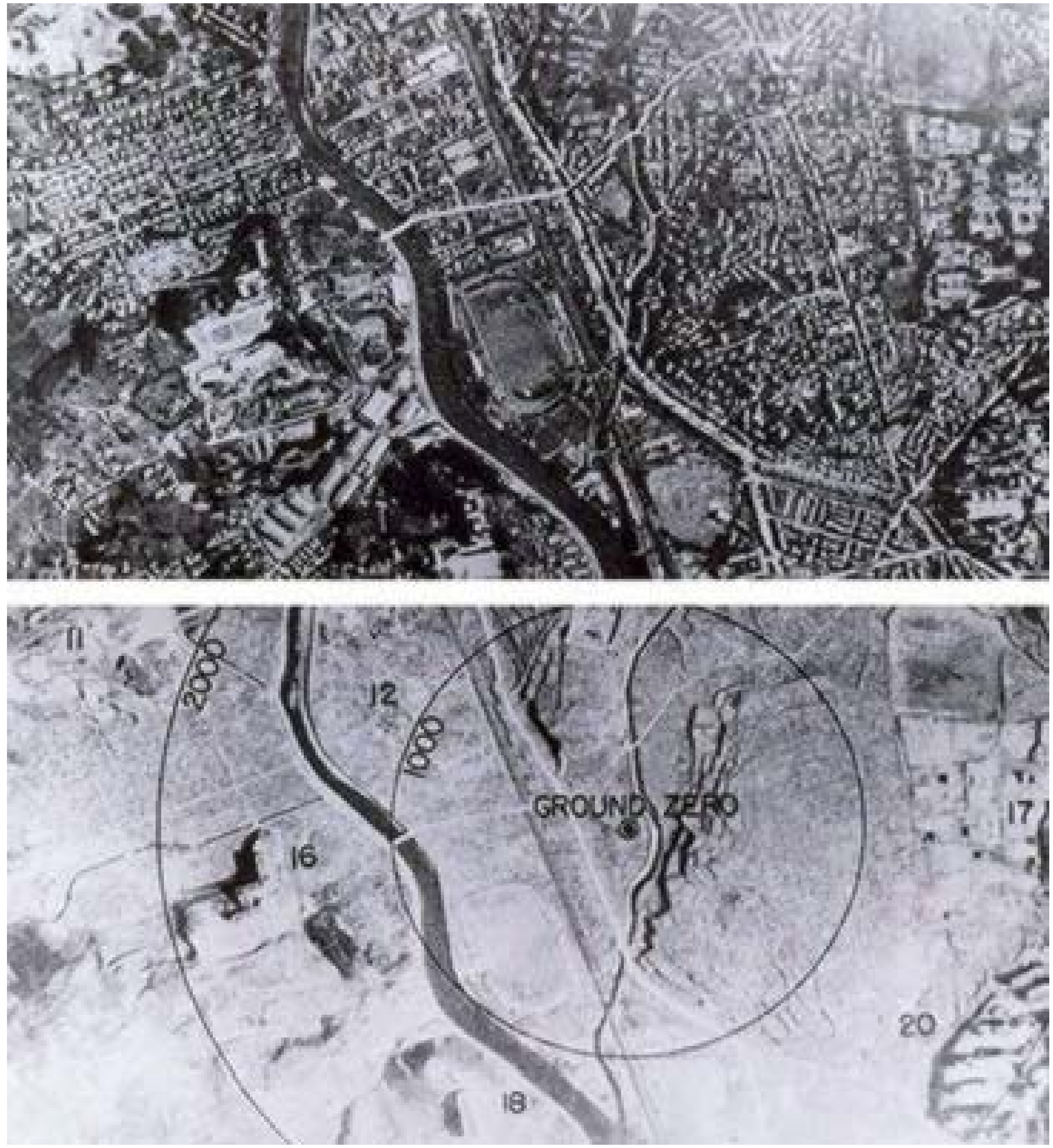
Cross-section drawing of the Y-1561 implosion sphere showing component placement. Numbers in ( ) indicate quantity of identical components. Drawing is shown to scale. (Author)

A) 1773 EBW detonators inserted into brass chimney sleves (32)
B) Comp B component of outer lens (32)
C) Cone-shaped Baratol component of outer lens (32)
D) Comp B inner charge (32)
E) Removable aluminum pusher trap-door plug screwed into upper pusher hemisphere
F) Aluminum pusher hemispheres (2)
G) Tuballoy (U-238) two-piece tamper plug
H) Pu-239 hemispheres (2)
I) Cork lining
J) 7-piece Duralumin sphere
K) Aluminum cups holding pusher hemispheres together (4)
L) Polonium-Beryllium initiator
M) Tuballoy (U-238) tamper sphere
N) Boron plastic shell
O) Felt padding layer under lenses and inner charges

"Atom Bombs: The Top Secret Inside Story of Little Boy and Fat Man," 2003, p 140. John Coster-Mullen drawing used with permission.

Nagasaki
August 10, 1945





Nagasaki
August 10, 1945

Nuclear Weapons: The Atomic Cannon

Test fired May 25, 1953. The explosion is seven miles away. Range is 20 miles.

See video of the test firing at http://www.youtube.com/watch?v=I-v92nxahDQ

Read about the atomic cannon at **http://www.chymist.com/The Atomic Canon.pdf**

Sedan crater at Nevada Test Site.

This is the result of a 104 kiloton underground test in July 1962.

The crater is 1,280 feet wide and 320 feet deep.

Read "The Plan to Nuke Panama"
http://www.americanheritage.com/articles/magazine/it/2002/4/2002_4_62.shtml

See a video of the Project Sedan explosion at
http://www.youtube.com/watch?v=e64T5VEYMYM

The First Nuclear Reactor, 1942

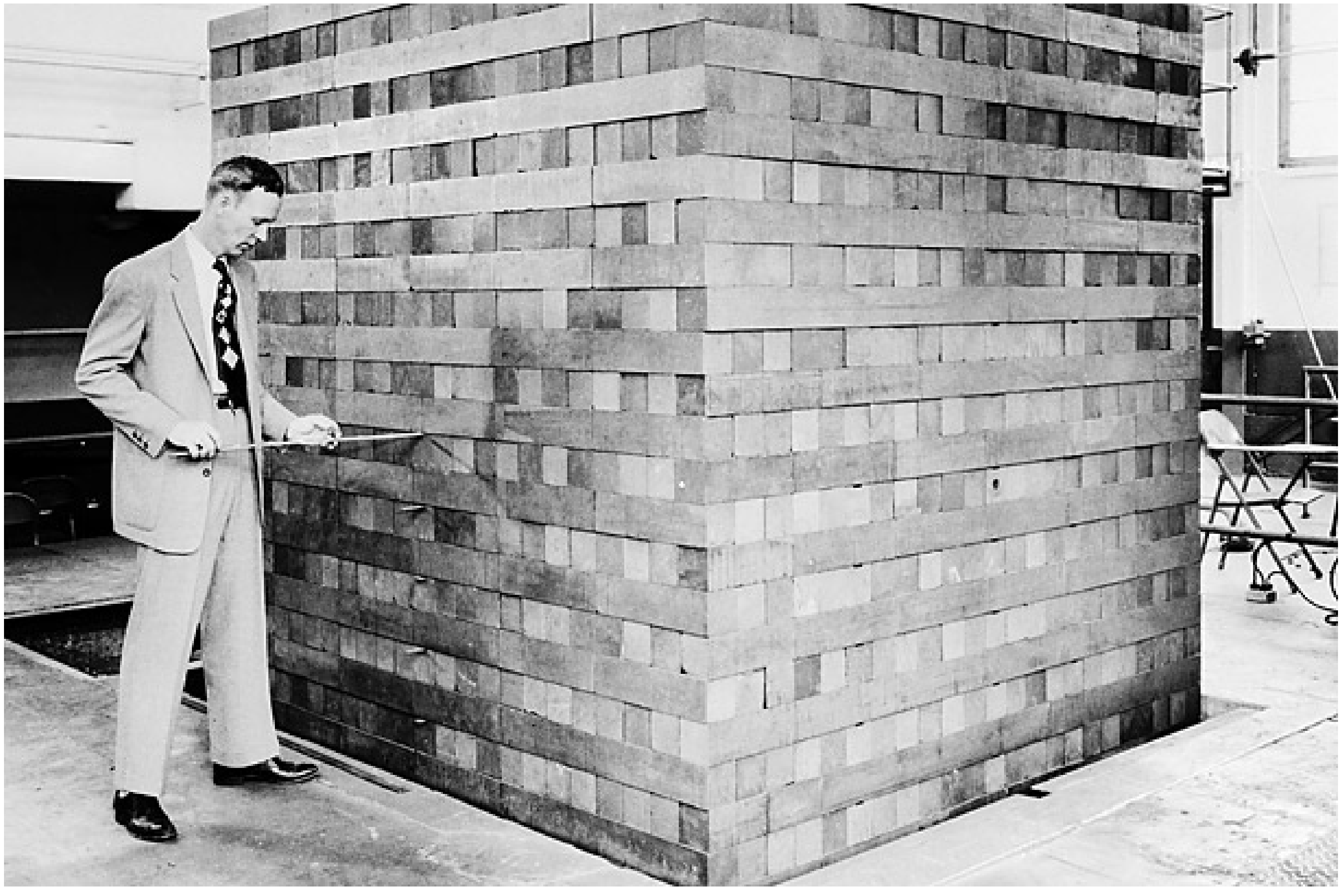
15:22 local time, December 2, 1942, under the stands of Stagg Field at the University of Chicago.

Enrico Fermi (upper left) monitored the radiation activity.
George Weil (lower center) operated the final control rod.

The First Nuclear Reactor, 1942

Enrico Fermi (left) and George Weil (right) testing the reactor.

The First Nuclear Reactor, 1942



The first functioning nuclear reactor, used an 8-ft.-square block made of 30 tons of graphite and 2.5 tons of uranium.. Here, an engineer shows how the control rod was inserted.

Nuclear Reactors

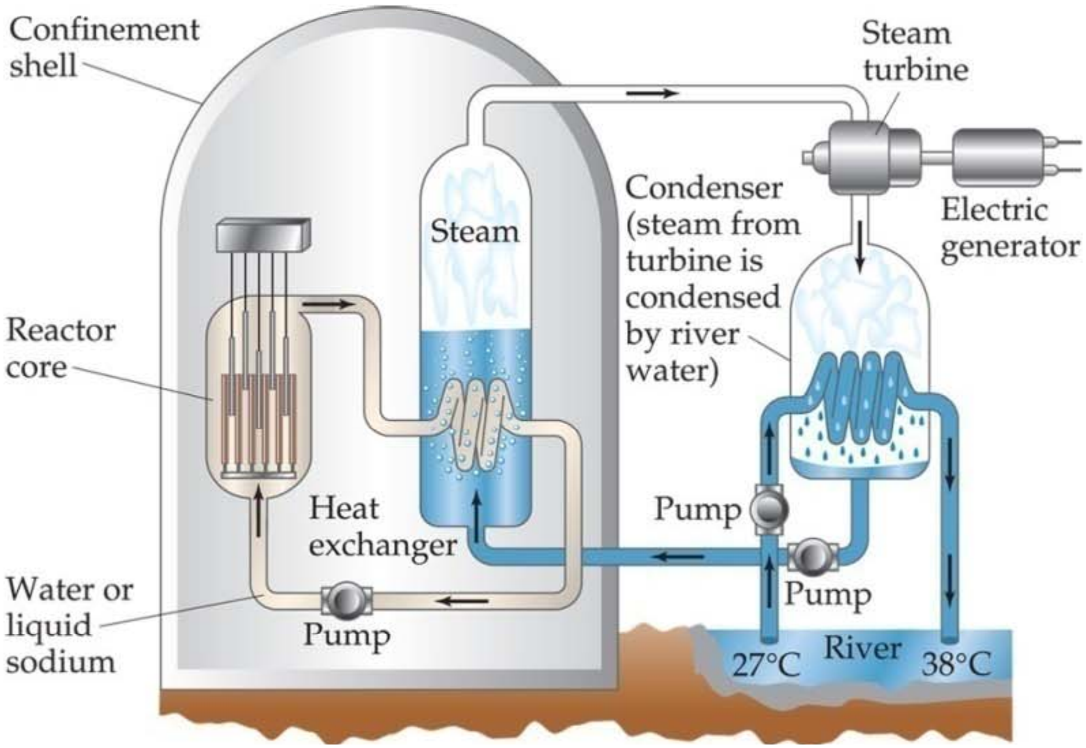
Palisades Power Plant

Nuclear Reactors

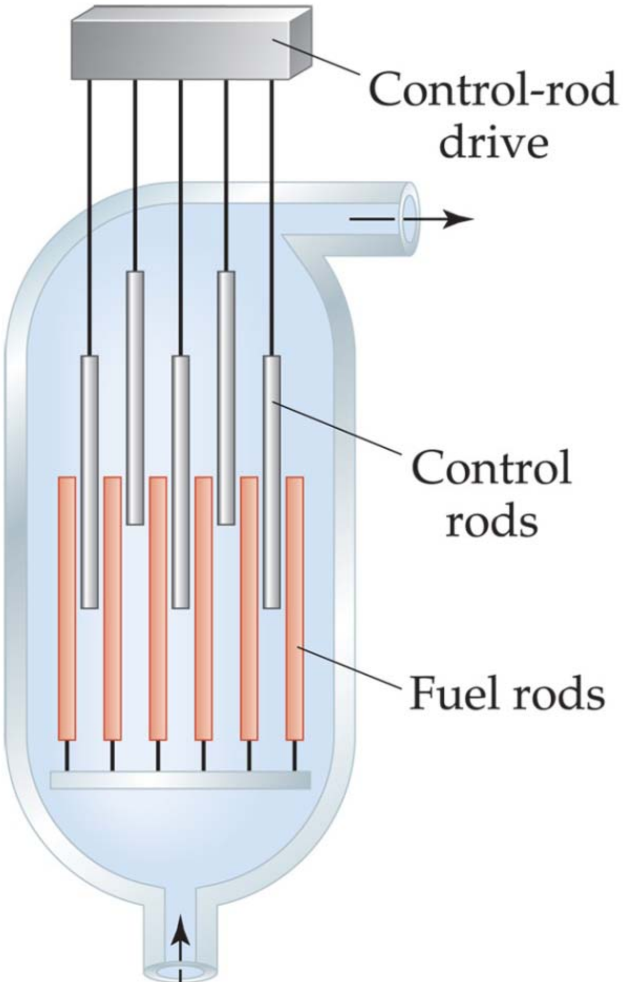
Photo courtesy of Palisades Power Plant

Nuclear Reactors

In nuclear reactors the heat generated by the reaction is used to produce steam that turns a turbine connected to a generator.

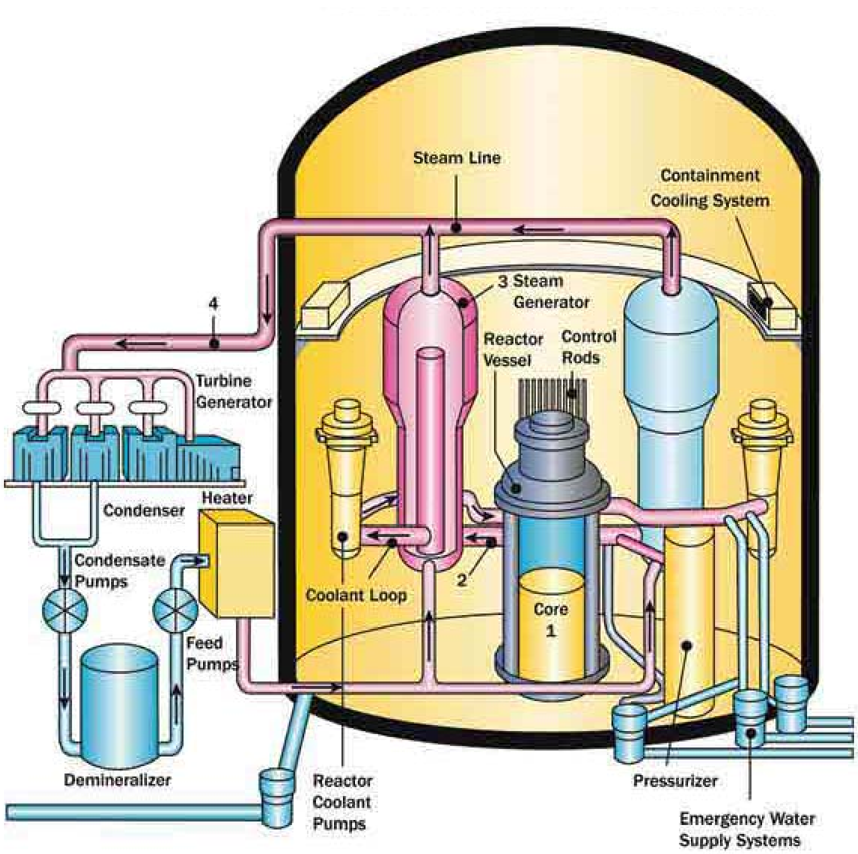


Nuclear Reactors



- The reaction is kept in check by the use of control rods.
- These block the paths of some neutrons, keeping the system from reaching a dangerous supercritical mass.
- The control rods must be withdrawn from between the fuel rods to initiate the nuclear reaction.
- The normal position of the control rods is in between the fuel rods.

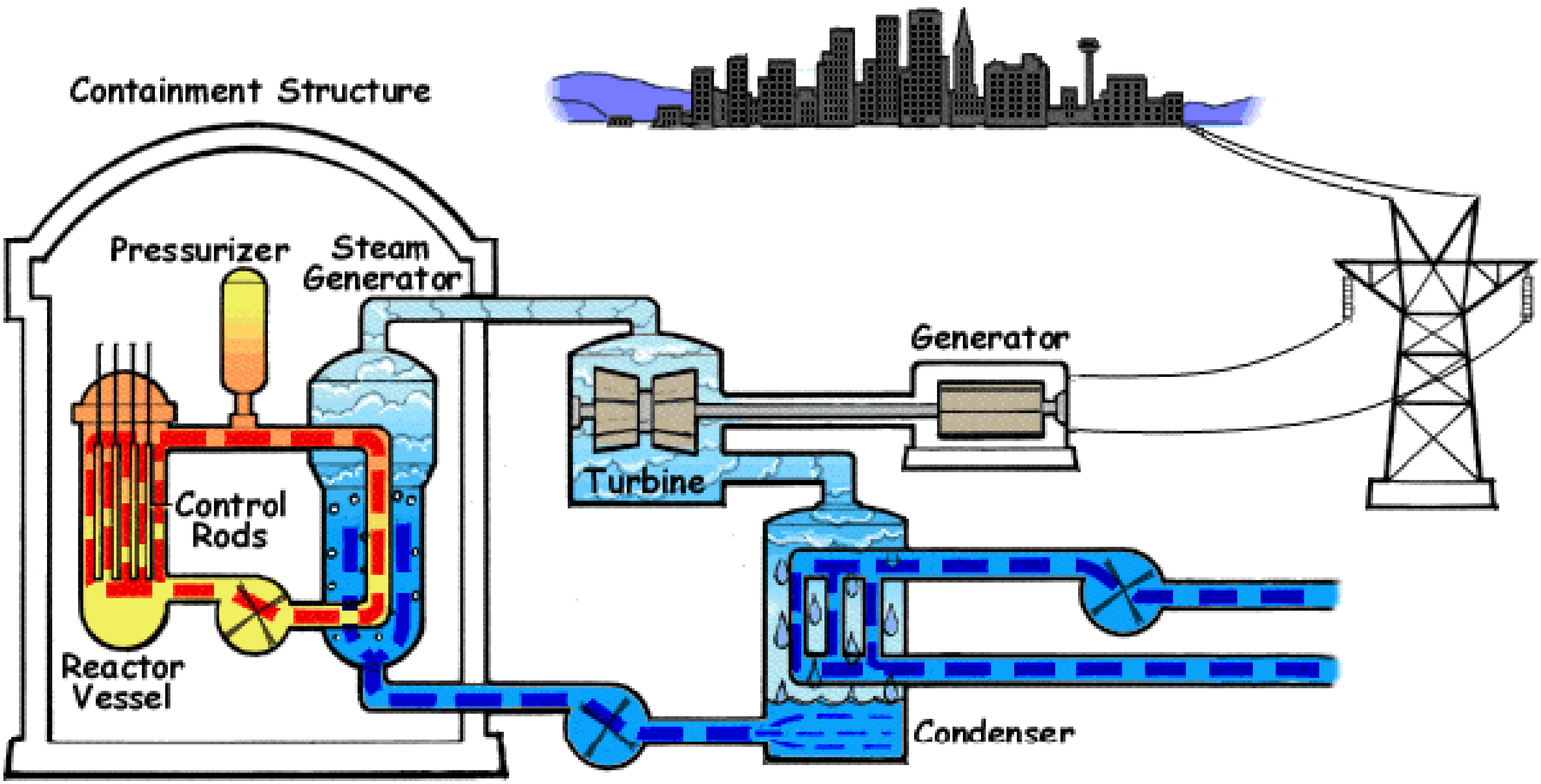
Pressurized Water Reactors



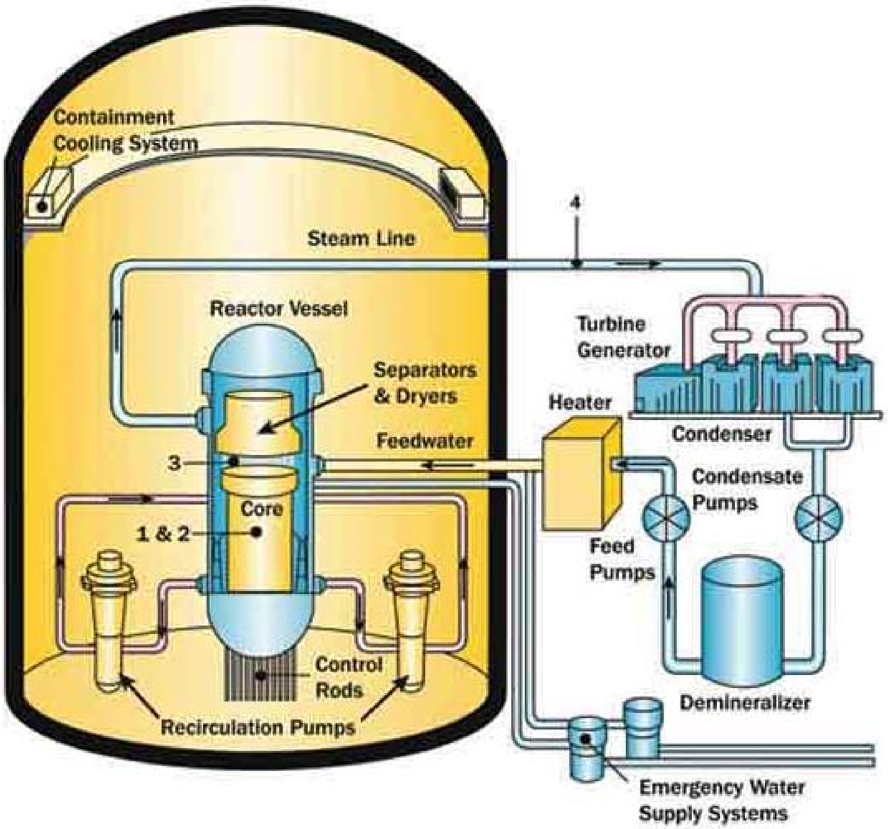
In a typical pressurized light-water reactor

1. The core inside the reactor vessel creates heat
2. Pressurized water in the primary coolant loop carries the heat to the steam generator,
3. Inside the steam generator, heat from the steam, and the steam line directs the steam to the main turbine, turning the turbine generator to produce electricity.
4. Unused steam is exhausted in to the condenser, condensed into water, pumped out of the condenser, reheated and pumped back to the steam generators.
5. The reactor's fuel assemblies are cooled by water circulated using electrically powered pumps. If power is lost emergency cooling water is supplied by other pumps, powered by onsite diesel generators..
6. Pressurized-water reactors contain between 150-200 fuel assemblies.

The Pressurized Water Reactor



Boiling Water Reactors



In a typical commercial boiling-water reactor:

1.The core inside the reactor vessel creates heat, producing a steam-water mixture

2.The steam-water mixture enters two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line

3.The steam line directs the steam to the main turbine, turning the turbine generator, which produces electricity.

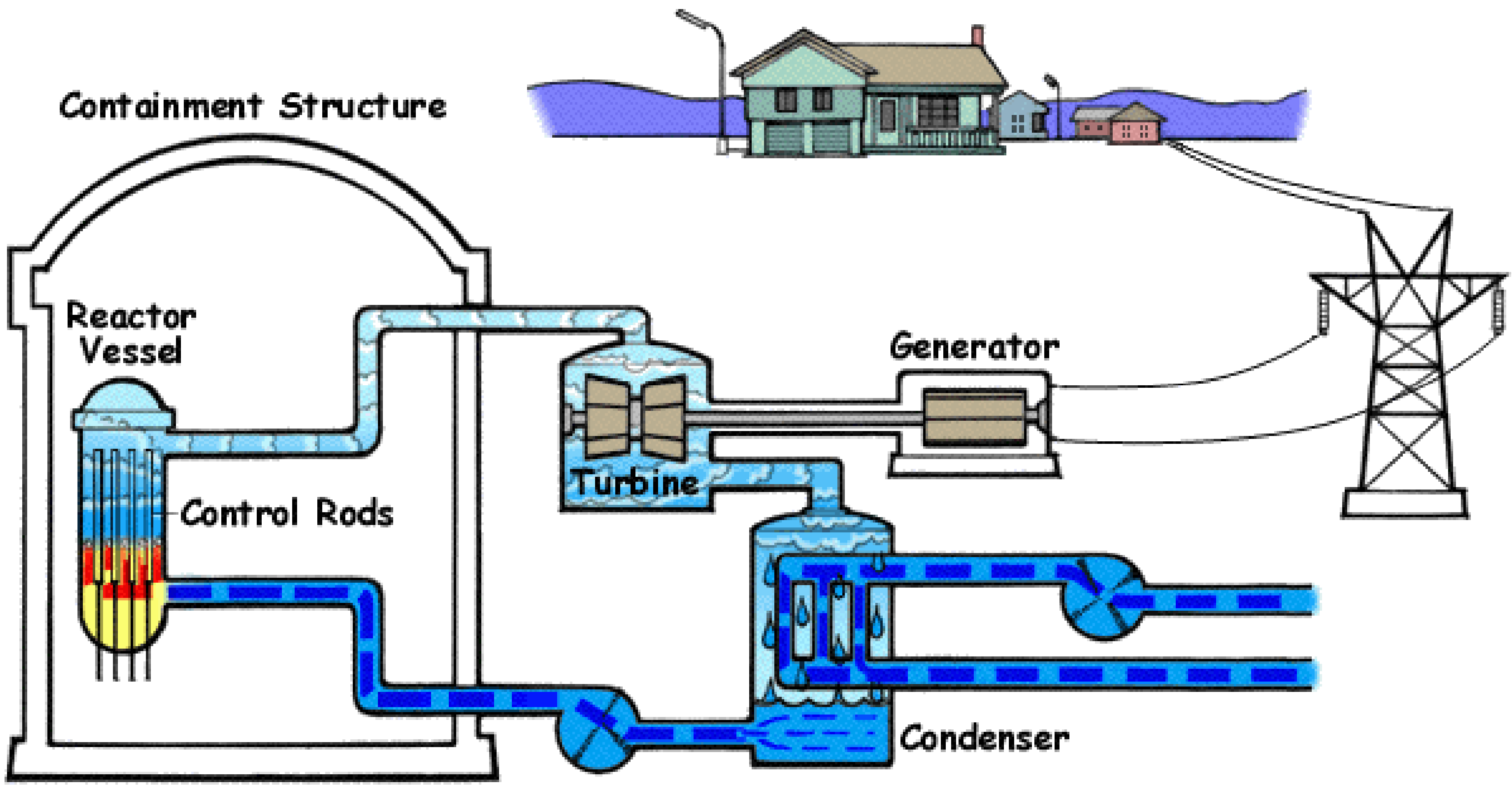
4.Unused steam is exhausted into the condenser, condensed into water, pumped out of the condenser, reheated and pumped back to the reactor vessel.

5. The reactor's core fuel assemblies are cooled by water circulated using electrically powered pumps.

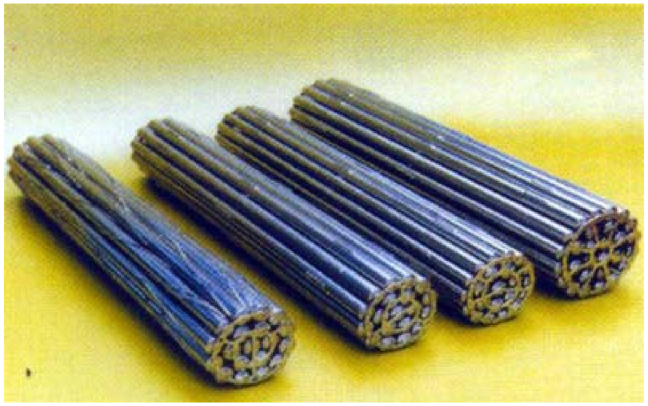
6.Pumps and other operating systems in the plant receive their power from the electrical grid. If offsite power is lost emergency cooling water is supplied by other pumps, which can be powered by onsite diesel generators.

7.Boiling-water reactors contain between 370-800 fuel assemblies.

The Boiling Water Reactor

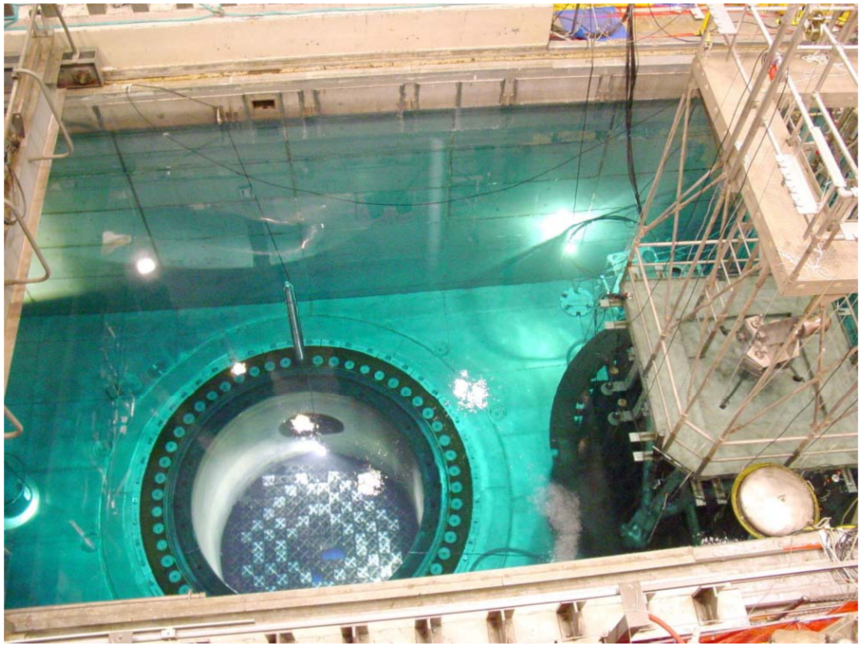


Nuclear Reactors: Nuclear Fuel



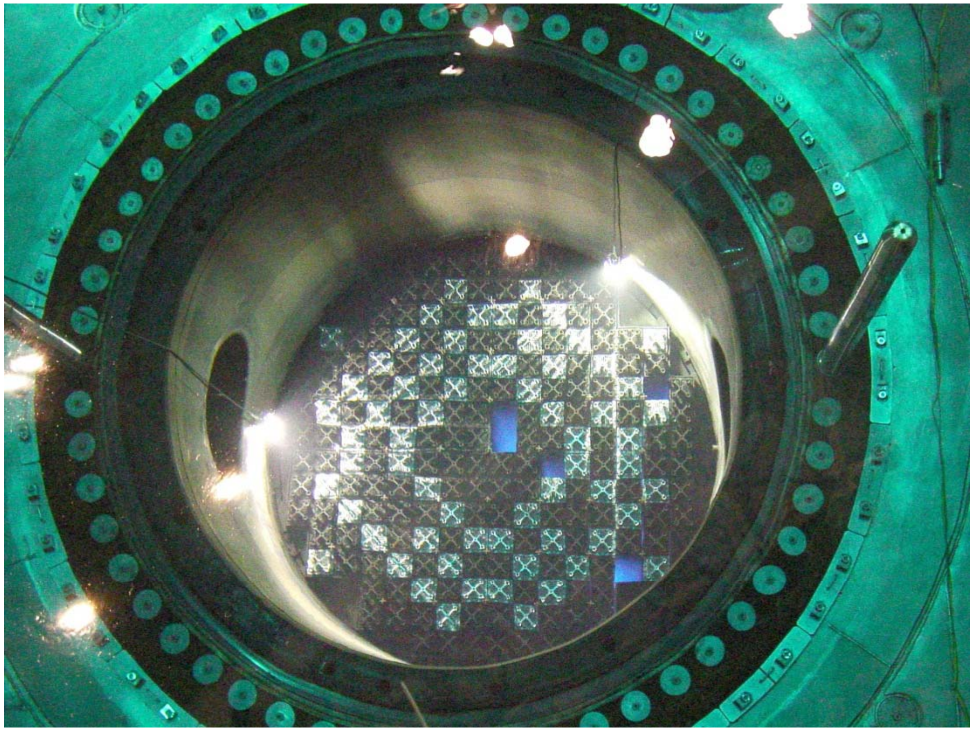
- The most common fuel for a nuclear reactor is usually uranium dioxide pressed into pellets
- The UO_2 is produced from enriched UF_6 gas.
- The pellets are encased in long metal tubes, usually made of zirconium alloy (zircalloy) or stainless steel, to form fuel rods.
- The fuel rods are sealed and assembled in clusters to form fuel assemblies for use in the core of the nuclear reactor.

Nuclear Reactors: Nuclear Fuel



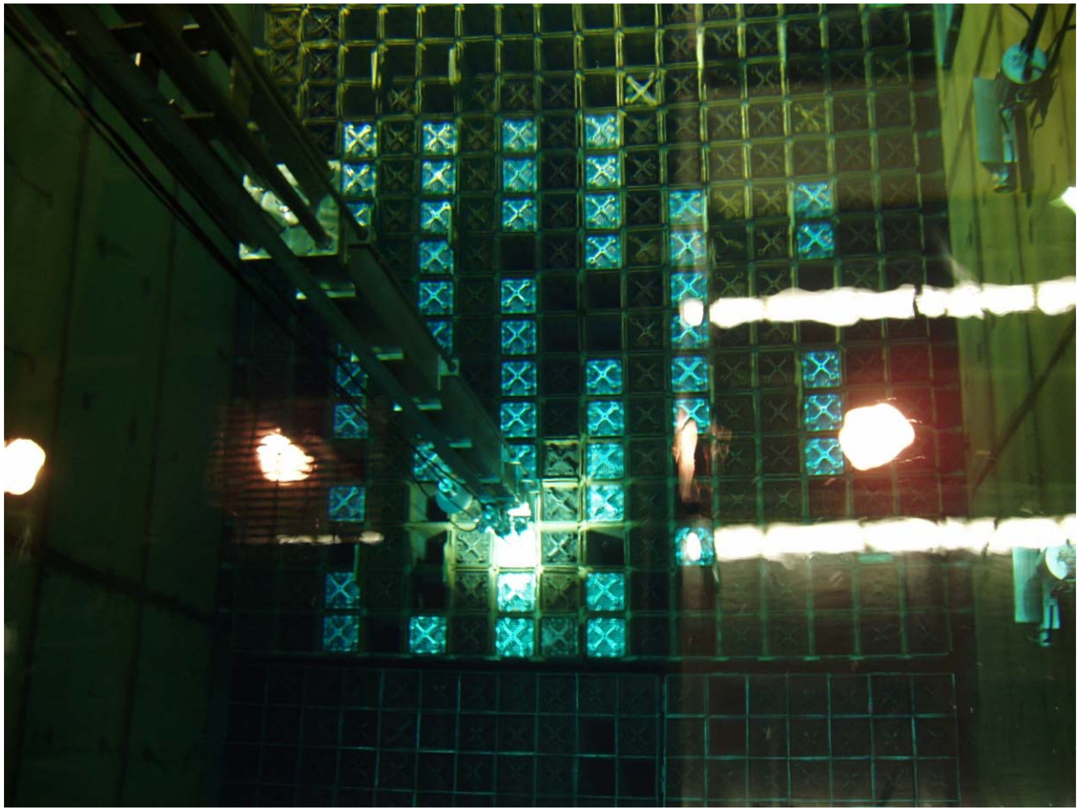
Left: Looking into the core of a pressurized water reactor.

Below: A close-up view of the reactor core.



Photos courtesy of Palisades Power Plant

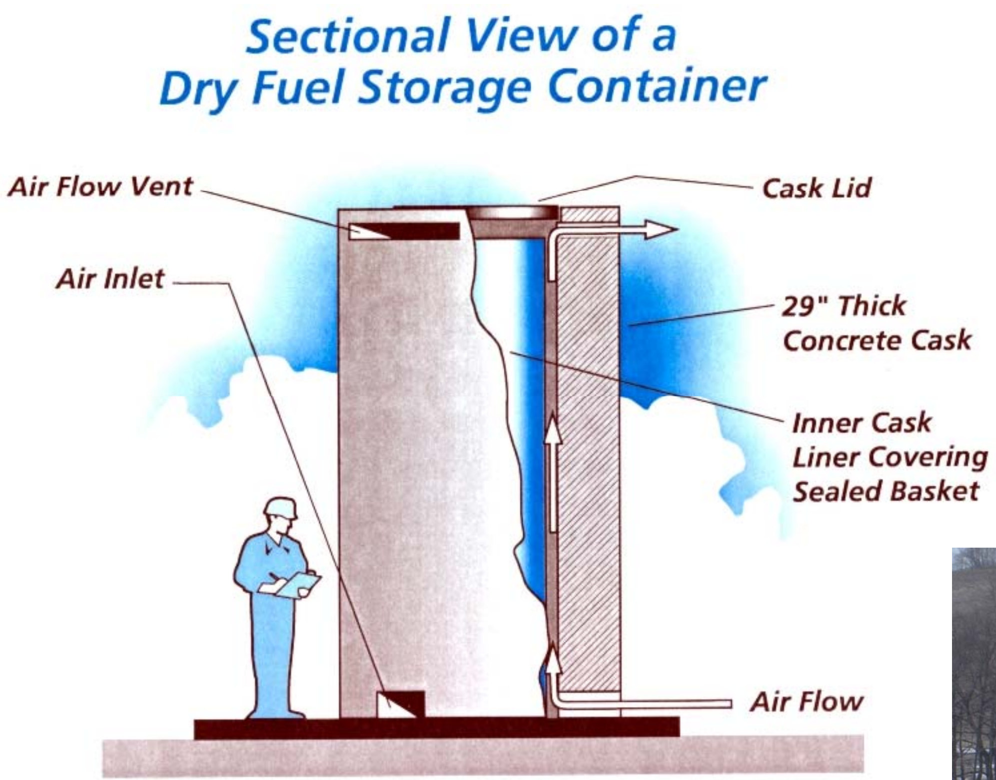
Nuclear Reactors: Nuclear Waste



The spent fuel pool

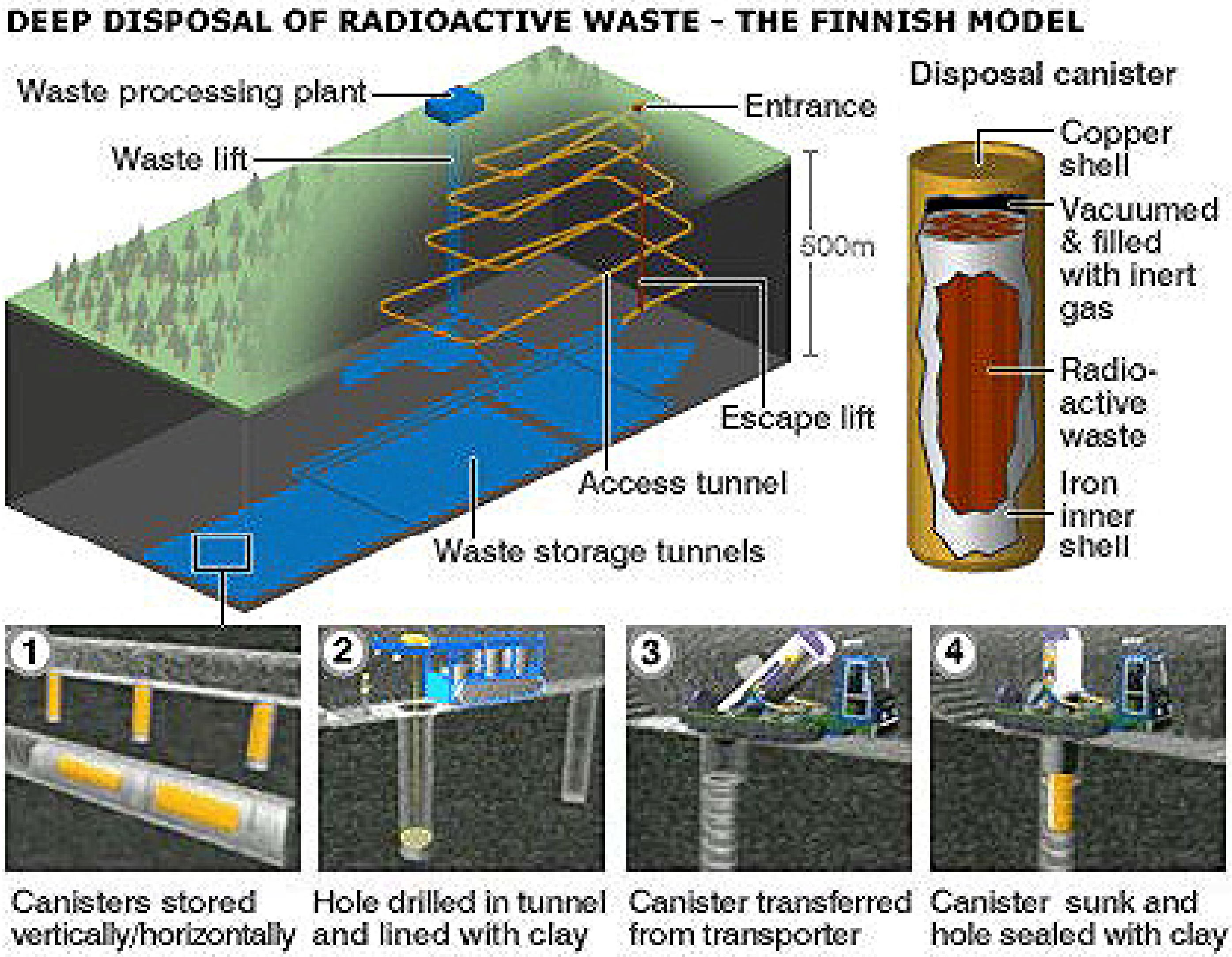
Photo courtesy of Palisades Power Plant

Nuclear Reactors: Nuclear Waste



Pictures courtesy of Palisades Power Plant

Nuclear Reactors: Nuclear Waste



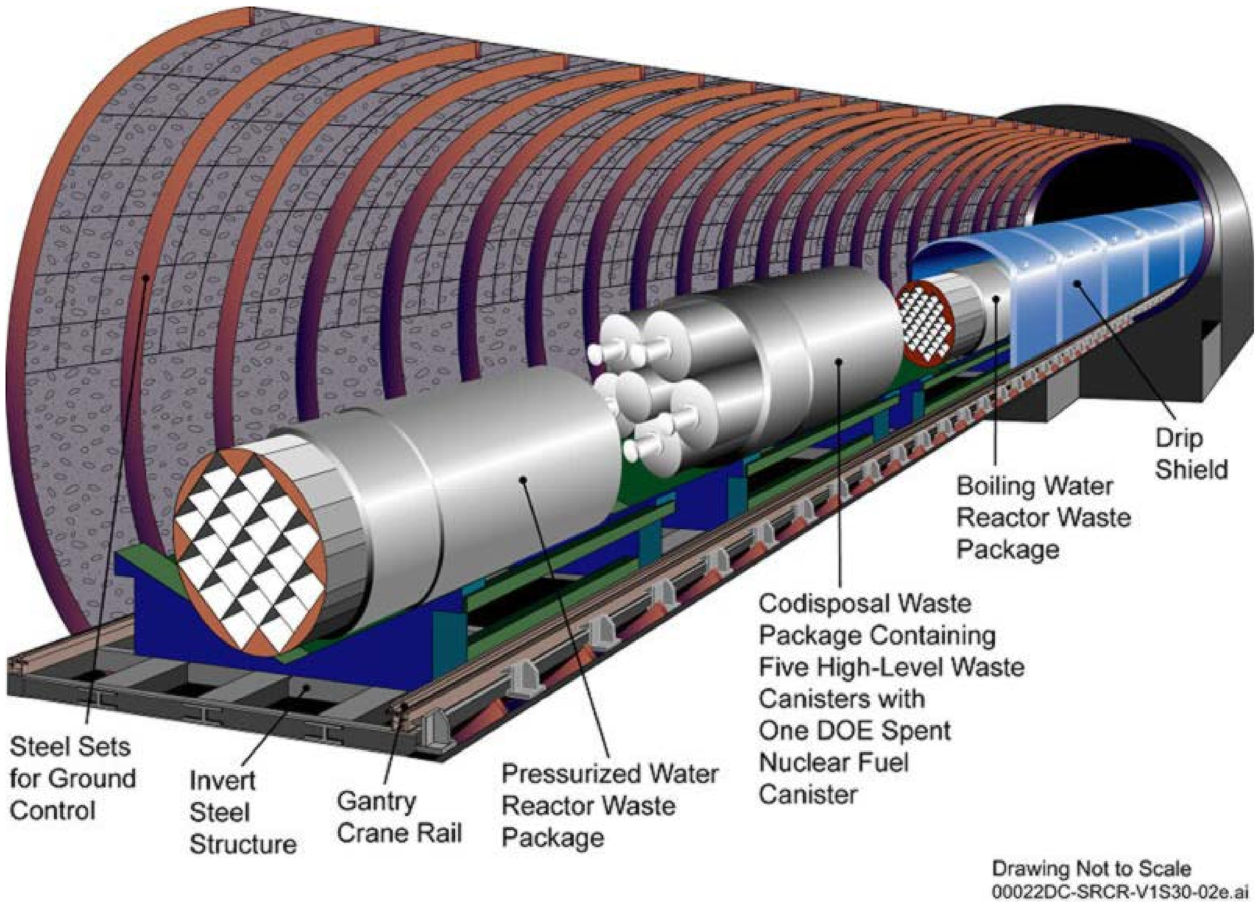
Nuclear Reactors: Nuclear Waste

Yucca Mountain, Nevada Test Site, Nevada

Nuclear Reactors: Nuclear Waste
Yucca Mountain, Nevada Test Site, Nevada

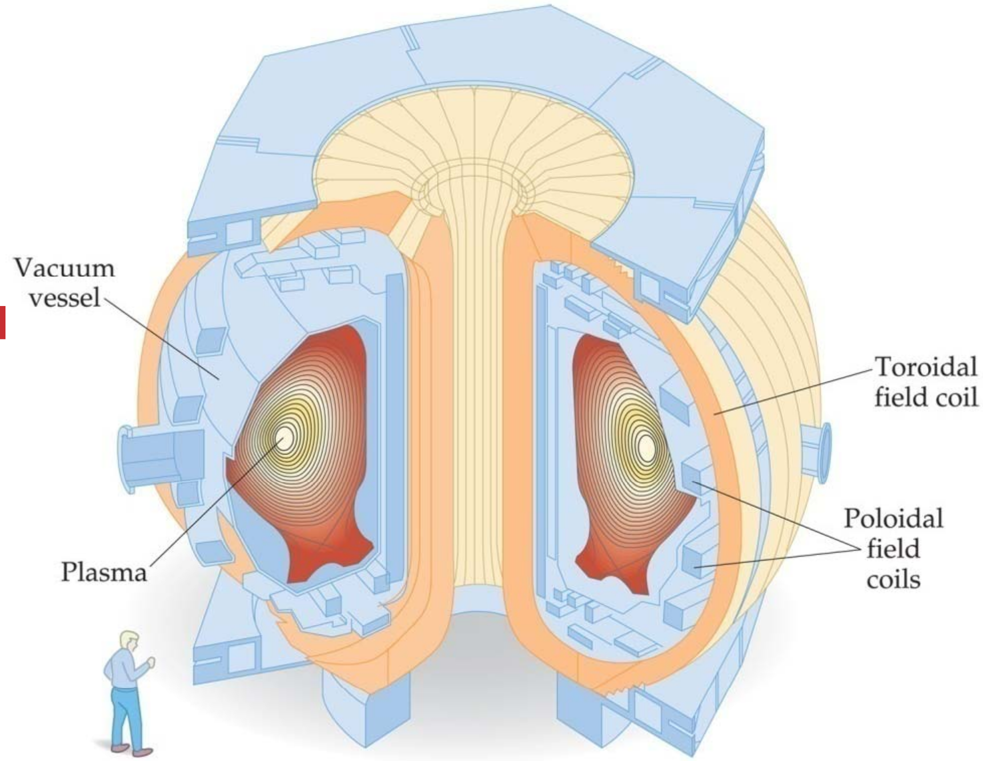
Nuclear Reactors: Nuclear Waste

Yucca Mountain, Nevada Test Site, Nevada



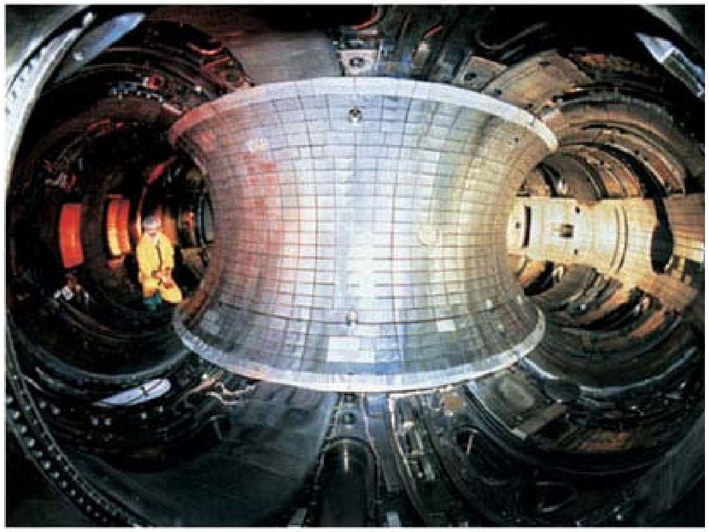
Nuclear Fusion

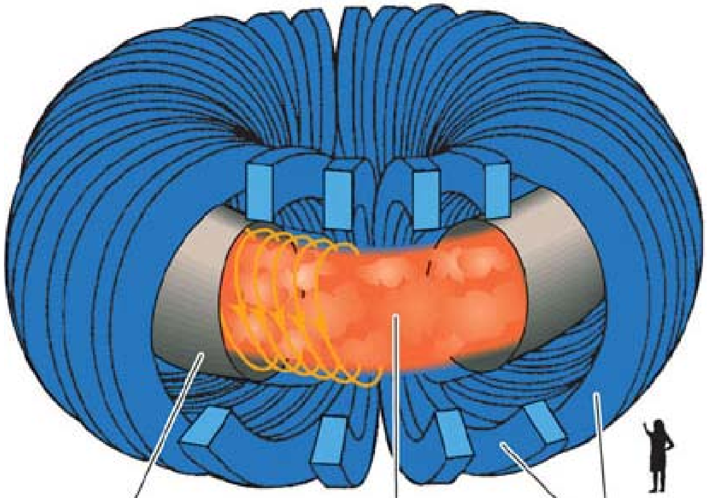
- Fusion would be a superior method of generating power.
  - Once fusion reactors are perfected, the products of the reaction will not be radioactive. (There are radioactive products of hydrogen fusion.)
  - In order to achieve fusion, the material must be in the plasma state at several million Kelvin's.



Nuclear Fusion

- A Tokomak reactor, like the one shown on the right, show promise for carrying out these reactions.
- Magnetic fields are used to compress materials to initiate the reaction.
- Today, lasers may be used to initiate the fusion reaction.
- Magnetic fields are used to contain the fusion reactants and products.





Biological Effects of Exposure to a Single Dose of Ionizing Radiation

Dose (rems)	Probable acute (immediate) effect	Probable delayed effect
0-25	Little or no detectable effect	Possible premature aging, small possibility of mild mutation in offspring, small risk of future tumors.
25-50	Small decrease in blood lymphocytes (white blood cells)	Possible premature aging, possibility of mild mutation in offspring, small risk of future tumors. Slight increase in susceptibility infections.
50-100	Lesions, slow or non-healing. Decrease in blood lymphocytes. Radiation sickness.	Individual susceptible to infection. Genetic damage. Probable damage to offspring, benign or malignant tumors, premature aging, and probable shortened lifespan.
100-200	Nausea, vomiting, diarrhea, lesions, loss of hair – with probable recovery in approximately 6 months. Premature aging – graying hair, skin pigmentation, flabby muscles, “tired blood”, and lowered disease resistance.	High probability of cancer (leukemia) or benign tumors within 10 years. Shortened lifespan. Genetic effects.

Biological Effects of Exposure to a Single Dose of Ionizing Radiation (continued)

Dose (rems)	Probable acute (immediate) effect	Probable delayed effect
200-500	Nausea, vomiting, diarrhea, lesions, loss of hair, hemorrhaging (vomiting of blood, bloody discharge from bowels or kidneys, nose bleeding, etc.), non-healing ulcers, destruction of bone marrow, lymph nodes and spleen with decrease in blood cells. Probable death to 50% of population affected	Person may be ill for several days, then, feel normal for a few weeks as the body deteriorates until infection, anemia, or hemorrhaging results in death. Survivors may experience keloids (scarred skin), ophthalmological disorders, blood dyscrasis, malignant tumors, and psycho neurological disturbances.
500+	Fatal – immediate or within a few days Note: cells irradiated with 500-50,000 rads may survive but lose ability to reproduce and can grow to 1 mm in diameter before dying.	

Biological Effects of Exposure to a Single Dose of Ionizing Radiation (continued)

Dose (rems)	Probable acute (immediate) effect	Probable delayed effect
10,000 Intense burst	Penetrating radiation: nervous system breakdown, person may be confused and clumsy, then, lapse into coma. Death within a few days. Non-penetrating radiation (from fallout): may not be as severe. Mostly skin reaction, burning, itching, dark patches, raised areas, and loss of hair.	
100,000 Intense burst	Penetrating radiation: extensive ionization of nerve cell cytoplasm causing central nervous system breakdown. Animal dies in convulsions. Non-penetrating radiation: absorbed in first few mm of tissue. Produces rapid reddening of skin (erythema), death resulting from toxic effects of the burn. (Animal may live long enough to blister.)	

Exposure to radiation from common sources

Source	Average Dose, mrem/yr
Cosmic rays	26
Ground: soil, rocks, minerals	30
House construction: stone, adobe, concrete	7
Radon gas	200
Food, water, air	24
Fallout (from air testing of nuclear weapons)	4
Medical x-rays	10 to 2000
Dental x-rays: routine bitewing series	40
Airplane travel	0.5/hour
Household: TV viewing or computer CRT	0.15/hour
Household: smoke detectors	0.002 each
Sleep with significant other	0.1

Some radioactive isotopes used in medicine

Name	Symbol	Half-life	Use
Carbon-11	${}^{11}_{6}C$	20.3 min	Brain scan
Phosphorus-32	${}^{32}_{15}P$	14.3 days	Eye tumors
Chromium-51	${}^{51}_{24}Cr$	27.7 days	Spleen and gastrointestinal
Iron-59	${}^{59}_{26}Fe$	44.5 days	Bone marrow, anemia
Cobalt-60	${}^{60}_{27}Co$	5.2 years	Cancer treatment
Galium-67	${}^{67}_{31}Ga$	78.3 hours	Whole body scan
Technetium-99m	${}^{99m}_{43}Tc$	6.01 hours	Brain, liver, kidney, bone scans
Iodine-131	${}^{131}_{53}I$	8 days	Thyroid treatment