Controlled Thermo-nuclear Fusion

Inexhaustible and Incessant Nuclear Fusion Power is Probably Just a Decade Away !

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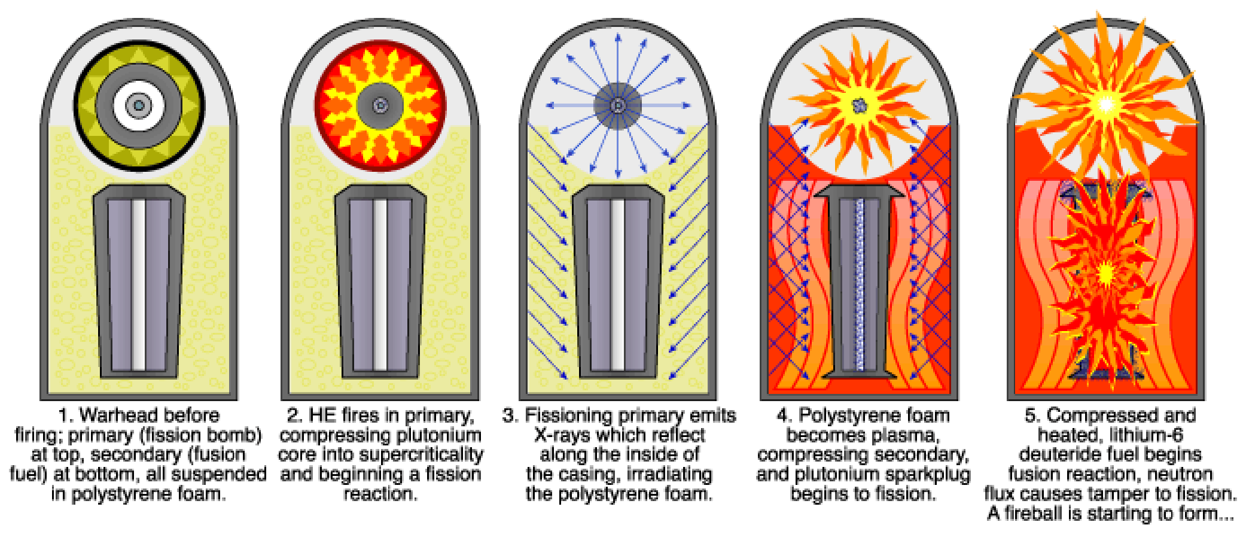
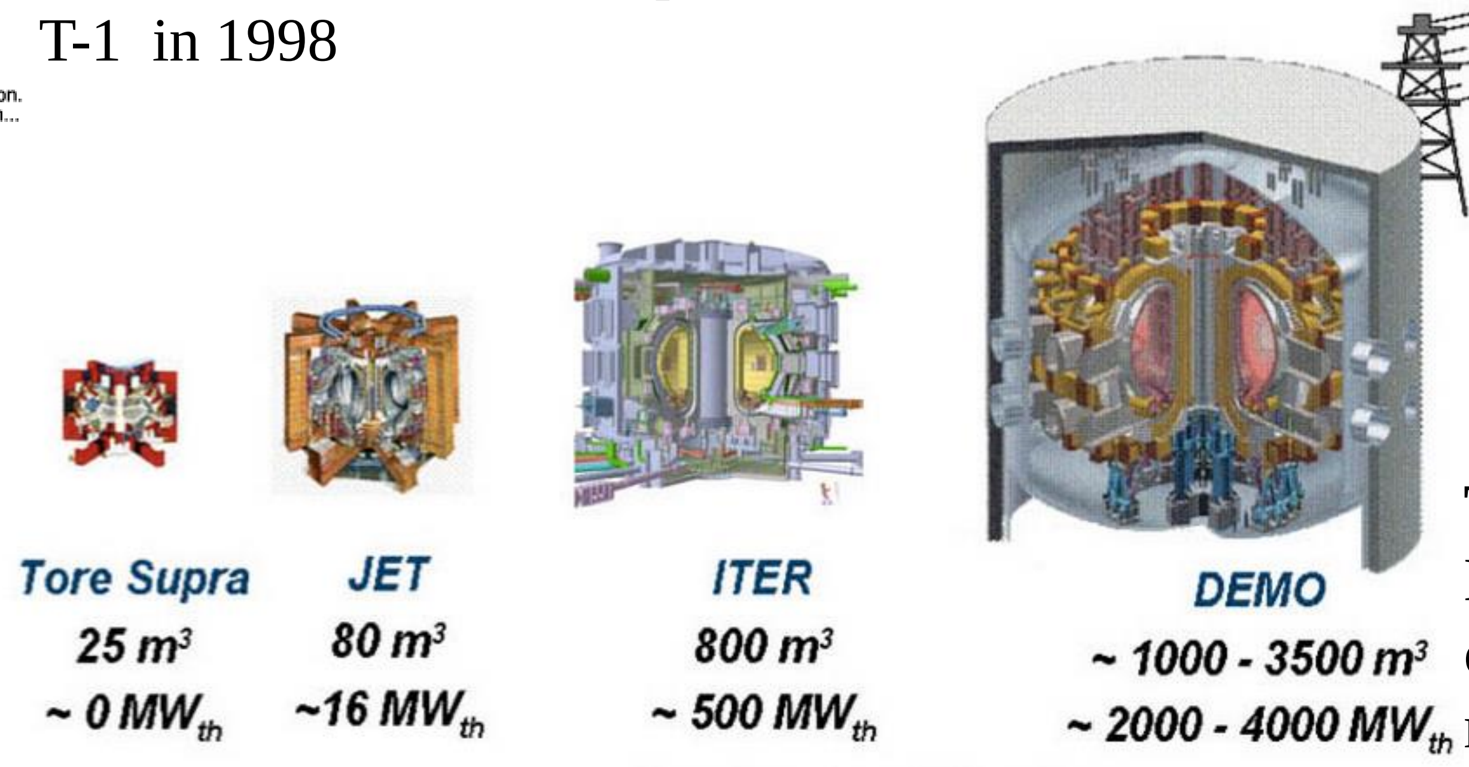
The insurmountable scientific and technical challenges as well the cost involved in materialising controlled nuclear fusion have brought Nations to work together .The vast knowledge accrued and the most modern technical advancements have resulted in a optimistic view in harnessing the full potential of the process in the next two decades.

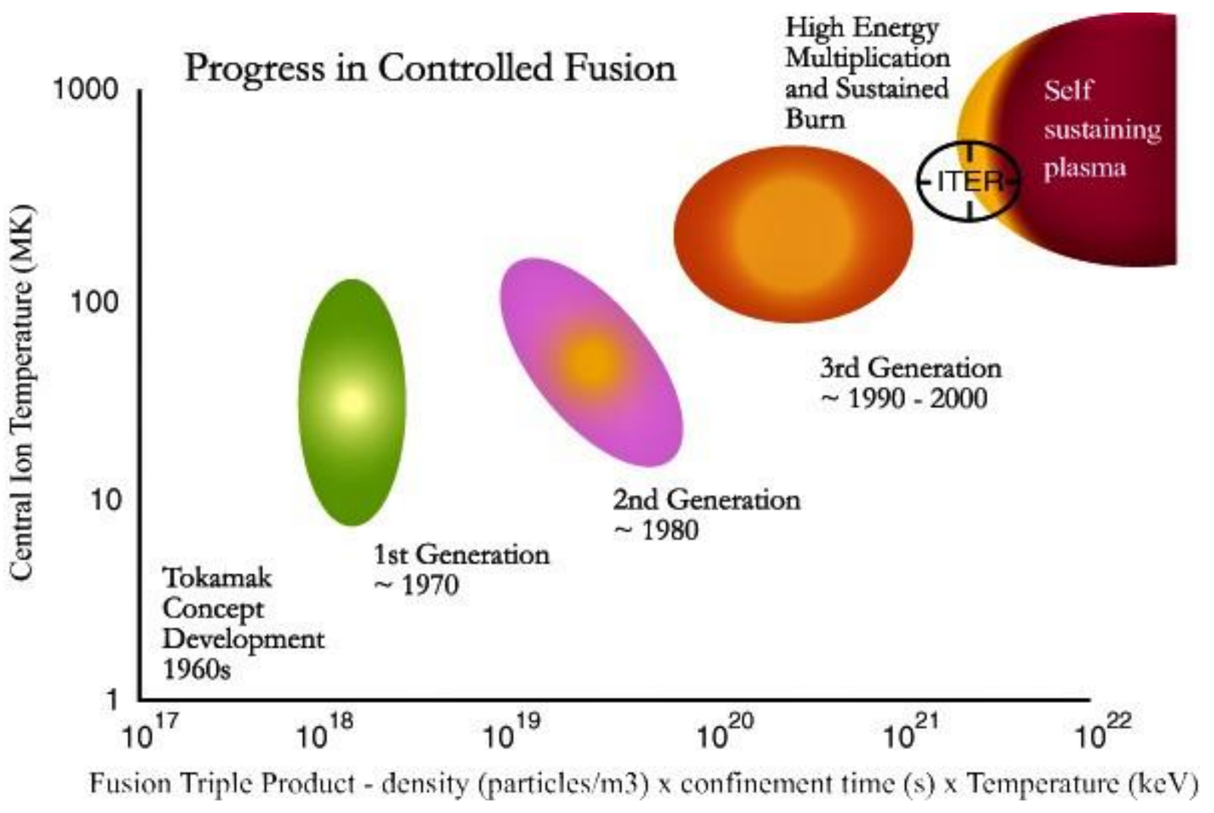


Till 1958 **fusion research** was a classified nuclear weapon development programme. The first **Hydrogen bomb**, Ivy Mike, was detonated in 1952. A deliverable system,TX-16/EC-16 system was developed in 1954. The process basically used cryogenic liquid deuterium as fusion fuel and the nuclear fission process to trigger and achieve the required compression and temperature to make fusion possible.

The Controlled nuclear fusion (CNF) research got its first milestone with the invention of 'Tokamak' in 1950s by Russian scientists. The first major break through was achieved in 1968 when the two major criteria for plasma fusion– the plasma temperature levels and confinement times- was peaked as never before in the first Tokamak T-1 in 1998



Evolution of Tokamaks over the past decades and its prospects into the future

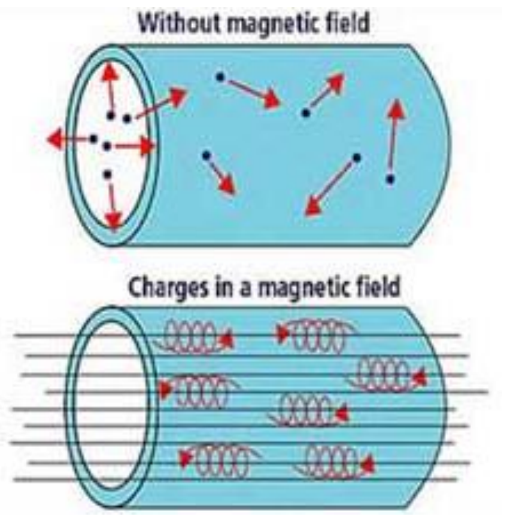


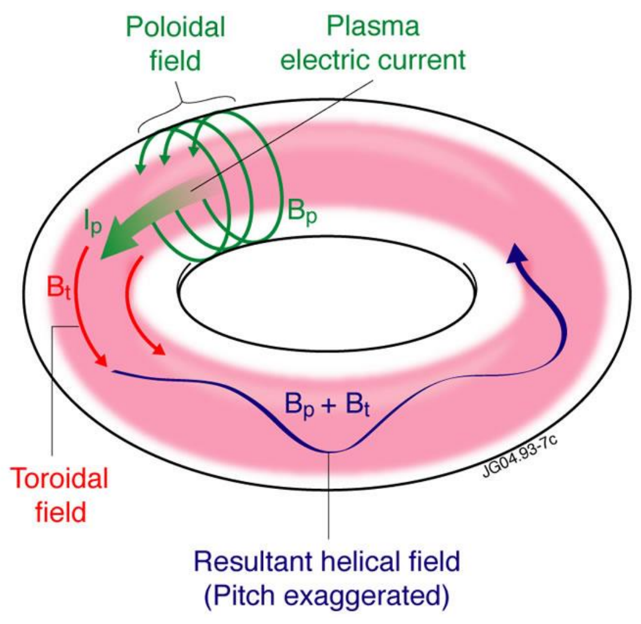
The Tokamaks remain in the forefront in the quest for CNF. Data from different tokamaks demonstrates progress made over many decades. Machines in the frontiers have over 100 million kelvin temperatures in routine operations and the JET has reached break evens with an energy gain of 0.7

Sustained fusion reaction could be achieved by confinement of hot high density plasma by different methods :- Mainly Magnetic (MCF) and Inertial (ICF) Confinement

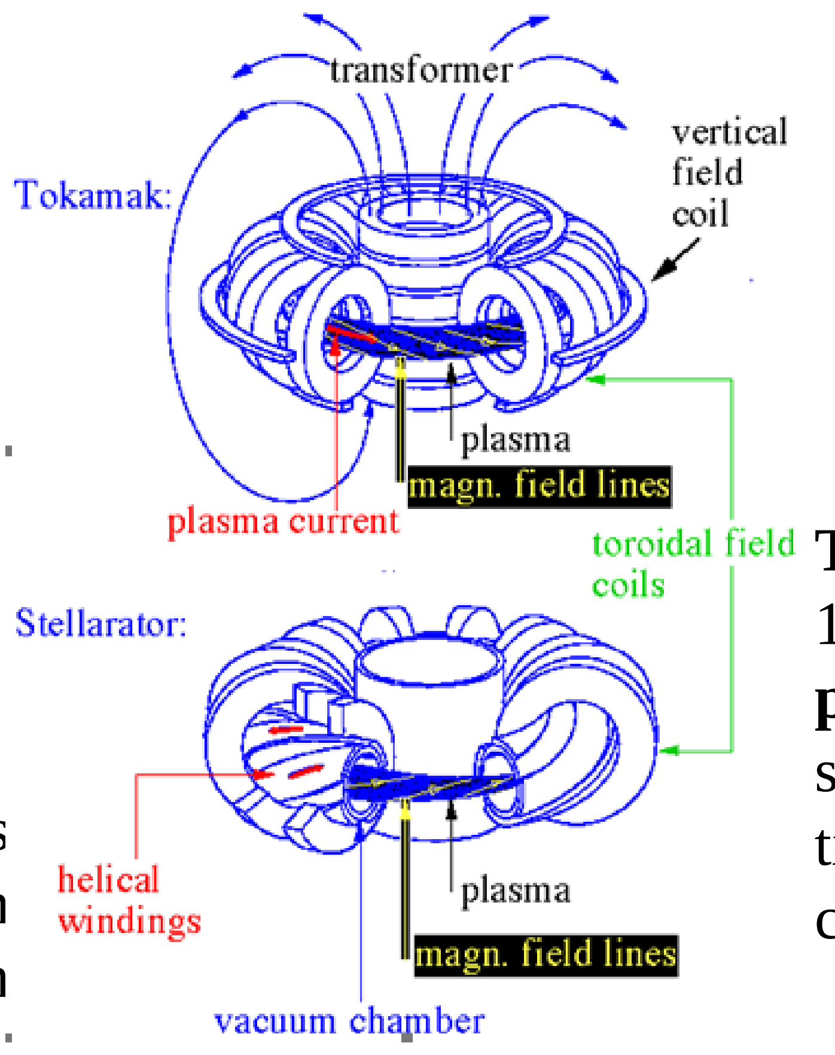
There are several types of Magnetic confinement systems, the most important being Tokamaks, Stellarators and Reversed Field Pinch (RFP) devices.

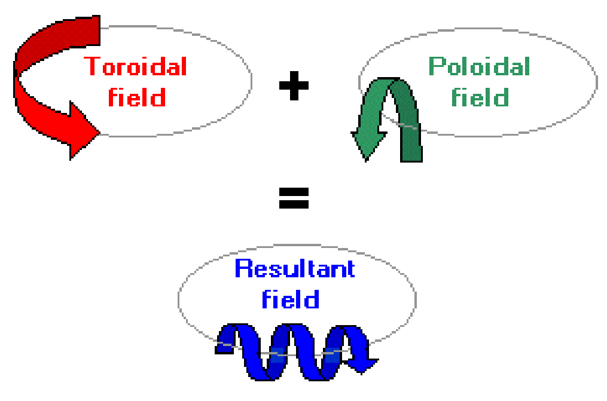
The basic process in **magnetic confinement** is to restrain high density high temperature plasma from losing on to vessel wall using powerful magnetic fields.





Ions and electrons spiral around the magnetic field lines which, by design, are concentered at the center of the vacuum vessel. Plasma density and confinement depends on the strength and duration of magnetic field.



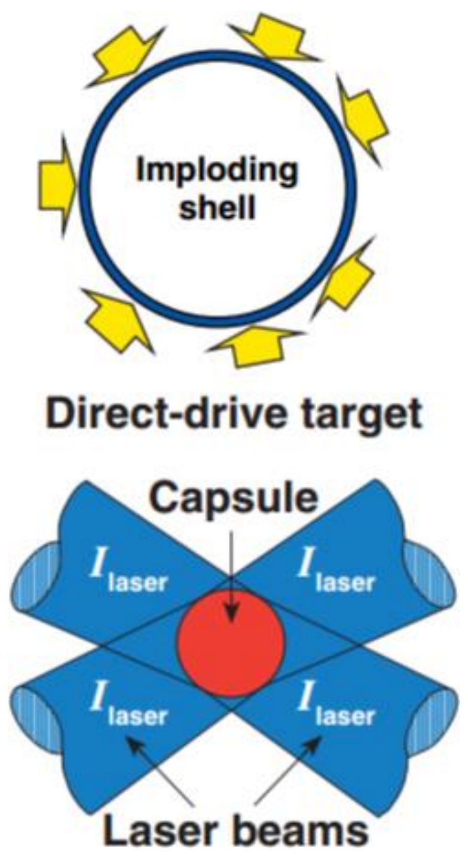


Tokamaks, **has a toroid (endless pipe)** as the vacuum vessel. Suitably distributed and placed high intensity **magnetic field coils** concentrate field lines at the center of the toroid to confine and position the hot plasma.

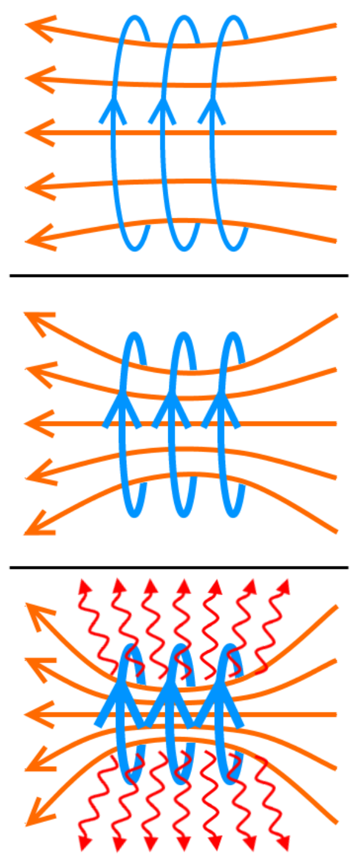
The Stellarator magnetic Confinement configuration was developed in 1951. The circulating charged particles are made to follow **twisting paths along the long axis** of the machine. This cancels out instabilities seen in tokamaks and also keep the charged particle confined for longer time to heat them to further high levels.The disadvantage is in the complexity of the coil configuration.

RFP configuration is similar to tokamak but has magnetic fields ten times weaker with the TF reversing its direction along the radial axis . This results in many positive features like high mass power density, compactness, less or no neutron shielding leading lesser cost and maintenance. RPF has the potential to achieve ignition solely by ohmic heating where current passing through plasma heat it resistively . The disadvantage of this design is surface instabilities .

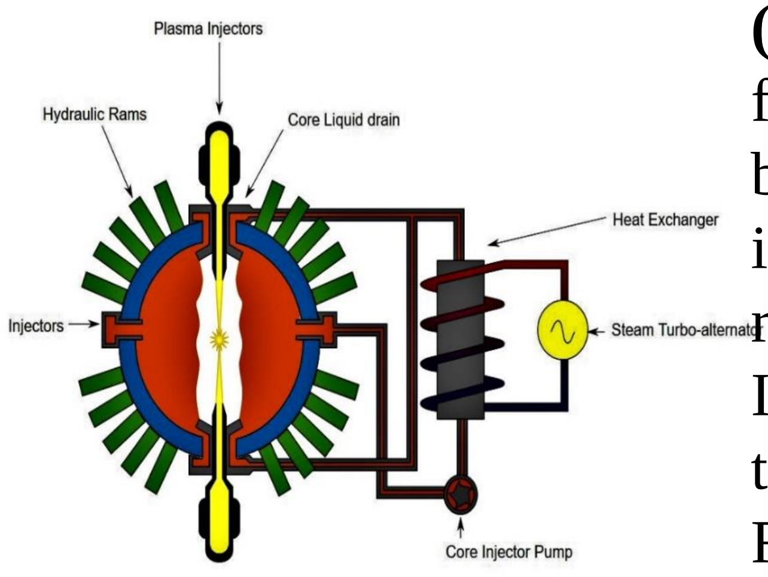
Reversed Field Pinch (RFP) MF Configuration



In **Inertial fusion** super dense plasma suitable for fusion reaction is generated by imploding solid deuterium–tritium pellets by high power lasers. Plasma gets compressed to extremely high density and spark ignition happens.

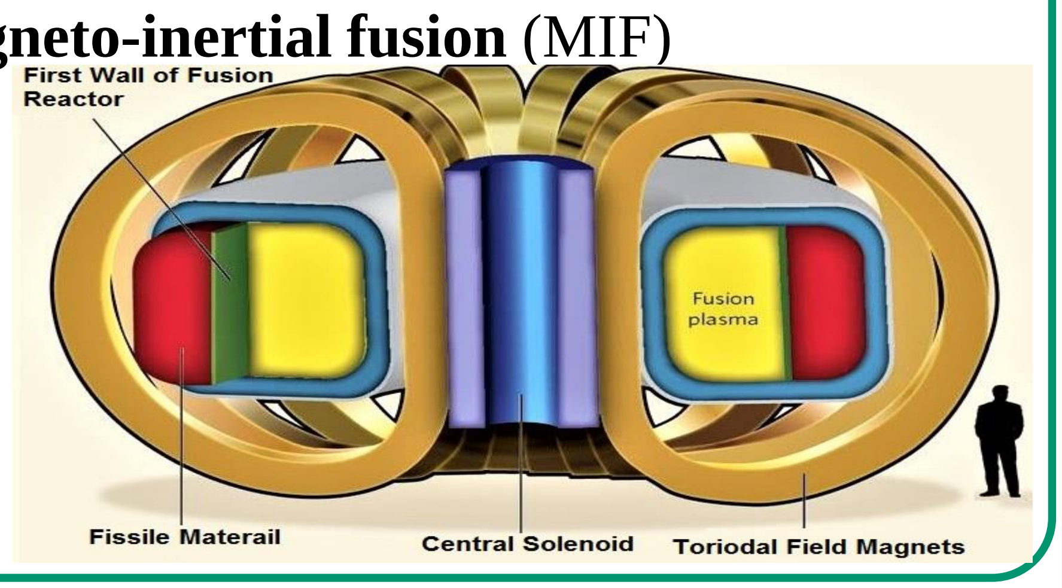


The Z-pinch is another concept which uses a strong electrical current passing through plasma to create high magnetic field and X-rays. The compression results in a tiny D-T fuel pellet into fusion conditions along the Z axis. The Z Machine located at Sandia National Laboratories in New Mexico is an example.

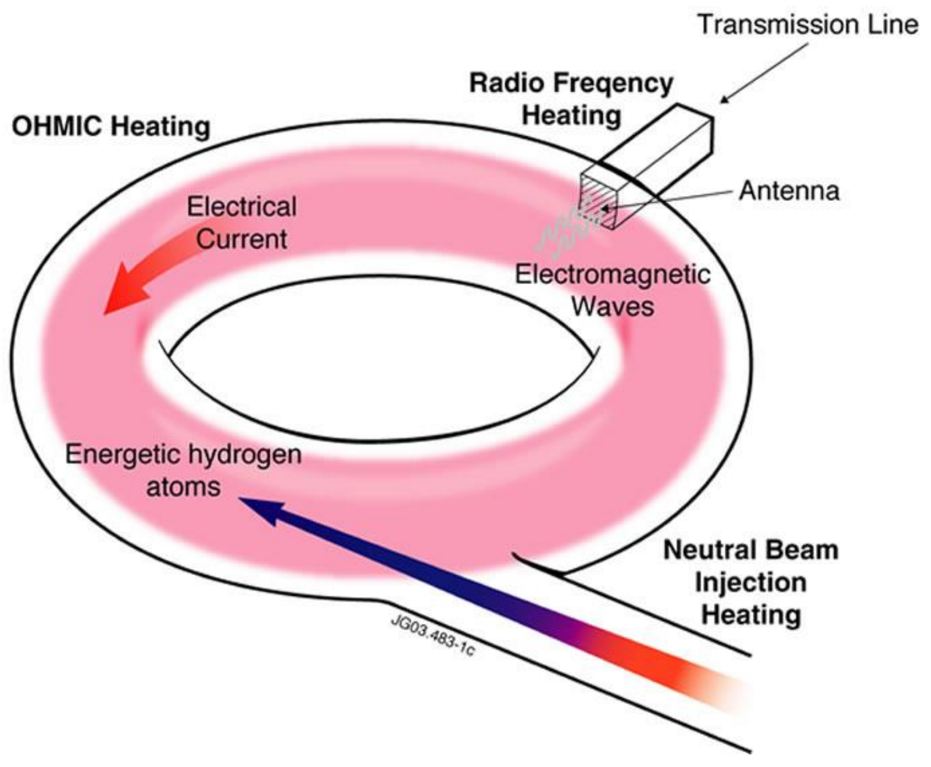


Magnetized Target Fusion (MTF) combines both MCF and ICF. The fusion fuel at lower density is confined by MF and is heated into a plasma. Fusion is initiated by rapidly squeezing the target to reach fusion fuel density and temperature by ICF. The combination of longer confinement times and improved heat retention helps Fusion and the machine is easier to build. Another but more elaborate version is **magneto-inertial fusion** (MIF)

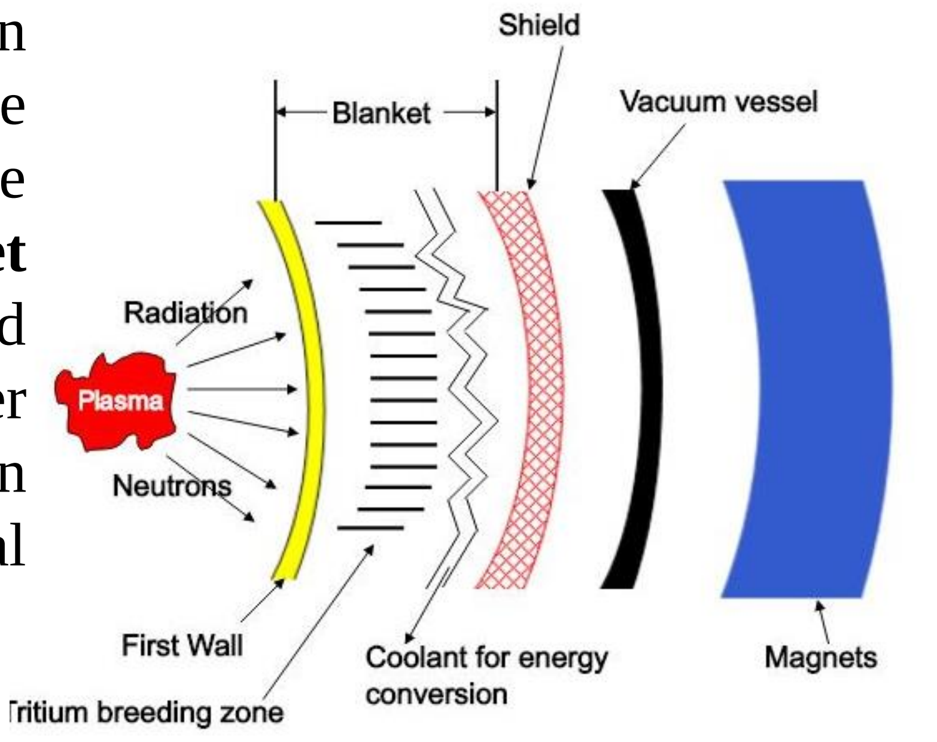
Hybrid nuclear fusion–fission (hybrid nuclear power) is a highly promising proposal where a combination of nuclear fusion and fission processes is used. The high-energy fast neutrons from a fusion reactor is used to trigger fission in non fissile fuels like U-238 or Th-232. Several fission events gets triggered multiplying the energy released by each fusion reaction hundreds of times over. This would make fusion more economical in power terms and also buring fuels that are not usable in conventional fission reactors . Even fission waste could be a fuel such hybrid concepts.



Fusion plasma also needs to be heated to make up loses at the edges. **Neutral Beam, Radio frequency and Ohmic heating** are the three main techniques employed.



In the present D-T fusion concept with tokamak, the neutron generated by fusion are absorbed in a **lithium blanket** transforming it into Tritium and helium. Lithium also transfer heat to the coolant which in turn turn turbine in conventional way generating power.



Complex tokamaks like Tore Supra, JET, TFTR , DIIID and JT-60U have been built and appreciable progresses have been achieved in the fusion related technologies. TFTR and JET have been operated with DT fuel. ITER- a multi national effort including India would become operational by 2021. Later it will also demonstrate an output of 500 MW power with a total input of 50 MW. On the success of ITER, it is expected that demonstration of electric power production from fusion will follow, through the next stage , the DEMO.

The CNF systems require **high end engineering** to overcome severe mechanical, thermal, electromagnetic, neutron flux and vacuum related stress. Cryogenic conditions for Super conductor magnets, Ultra High vacuum generation, Lithium blanket, Diverter system are where the **frontier technologies** applied. Theoretical and experimental answers are continuously probed into issues on the **plasma instabilities and wall plasma interactions**. **Remote control** of systems and subsystems are another field to be perfected.

Illustrations owed to Internet websites and readily available on image search with related keywords