Aalto University
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A short history of nuclear technology and its applications

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1895: inspiration to a new line of research

Wilhelm Röntgen discovered the X-rays on 8 Nov. 1895 while studying the propagation of electric current in very thin gases using a cathode ray tube.

- Observation: covering the tube with black cardboard and making the room dark, a sheet of paper treated with a barium compound began to luminesce up to 2 m from the tube. Photographic plates were exposed as well.
- Röntgen studied the penetration of these ”X-rays” by placing objects of varying thickness in their path and recording the penetrating rays on a photographic plate.
- The first Nobel price in physics (1901).
- **First medical applications in 1900**: The British army in the Sudan used portable X-ray machines to find shrapnel and bullets in wounded soldiers.

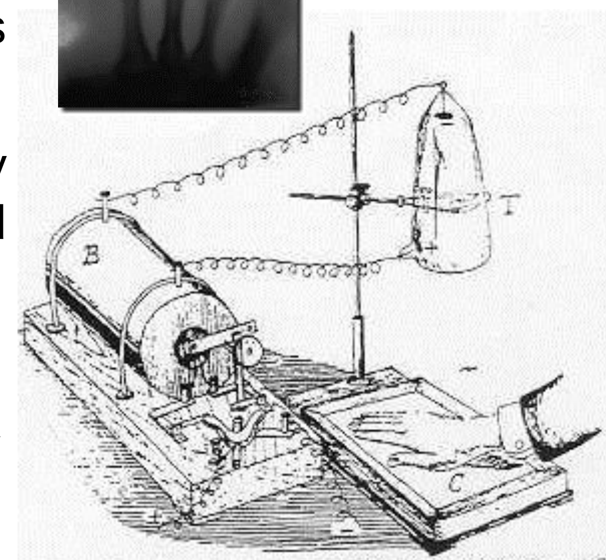
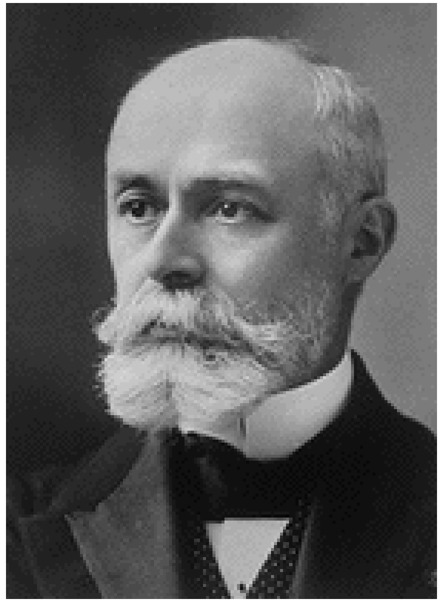


Fig. 1.1. Röntgen's experimental apparatus in 1895. B, Rehmkorff induction coil; C, photographic plate; T, Hittorf-Crookes evacuated tube.

1896: the strange properties of uranium

- Henri Becquerel noticed that a photographic plate covered in thick paper was ruined in the vicinity of uranium salts. He proved that the radiation was emitted by uranium.
- After discussing the recently discovered X-rays with Henri Poincaré, Becquerel decided to study the possible connection of the phosphorescence seen in context of X-rays and the natural radiation of uranium compounds he had discovered.
- Later Becquerel showed that the radiation of uranium was different from X-rays: it ionized gases and its direction could be changed with electric or magnetic fields.
- 1903 Nobel prize in physics (shared with Pierre & Marie Curie, who had made significant contributions in the study of ”Becquerel’s radiation”.)

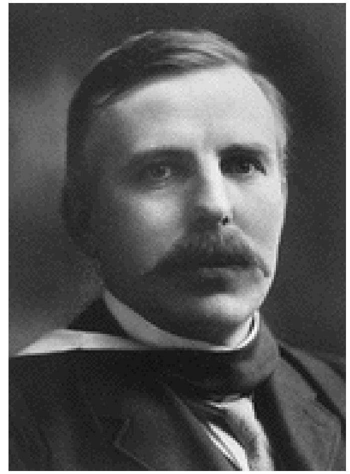


1898: new ideas

- Becquerel's pupil Marie Curie made a groundbreaking hypothesis: *the radiation could be an atomic-level property of uranium*.
- She coined the word ”radioactivity” to describe the radiation of uranium and thorium.
- The Curies also isolated the radioactive elements radium and polonium from the pitchblende of Joachimstal in Bohemia (1898).
- Marie & Pierre Curie: Nobel prize in physics 1903 (shared with Henri Becquerel).
- Marie Curie: Nobel prize in chemistry 1910 for the chemical isolation of radium.

1899: new kinds of rays

- In Cambridge, the New Zealander Ernest Rutherford observed two distinct components in the radiation of radium and its ”emanations”.
- One kind (”alpha”) was stopped by a thin (20 μm) aluminium foil or ordinary paper. The other kind (”beta”) was more penetrating.
- Theory of radioactive decay 1902 (Rutherford & Soddy): *the atoms of a radioactive substance emit alpha or beta particles and turn into other elements*. In 1904 Rutherford proved that alpha rays were positively charged heavy particles.
- Nobel prize in physics 1908.



Rutherford continued his studies of radium in Manchester and developed with H. Geiger a method for observing and counting individual alpha particles. **In 1910 Rutherford’s studies of alpha scattering and the structure of the atom led to the model of the atomic nucleus (1911):** ***almost all of an atom’s mass and all of its positive charge is concentrated in a small space at the center.*** In 1920 Rutherford named the proton and theoretically predicted the neutron.

1905: Newton’s universe crumbles

- Technical assistant (III level) Albert Einstein of the Bern Patent Office publishes his special theory of relativity, and later an addendum containing the famous formula:

$$E = mc^2$$

- Conclusion: *mass is a form of energy. A small amount of mass equals a huge amount of energy, and vice versa.*
- In the same year, Einstein publishes two other important scientific papers on the photoelectric effect and on Brownian motion. (Physics Nobel prize in 1921 for these studies).

Early applications of radioactivity

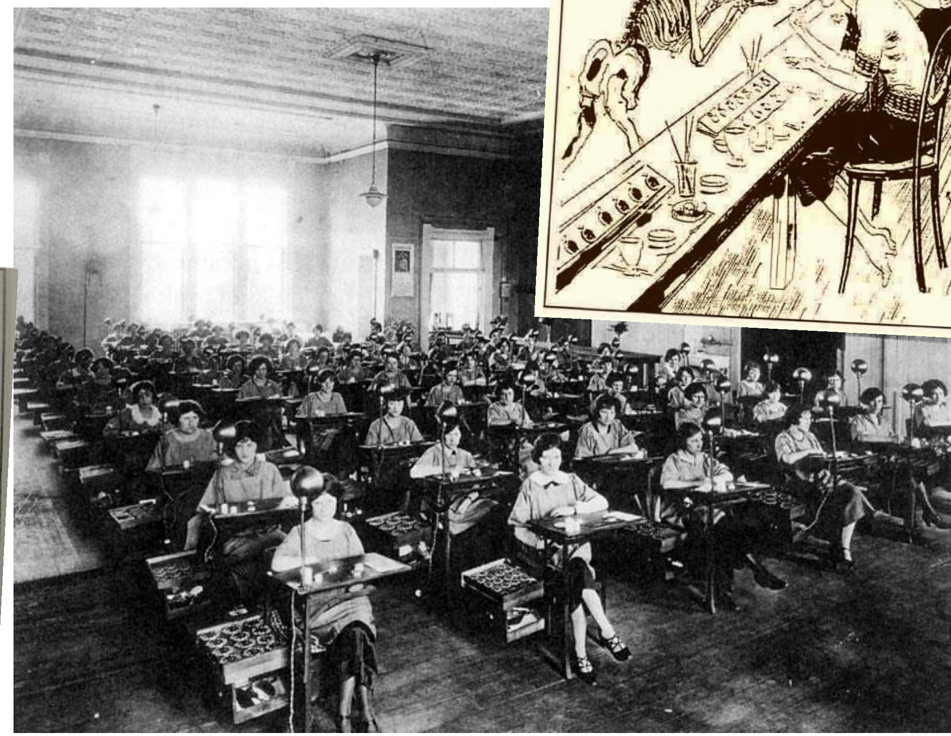
- **1911:** Hungarian Georg von Hevesy has the notion of radioactive markers. As the first application to a biological problem in 1923, he studied the absorption of lead in plants.
- Nobel prize in chemistry,1943.
- Herman Blumgart used the method at Harvard for diagnosing heart diseases in 1927.
- Lots of applications: medical use e.g. in finding tumors and deficiencies in organs, studying food chains in biology, groundwater transport studies in geology, etc.

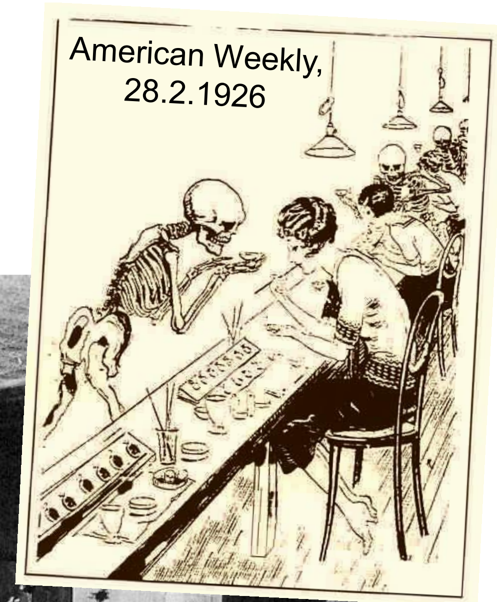
By 1912, 30 radioactive elements were known.

Early applications of radioactivity

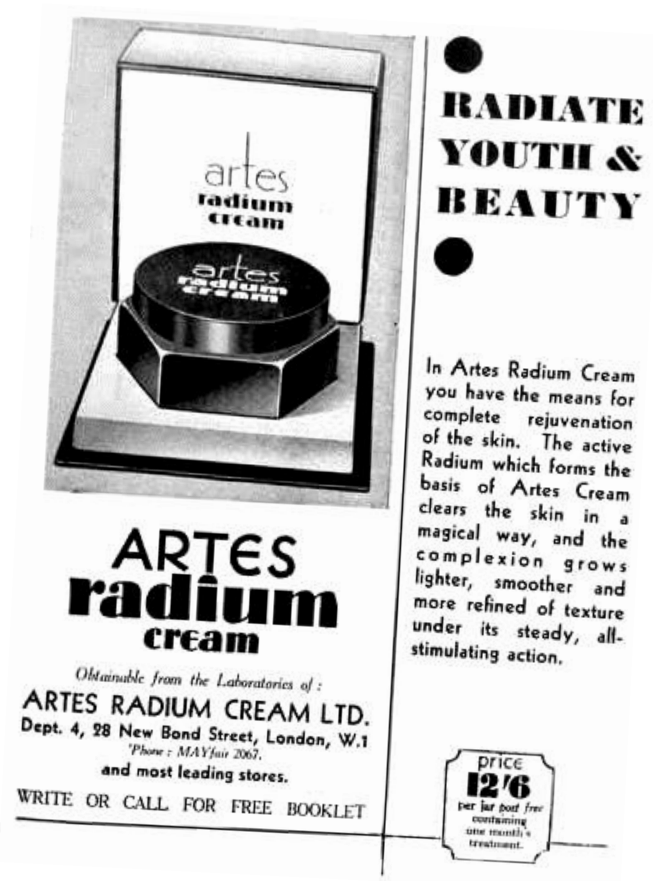
Radioluminescence in watches (already in the 1910's)

- phosphorescent lighting without daylight: radium paint
- adverse health effects of radiation revealed – "Radium girls"





Early so-called ”applications”



Early so-called "applications"

74 kBq/14 ml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The 1930’s: a chain reaction of inventions

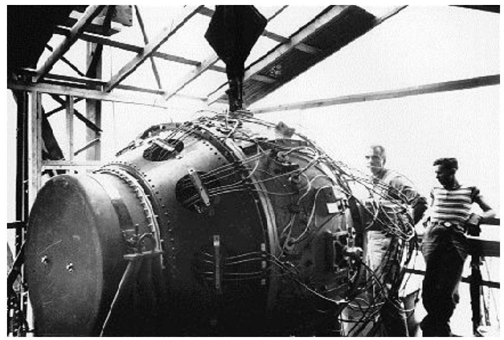
- 1932: James Chadwick proves the existence of neutrons by bombarding a beryllium foil with alpha particles. He also measures the neutron mass from recoil orbits of atoms in a bubble chamber. Nobel prize in physics, 1935.
- 1933: Leó Szilárd’s hypothesis: *”If we were able to find an element that in a collision with a neutron releases two neutrons, such an element could sustain a nuclear chain reaction.”*
- 1934: Enrico Fermi irradiates uranium with neutrons, attempting to produce the first transuranic element. Without realizing it, he produces artificially induced fission for the first time. Physics Nobel prize in 1938 for advances in producing new elements and for studies of nuclear reactions caused by slow neutrons.
- Joulukuu 1938: Szilárd’s hypothesis becomes reality – In Germany, Hahn and Strassmann split uranium atoms into barium ja crypton by neutron bombardment. Energy is also released. As chemists, Hahn and Strassmann cannot interpret their results; Lise Meitner and Otto Frisch explain that heavy elements *capture neutrons, become unstable and split* (”fission”) releasing new neutrons, making a chain reaction possible.




1939: a nuclear arms race begins

- August 1939: Albert Einstein sends to president Roosevelt a letter formulated with Leó Szilárd, warning him about German nuclear research and the possibility of a nuclear bomb.
- September 1939: Germany invades Poland; World War II begins.
- 1940-1942: The Manhattan Project begins, aiming to build a nuclear weapon for the USA before Germany succeeds. A top secret nuclear materials production and research programme with 300.000 employees is launched. J. Robert Oppenheimer is selected as scientific leader.

- May 1945: the war ends in Europe. It is found out that Germany's nuclear programme has not progressed far and is nowhere near building a bomb.
- 16 July 1945: the first nuclear test explosion in Alamogordo, New Mexicossa.
- 26 July 1945: In Potsdam, the Allies require Japan's unconditional surrender. Japan refuses.



1945: the fear of nuclear energy is born

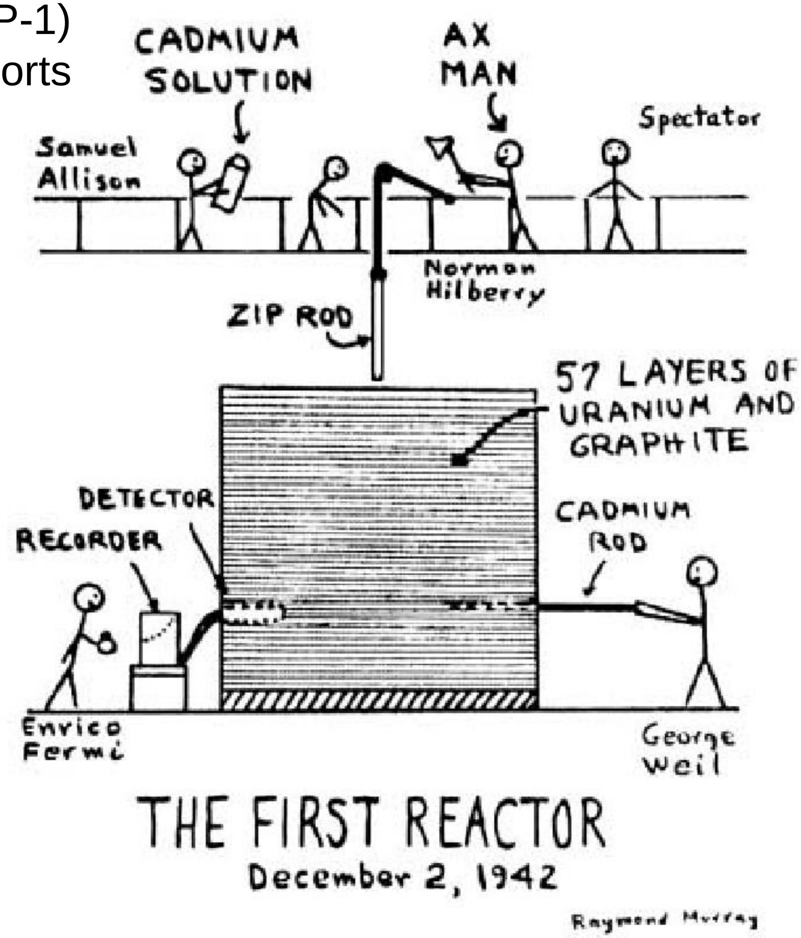
Hiroshima, 6 August 1945

A new nuclear arms race begins after the Soviet Union tests its nuclear bomb on 29 August 1949.

First U.S. H-bomb test on 1 November 1952, Soviets follow suit in August 1953; missile technology, Cold War, etc. – watch ”Atomic Café”.

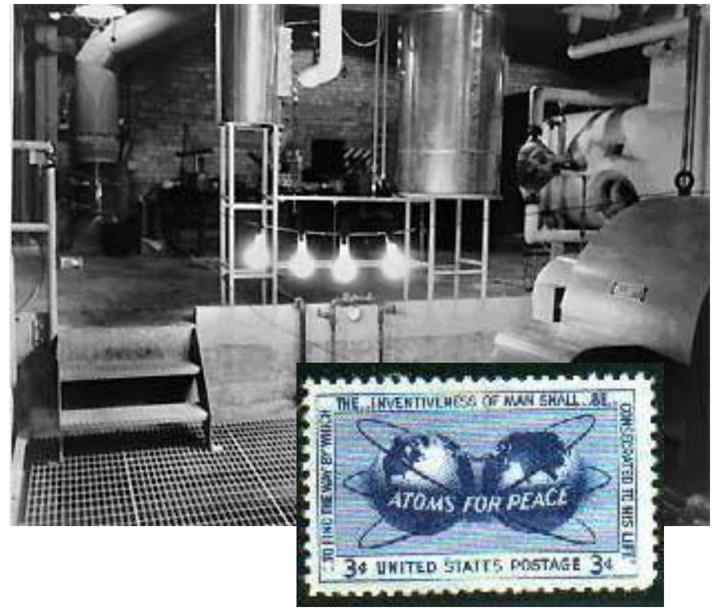
Elsewhere, a bit earlier…

- 2 Dec 1942: the first ”atomic pile”, Chicago Pile 1 (CP-1) of Fermi & Szilárd team goes critical under the sports field of Chicago University campus.
- After hours of systematic testing Fermi records at 15:36 pm: ”The reaction sustains itself.”



Peaceful nuclear technology develops

- August 1946: Oak Ridge National Laboratory sends the first reactor-produced radioisotopes for civilian use to Bainard Cancer Hospital, St. Louis, Missouri. After the war, ORNL produced several inexpensive radioactive compounds for medicinal diagnostics, treatments, research and industrial applications.

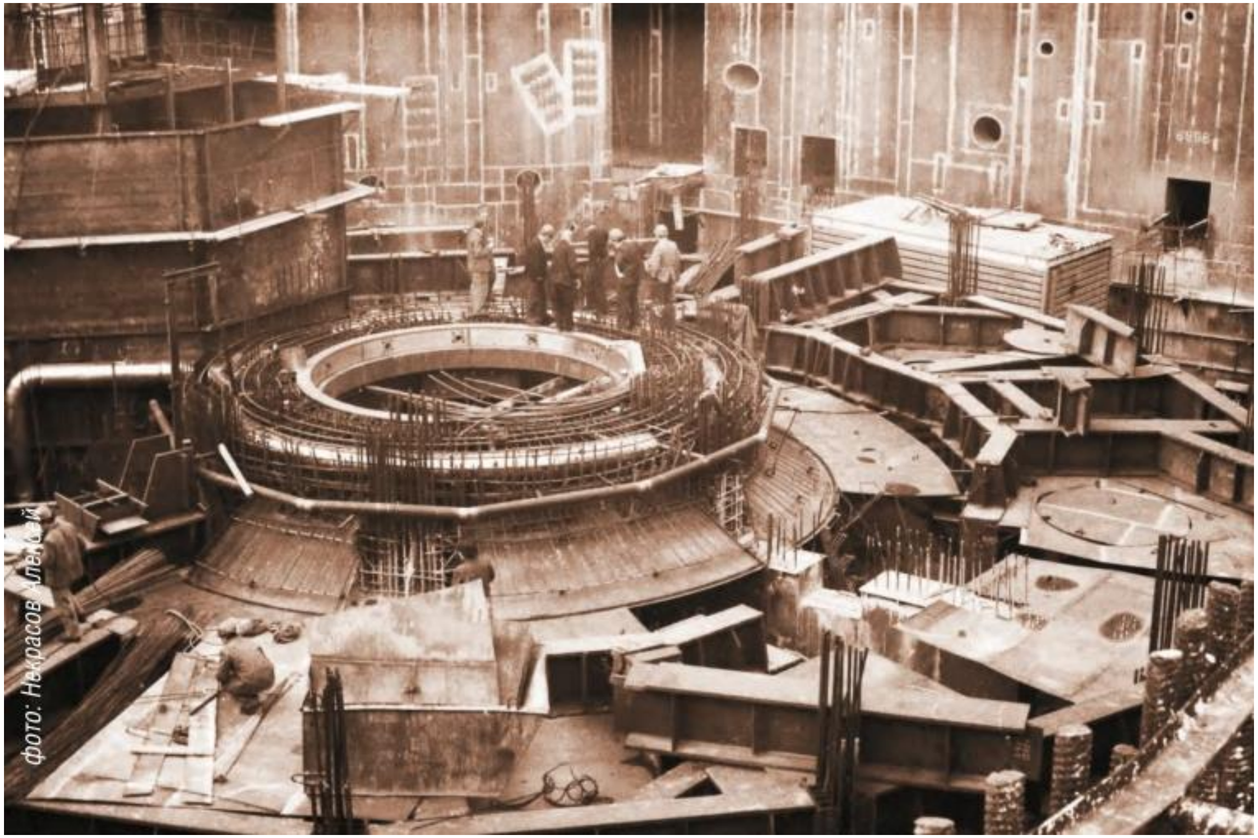


- 20 December 1951: *usable electricity is produced for the first time by a nuclear reactor* (National Reactor Testing Station, Idaho Falls). The experimental breeder EBR-I produced enough power to light four bulbs hanging from a handrail in the turbine hall.
- 1953: EBR-I proved that a *nuclear reactor can produce more fuel than it uses* – it was “breeding” fuel while producing electricity.
- August 1954: Eisenhower’s ”Atoms for Peace” programme to promote peaceful use of nuclear energy.
- 17 October 1956: Queen Elisabeth II inaugurates the first commercial-scale nuclear power station, Calder Hall A in Sellafield. The A and B stations had four graphite-moderated, CO_2-cooled MAGNOX reactors (à 50 MWe). The last of them was shut down in 2003.

Prototypes of power reactors

AM-1 (Soviet Union)

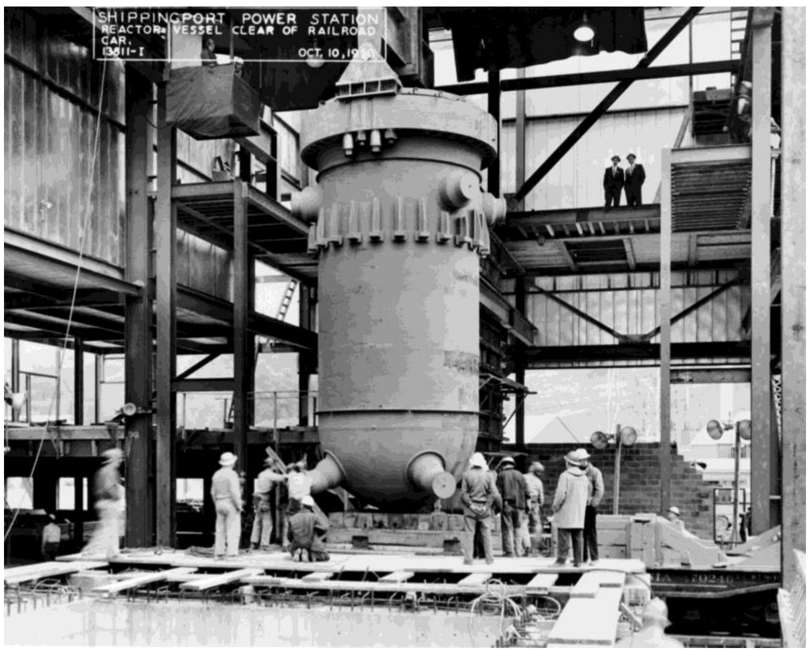
- predecessor of RBMK
- 5 MWe (net) graphite-moderated pressure-tube boiling water reactor
- produced both electric power and heat in Obninsk
- connected to grid on 2 December 1954
- closed down in 2002

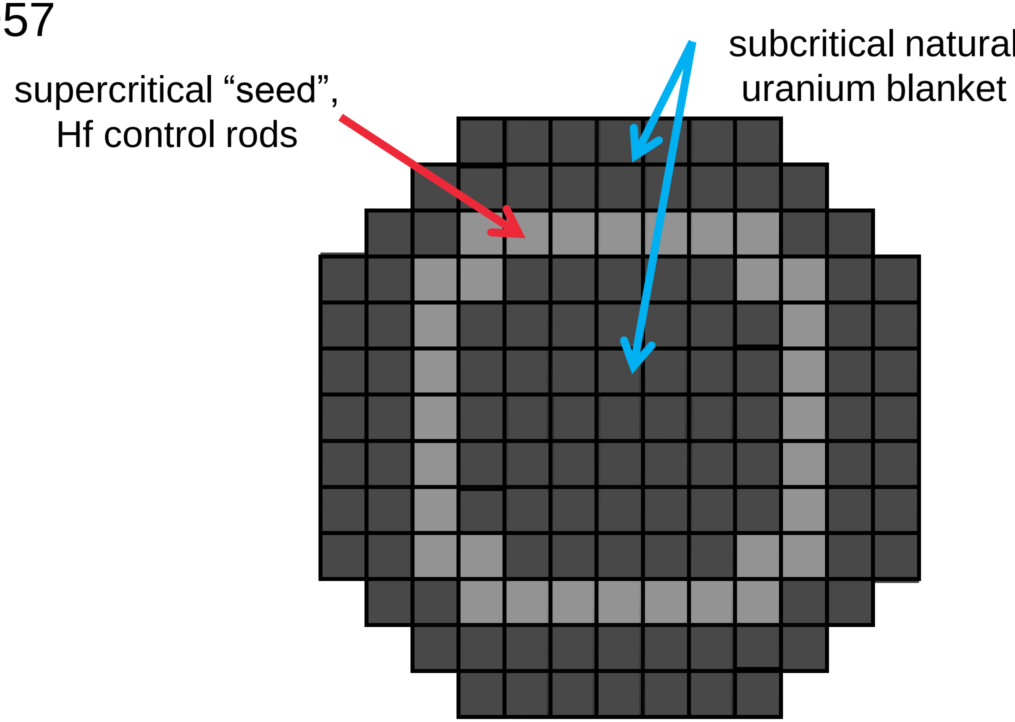


Prototypes of power reactors

Shippingport PWR (USA)

- 60 MWe (net) pressurized water reactor for marine propulsion & power production
- 90% enriched neutron source (metallic uranium), UO_2-blanket (pellets in cladding)
- connected to grid on 2 December 1957

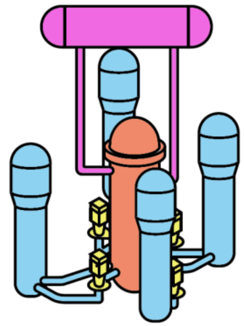




Prototypes of power reactors

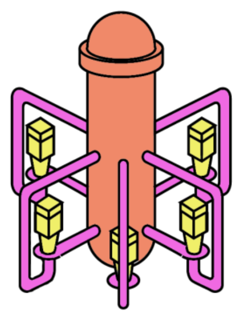
Dresden-1 BWR (GE)

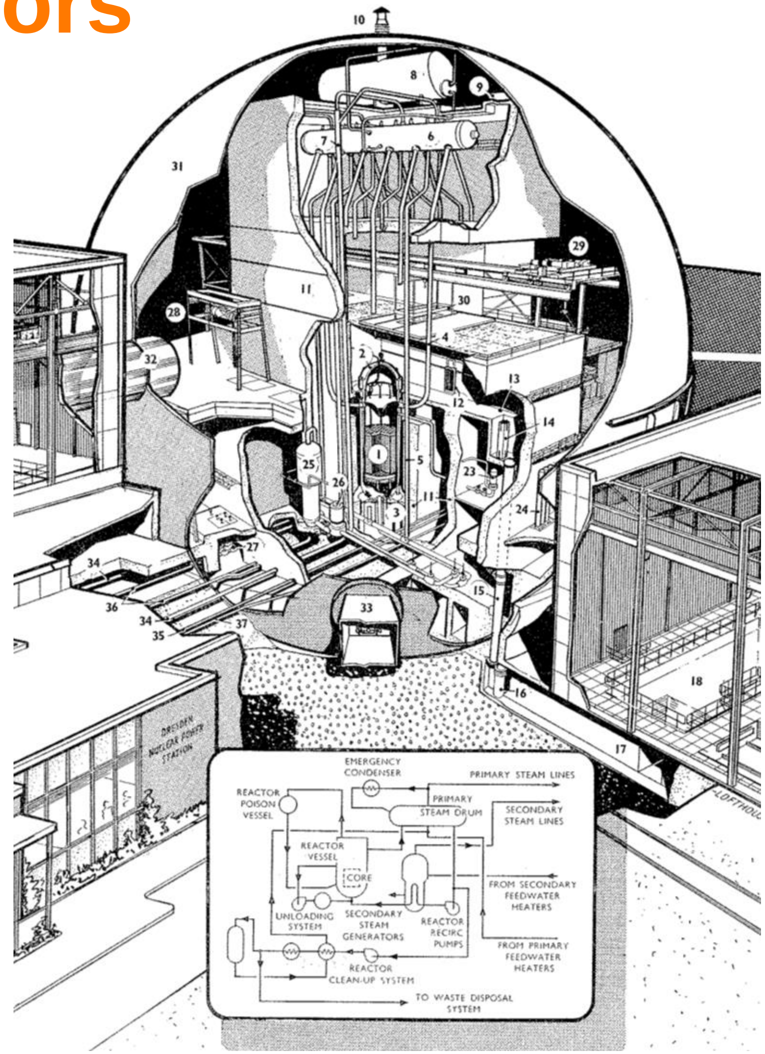
- The first commercial boiling water reactor for energy production
- 197 MWe (net)
- connected to grid 15 April 1960
- not a “genuine” BWR – a separate steam drum and secondary steam generators



Oyster Creek BWR/2 (GE)

- first “genuine” direct steam cycle BWR for energy production
- 515 MWe (net)
- connected to grid 23 September 1969



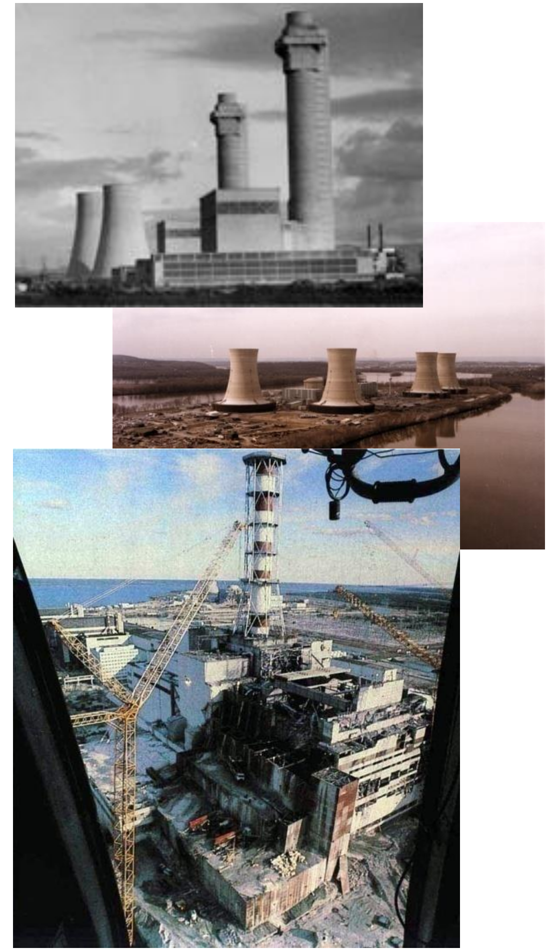


Nuclear reactor generations

- **Generation I:** prototypes of commercial reactors in the 1950's and 1960's, e.g. MAGNOX (UK), Shippingport PWR and Dresden-1 BWR (USA). Two especially important water-moderated, water-cooled light water reactor (LWR) types emerge:
  - **PWR:** Pressurized Water Reactor. The primary circuit coolant water circulates in liquid form at high pressure (>100 bar); in the secondary circuit's lower pressure water is boiled in a heat exchanger (steam generator) to provide steam for turbines.
  - **BWR:** Boiling Water Reactor. No separate secondary circuit, the coolant water boils in the reactor vessel (at ~70 bar) and the steam is led to the turbines.
- **Generation II:** Commercial power plants built in the 1970's and 1980's. E.g. basic PWR, BWR, CANDU, RBMK and AGR.
- **Generation III:** LWR's further improved from the basic types to be more economical, safer and more efficient, e.g. ABWR, APWR, VVER-1000 ja AP600. Already in use. Even more advanced versions designed in the 1990's form **Generation III+**.
- **Generation IV:** New designs expected to be in use by the 2030's. Extremely safe and economical with minimal nuclear waste production, unsuitable for producing nuclear weapons material.

Worst blows to the reputation

- 10 Oct 1957: A fire in the graphite moderator of one plutonium-producing air-cooled reactor in Windscale (now Sellafield) – the first significant release of radioactivity to the environment.
- 28 Mar 1979: A serious accident in Three Mile Island power station unit 2 in Harrisburg,4 Pennsylvania. The first core meltdown accident of a commercial power reactor, originating from a stuck valve and inadequate control room instrumentation. The reactor vessel did not fail, no significant releases of radioactivity to the environment.
- 26 Apr 1986: Steam explosion and graphite fire in one of Chernobyl’s graphite-moderated, water-cooled RBMK reactors spread a significant portion of the reactor’s radioactivity inventory to the environment. Main reason: gross negligence of the safety and operating instructions of the reactor.
- 11 Mar 2011: Fukushima I-1…I-3, a station blackout / core meltdown accident caused by an earthquake and a related tsunami. Significant damage and releases to the environment. Main reason: inadequate preparation for natural disasters.



Nuclear energy in Finland

- 1958: Subcritical ”Miilu”, Helsinki University of Technology
- Late 1950’s: Triga Mk II pool reactor FiR-1 for research use (HUT/VTT). Developed into a BNC therapy station for the treatment of inoperable tumors in the 2000’s.
- 1977: The first unit of the first nuclear power station in Finland is completed in Loviisa. Two Soviet-made VVER-440 PWR’s, originally rated at 440 MWe each (now 510).
- 1978: The first unit of Olkiluoto power station near Pori is completed. Two Swedish-made ABB Atom BWR’s with net output of 660 MWe each (now 860 MW due to modernizations in steam circuit).
- Both power stations are operated at world-leading capacity factor: 80-90% in Loviisa, more than 90% in Olkiluoto. The power stations produce more than 25% of Finland’s electricity acquisitions.
- Future: 1600 MWe EPR under construction at Olkiluoto, two new power plant applications have been approved in Parliament on 1 July 2010 (TVO & Fennovoima).