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Nuclear Fusion Power (Adopted 9/8/12)

Early History Fusion was discovered by Ernest Rutherford (NZ) and two of his young colleagues Marcus Oliphant (an Australian) and Paul Harteck (German) at the Cambridge University in 1934. They found that the bombardment of heavy water (D2O) with accelerated deuterium atoms (D) produced Helium-3 atoms.

Later the fusion reactions were further researched and although the energy of fusion was less than that of fission (i.e. about 200 MeV) it was found that a tremendous amount of energy could be generated by this method. Further, it was determined that the primary energy source of the sun was the fusion reactions of the light isotopes.

Isotopes and Particles of Interest

n = neutron
p = proton
H-1 = ordinary light hydrogen; nucleus consists of one proton
D = deuterium; nucleus consists of 1 proton and 1 neutron
T = tritium, nucleus consists of 1 proton and 2 neutrons
He-3 = helium 3, nucleus consists of 2 protons and 1 neutron
He-4 = helium 4, 2 protons and 2 neutrons (over 99% of naturally occurring helium)

Light Nuclei Fusion Reactions

H-1 + H-1 → D + positron + neutrino + 0.42 MeV
D + H-1 →He-3 + 5.49 MeV
D + D → He-3 + 50%(T + p + 4.03 MeV) + 50%(He-3 + n +3.27 MeV)
D + T → He-4 + 17.6 MeV
T + T → He-4 + 2n + 11.3 MeV
D + He-3 → He-4 + 18.3 MeV
T + He-3 → p + n + 12.1 MeV
He-3 + He-3 → He-4 + 2p + 12.9 MeV

Further, tritium (T) can be produced by the irradiation of lithium with neutrons: n + Li-6 → T + He-4 and n + Li-7 → T + He-4 + n.

The Hydrogen Bomb The concept of the hydrogen bomb was pursued by the US and the UK following the end of WWII when it became evident that the USSR had developed an atomic bomb and a nuclear arms race had begun. The first H-Bomb test (Mike) was carried out by the US at the Enewetok atoll in the Pacific on 1 November 1952. It used a fission bomb as an initiator to reach the necessary high temperatures and pressures, plus deuterium with some tritium as fuel for fusion. The energy generated was 10.4 megatons or about 650 times more powerful than the Hiroshima bomb. The USSR did a preliminary H-bomb test the next year and the UK exploded its first H-bomb in 1956, followed by China (1967) and France (1968).

Fusion Power Development The tremendous energy potential of the fusion reactions were very attractive to researchers and work began just after WWII to develop systems to produce fusion reactors based mainly on the D+T reaction. This fusion reaction produces a high reaction energy and can be achieved at relatively low temperatures because the number of protons involved is small. Also, the deuterium could be produced relatively easily by physically separating it from light hydrogen as was done during WWII as a means of securing D_2O to build heavy water moderated reactors. Tritium could also be produced by irradiating lithium with neutrons from the fusion reaction itself. The first major problem to be overcome was to create a plasma of D and T atoms stripped of their electrons that would be hot and confined under pressure long enough for a significant number of reactions to occur. Starting in 1946 much research has been carried out in the UK, US and the USSR and has now developed into two major approaches: magnetic and inertial confinement.

Magnetic Containment of Plasma Early work was involved a series of various devices such as ZETA and Scepter in the UK and the Stellerator in the US. None, however, managed to produce fusion reactions because of plasma confinement problems. Then the Russians started building machines they called “Tokamaks” and in 1964 the first thermonuclear fusion reactions were produced.

Work continued on refining the Tokamak leading to the JET (Joint European Torus) experiment at Culham in the UK which was opened in 1984 and in 1997 achieved a fusion output of 16 MWt a level that was about 70% of the input energy (a commercial fusion power plant would require a fusion energy production some 10 times the input energy). This work led to the construction of the similar but larger internationally funded (EU, Japan, Russia, China, India, S Korea and the US) ITER machine to be built at Cadarache in southern France with start of construction in 2020 and completion in 2026 at a cost of some 16 billion euros.

The ITER has been designed to produce 500 MWt of fission power for a continuous period of 1000 seconds at a time which is equivalent to the fusion of 0.5 g of D+T. Of course the development of commercial fusion power plants will await the results of the ITER testing and the successful operation of the planned semi-commercial version DEMO designed for 2000 – 4000 MWt continuous output. Once this concept is proven then research will be directed towards developing a design that is cost-effective for commercial application.

Intertial Containment of Plasma The other major concept for creating fusion energy was the basis of the National Ignition Facility at the Lawrence Livermore Labs in the US. The principle of this device is to achieve fusion in small capsules (about BB size) containing D and T by irradiation with 192 high-power lasers. The final cost of the facility was about $4.2 billion and it was first operated in 2010. Then in 2012 the lasers were able to deliver a pulse of energy some 1000 times more than the US uses at any moment, theoretically enough energy to achieve plasma density about 100 times that of lead and at a temperature greater than 100 million degrees Celsius. The ensuing fusion reaction should generate about 100 times the energy used to produce it.

The idea of a commercial version of this concept would be to ignite the capsules in a semi-continuous stream, collect the heat generated and use it to generate steam and then electricity by a conventional turbo-generator. But of course such an application lies in the future after a design is developed that can provide electric power at a price reasonably comparable to present generation methods.

Comments on Fusion Power Part of the fusion power story has to do with the length of time it has been expected to become a commercial proposition. Seeing that fission power became commercial in about 18 Years after fission was discovered, fusion power is relatively slow since 72 years have now passed since fusion was discovered.

ITER was originally an acronym for International Thermonuclear Experimental Reactor but the worded title was dropped because of the nuclear weapon connotation of the second word.
1970s – General Atomics pamphlet, “by the year 2000, several commercial fusion reactors are expected to be on-line.”
1970s – “Tokamaks looked so promising that some researchers predicted they could build fusion electricity plants by the mid-1990s”, Scientific American June 2012.
2005 – “With 10 billion [ITER cost] we could build 10,000 MW offshore windfarms, delivering electricity for 7.5 million European households” JanVande Putte of Greenpeace International.
2006 – An editorial in New Scientist said, “If commercial fusion is viable, it may well be a century away.”
2008 – “We’ll certainly have it in 50 years,” ITER’s Neil Calder told the Swiss Broadcasting Corporation last week, “But not if Greenpeace has its way.”

References
1. “Dark Sun, The making of the Hydrogen Bomb,” Richard Rhodes (1995)
2. Fusion’s Missing Pieces, Scientific American June 2012
3. “Proton-Proton Chain Reaction”, Wikipedia
4. “Fusion Power”, Wikipedia