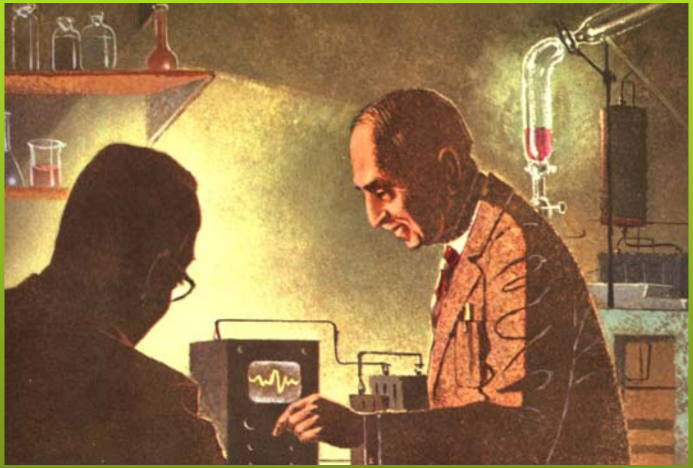
The ATOMIC NUCLEUS

NUCLEAR FISSION- a Tunneling Process

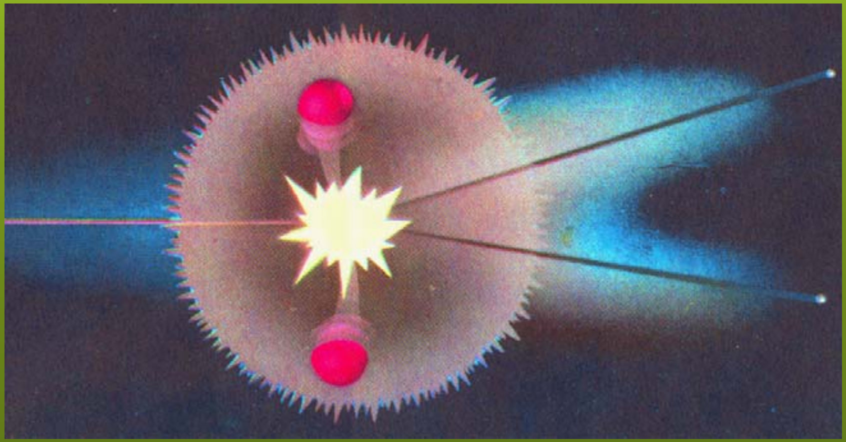
Kaiser Wilhelm Institute (Berlin) in 1938

Nuclear fission, described on p. 4.30, is an extremely rare process. A **U** nucleus will on average take 4.5 billion yrs. to undergo fission- although the frequency of oscillations inside the nucleus is ~ 10^{21} per second. This means a tunneling probability ~ 10^{-38} – a very small number. Actually all heavy nuclei down to **Fe** decay, but only a few do it fast enough to be seen, except for very heavy ones- which decay rather fast. The tunneling rate increases with nuclear mass because of the increased Coulomb repulsion between the protons.



Hahn & Strassmann – the discovery of nuclear fission in Berlin (1938)

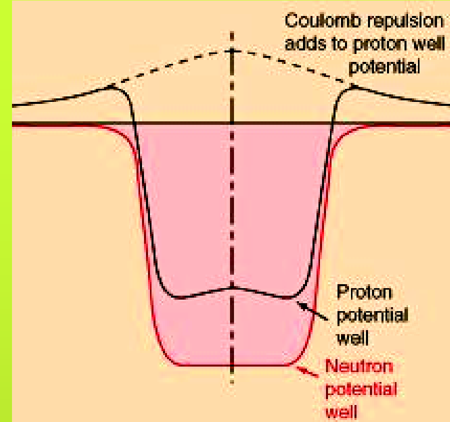
If a nucleus absorbs neutrons it becomes unstable, undergoing fission with emission of several neutrons- giving the possibility of a chain reaction. All this was worked out by Otto Frisch & Lise Meitner within days of hearing of the discovery of fission!



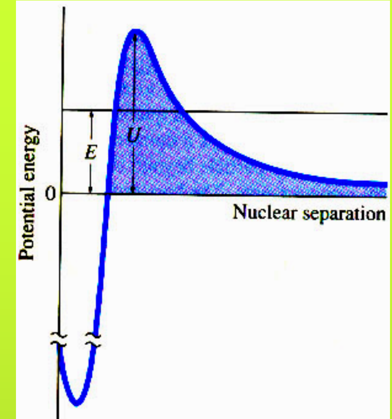
Neutron-induced fission- with accompanying emission of 2 neutrons

ENERGETICS of NUCLEAR FISSION

Neutrons & protons in the nucleus are strongly attracted to each other at very short range by the nuclear *strong force*, but protons also repel each other via long-range *Coulomb interactions.* The net result is that small nuclei are stable (all nucleons feel each other's strong force) but large heavy nuclei are not- they can reduce their energy by splitting off parts, although there is a large energy barrier to doing this.



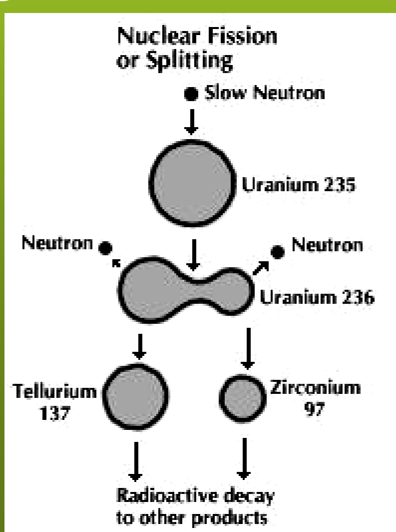
Short-range potential acting on nucleons in a nucleus

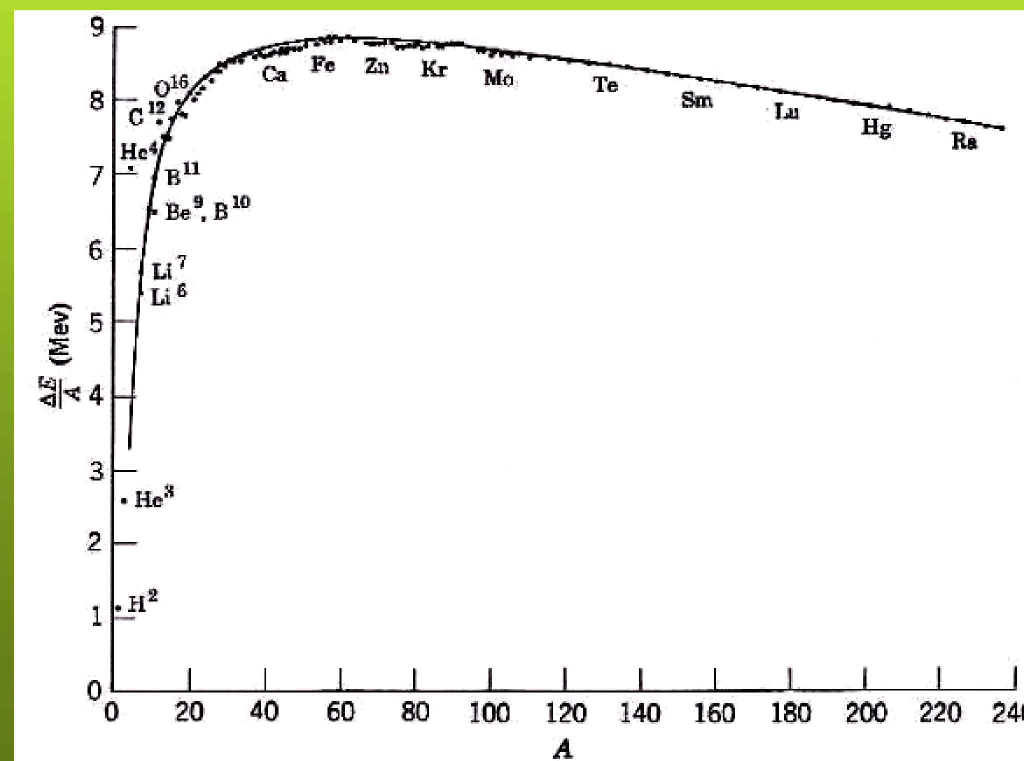


Nuclear potential at longer ranges


H Yukawa (1907-1981)

The theory of the strong force was first given in 1934, in fundamental work by Yukawa. He postulated a new kind of 'quantum field', generalising the quantum EM field, calling the corresponding massive particles 'mesons'. π-mesons were discovered in 1947 by Powell.



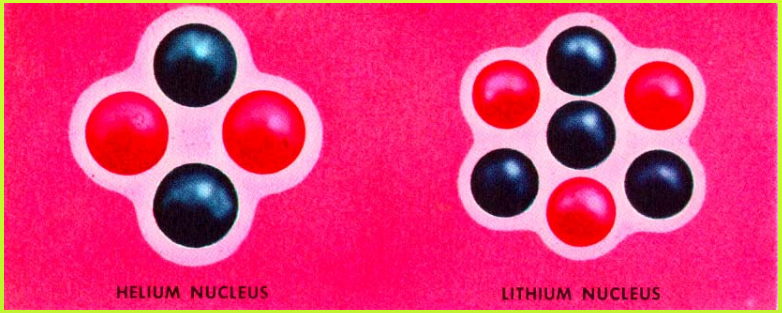


Binding energy (attractive) between nucleons in different nuclei

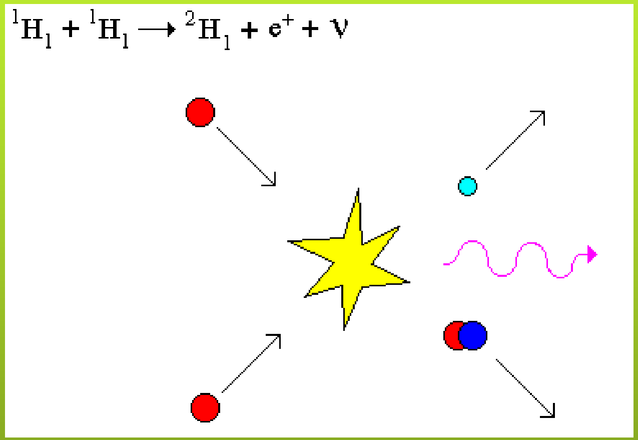
NUCLEAR FUSION

If high-energy charged particles approach a charged nucleus they will usually "bounce off" the strong repulsive potential (recall Rutherford scattering, page 4.15). However there is also a small probability they can tunnel through the barrier and fuse with the nucleus, forming a new heavier nucleus.

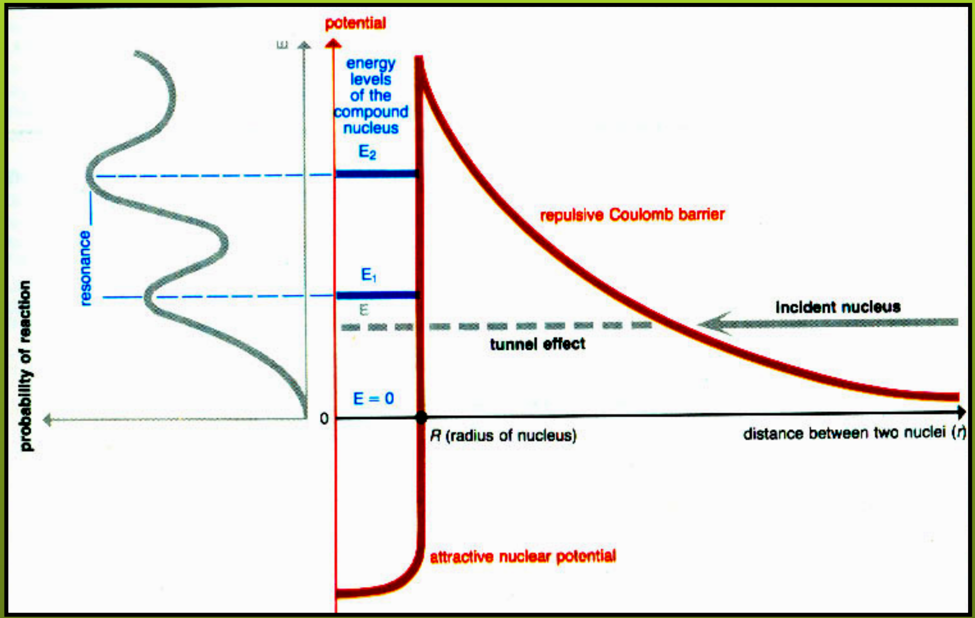
This will get rid of its excess energy by re-emitting photons or a few sub-nuclear particles (protons, neutrons, etc)- which can then fuse with other nuclei.



A He-4 nucleus (2 protons, 2 neutrons) +H-3 (tritium-1 proton + 2 neutrons) gives Li-7



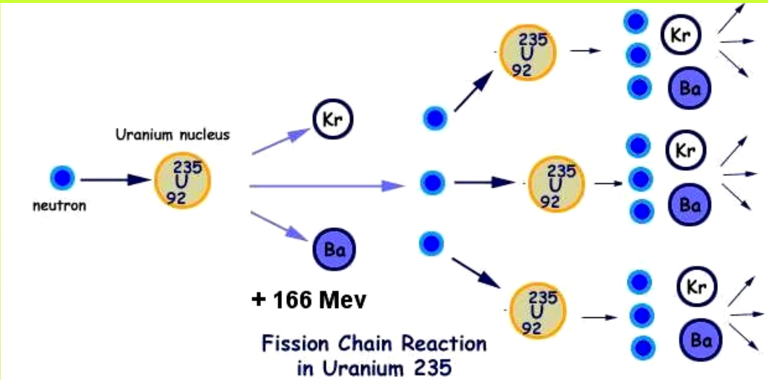
2 H fusing to give deuterium, with emission of a photon and neutrino.



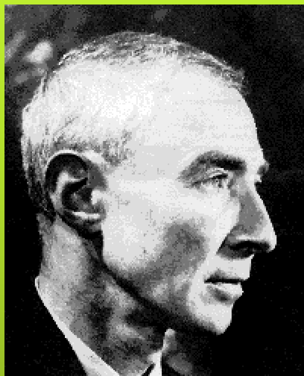
A high energy particle coming from the right can tunnel through the Coulomb barrier to an energy level in the nucleus- a bound state of both together

At low E we get scattering- the tunneling probability is very small. To increase it we need higher energy particles- fusion occurs if the nuclei are rushing around at very high T (10^8 K in a nuclear fusion bomb). The photons (γ rays) & other particles emitted, come out with similar energies.

The ATOMIC BOMB (USA)



The possibility of a chain reaction involving U nuclei led Einstein, in a famous letter to FD Roosevelt, to warn the US President that the Nazis might be able to make an atomic bomb – this launched the 'Manhattan project'.



JR Oppenheimer (1904-1967)

In Los Alamos, New Mexico, a large team led by JR Oppenheimer designed and built the A-bomb. This was primarily a theoretical *tour de force*, in which H Bethe, E Fermi, and J von Neumann played key roles. When the bomb was finished, the Germans were already defeated – in a controversial move, H Truman dropped it on Japan

Hiroshima, Pre-attack - April 13, 1945; 1 km

Hiroshima, Post-attack - August 11, 1945; - Ground Zer

S Ulam, RP Feynman, and J von Neumann at Los Alamos

The SOVIET A-BOMB: The ARMS RACE

Churchill, Roosevelt, & Stalin at Yalta (Feb 1945)

The Soviet scientific team led by Igor Kurchatov, under the brutal control of Beria, was apprised of American efforts via the spying of K Fuchs. On Aug 29, 1949, the Soviets exploded their 1st atomic bomb, and continued at top speed to develop the 'Super', later called the 'fusion' or 'H-bomb' (see next page). Thus began the Cold War, between former allies. The death of Stalin in 1953 changed the Soviet regime but not the conflict, inflamed in the USA by fanatics like Gen. Curtis LeMay and Sen Joe McCarthy.

I Kurchatov (1903-1960)

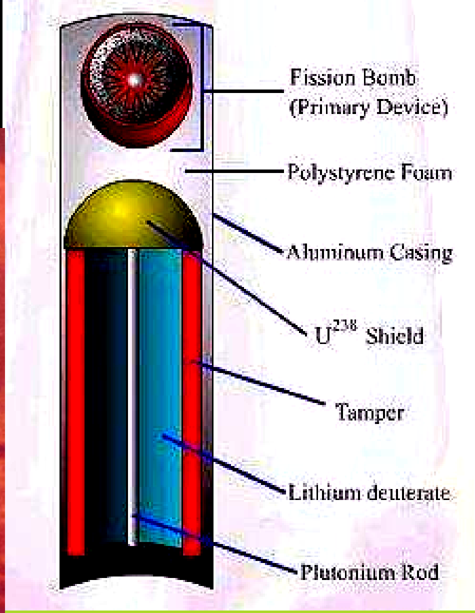
On at least one occasion, in late Oct 1962, the world came to the brink of all-out nuclear war, during the Cuban missile crisis. From then until the 1990's, the possible complete destruction of civilisation was the central factor governing geopolitics. In the USA and the Soviet Union, an important fraction of the economy was devoted to the arms race during this period. During this period the technology of nuclear arms changed very little. Instead huge developments occurred in electronics, computing, and telecommunication.

The end of the Cold war brought an end to the nuclear arms race (although not to nuclear arms stockpiles). However it left deep changes in science (page 5.7)

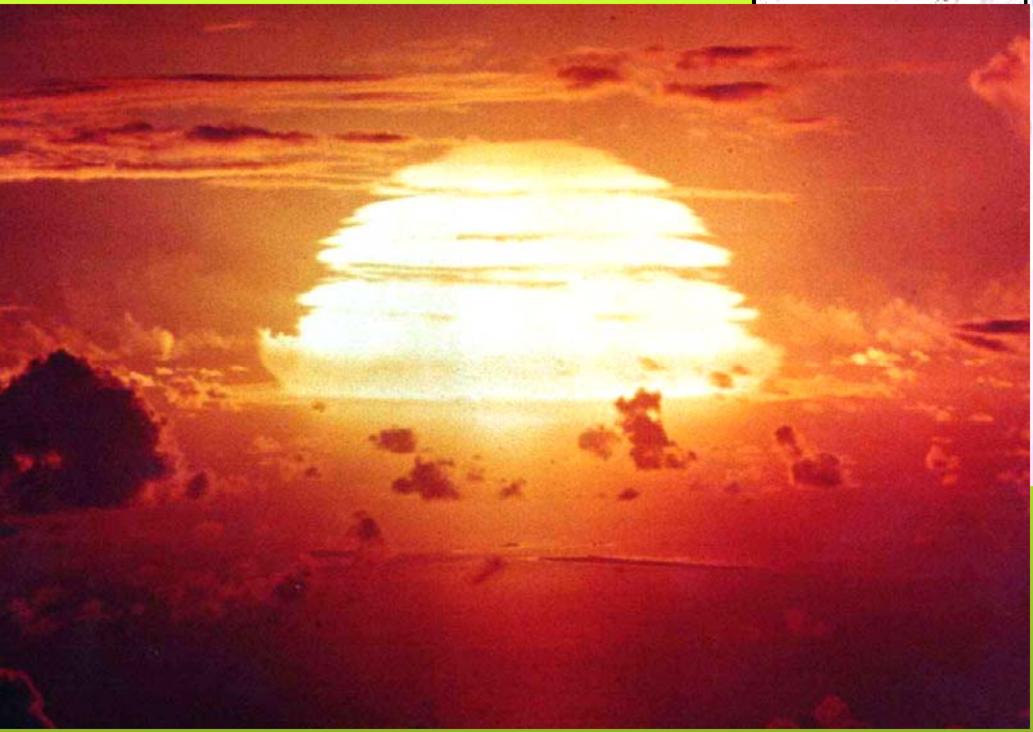
J Stalin & L Beria at Stalin's dacha

The HYDROGEN BOMB

Length:	225 inches
Diameter:	61 inches
Weight:	39,600 lbs
Yield:	13.5 megatons



In the H-bomb, a fission bomb initiates fusion of light elements (which are cheap to prepare in large quantity, and which release far more energy). Thus was born 'MAD' (Mutually Assured Destruction)



The explosion of 'Mike', the first US H-bomb, at Eniwetok (Nov 1, 1952); the Ulam-Teller design appears above right

Stanislas Ulam (1909-1985)

Edward Teller (1908- 2005)

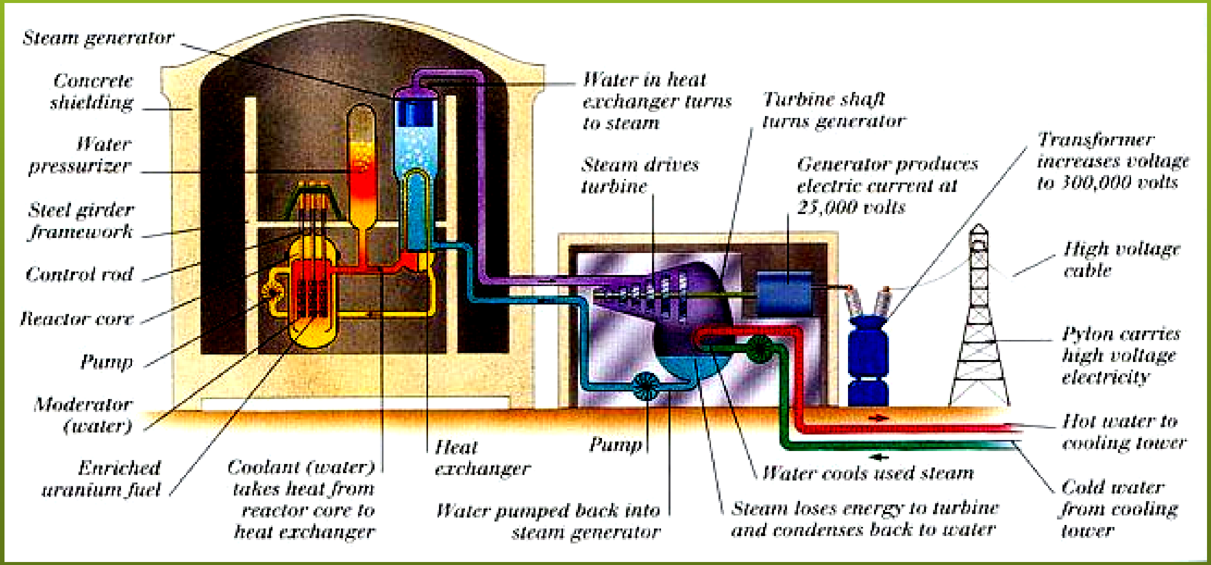
Andrei Sakharov (1921-1989)

1st Soviet mixed bomb (Joe 4) came in Aug 13, 1953; On Nov 22, 1955 a full H-bomb followed (above)

The 'MILITARY/INDUSTRIAL COMPLEX'

The Los Alamos complex not long after the war finished

In the USA, the Soviet Union, & several other countries (eg. France) the war & subsequent arms race created a large cadre of scientists working for the government and/or industry on arms development. The need to coordinate a wide variety of R&D projects created huge networks linking hi-tech companies (particularly in electronics, computing, and aerospace) to governments and military establishments. A large fraction of current technology around the world is the direct or indirect result of developments made initially for military purposes. This includes everything from Teflon and mobile telephones to nuclear power.



Inevitably universities have been drawn into this network. The involvement of universities in large R&D projects, with commercial & military ends, has fundamentally changed the nature of universities. They are increasingly seen as serving the direct or indirect needs of industry, in many different countries. This change will continue.