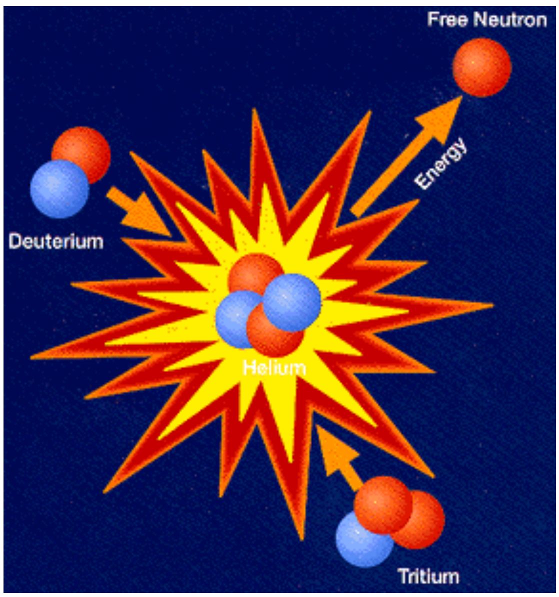
FUSION POWER

BASICS OF FUSION:



The principle behind fusion

For elements to fuse together, they must come so close together that they feel the strong nuclear force. As they naturally repel one another, they need a large amount of kinetic energy to overcome their mutual repulsion. They get this kinetic energy if their temperature reaches a certain amount. Along with temperature, density and confinement are important factors to cause fusion. These are obtained in a plasma. A plasma is a state of matter where the electrons are stripped from their host nuclei. In the Sun, fusion takes place at about 10-15 million degrees centigrade. However here on Earth the most suitable fusion reaction is that of Deuterium (D) and Tritium (T). Both of these are isotopes of Hydrogen. Deuterium occurs once in every 6700 Hydrogen atoms and so can be separated from all kinds of water. Tritium on the other hand is rare because it is naturally radioactive and so decays quickly. Tritium can be manufactured by bombarding Lithium with neutrons. This can then be incorporated into a nuclear reactor as a blanket around the containment vessel. The reactor would then breed its own fuel. The Deuterium-Tritium reactions occur around 100 million degrees centigrade.

The reason that Deuterium and Tritium are used in these reaction is the fact that each ion only has one positive charge and so the mutual repulsion is minimal. In a fusion reactor Deuterium and Tritium produce an alpha particle and a neutron with a combined energy of 17.6 million electron Volts. Four fifths of this is the kinetic energy of the neutrons. Because they are neutral, they can pass through the plasma with virtually no interaction. When they reach the chamber walls, they slow down and give their energy in the form of heat to the moderator (Lithium) built into the walls. This then produces more Tritium and the energy is taken out by a heat reservoir which by using a conventional steam turbine, produces electricity. The remaining 20% of the fusion energy is taken away by alpha particles. As these are charged, they don't escape very easily and remain within the chamber giving their heat to the fuel. The absorption of this energy by the fuel propagates more thermonuclear burning and if the density and radius if the fuel is large enough , a condition called 'bootstrap heating' is reached. This is the point where the fuel is said to have ignited.

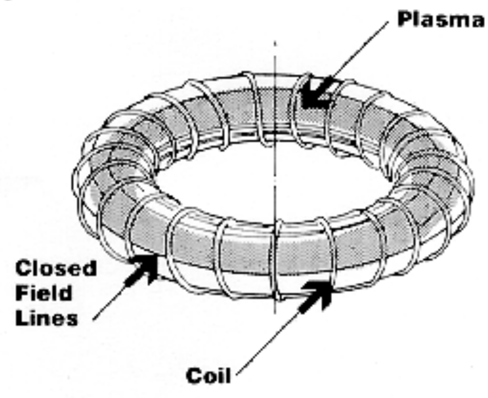
TWO TYPES OF REACTOR:

There are two types of fusion reactor being developed at the moment: the magnetic confinement reactor and the inertial fusion reactor. There are several types of magnetic reactors being used around the world but the two main ones are the Tokamak and the Stellarator. Both these use magnetic fields to confine the plasma inside a chamber. If it didn't the chamber walls would melt under the immense heat of the plasma. The other type, the inertial fusion reactor fires laser beams at fuel pellets to cause the nuclear fusion process to begin. Both of these systems have to abide by what is called the Lawson condition. This is an equation that defines the density and confinement time that a fuel pellet must have for fusion to occur. In inertial confinement experiments the confinement time is of the order of a billionth of a second and density much higher than Lead. For magnetic confinement experiments the confinement time is of the order of seconds with a density much less than air.

BASICS OF MAGNETIC CONFINEMENT:

There are two main methods for plasma containment, the Torus and the Mirror.

THE TORUS:

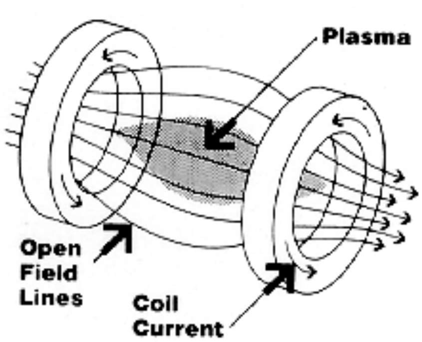


The torus

The magnetic lines of force in a Torus are closed, that is the field lines go around the Torus and meet back where they started. Every charged particle is confined to one of the lines. Actually these particles gyrate around the lines, but can move freely along it. As the particle trajectory meets itself, it is trapped. In a Tokamak, two magnetic fields are set up, a toroidal and a poloidal. The toroidal field magnet circles the Torus, there are about 16 of them. The poloidal field magnets are looped above and below the Torus. The plasma current is induced by a set of Ohmic heating coils that lie in the centre of the Torus. As the flux is increasing, the current flows. A Tokamak can confine a plasma at a density of about 1014 fuel particles per cubic centimetre. Some heating is produced by the electrical resistance to the current flowing through the plasma, but this is insufficient to cause fusion.

Two methods of heating are used, radio frequency and neutral particle injection. The radio frequency heating method uses coaxial cables or waveguides to set up standing waves with the particles within the plasma. These standing waves oscillate enough to heat the particles to the right temperature for fusion. The other method uses Hydrogen or Deuterium ions that are accelerated into the plasma. As these particles exchange energy with the particles in the plasma, they heat up. This method was used at the TFTR (Tokamak Test Fusion Reactor) in Princeton to produce 10 million Watts of power for half a second.

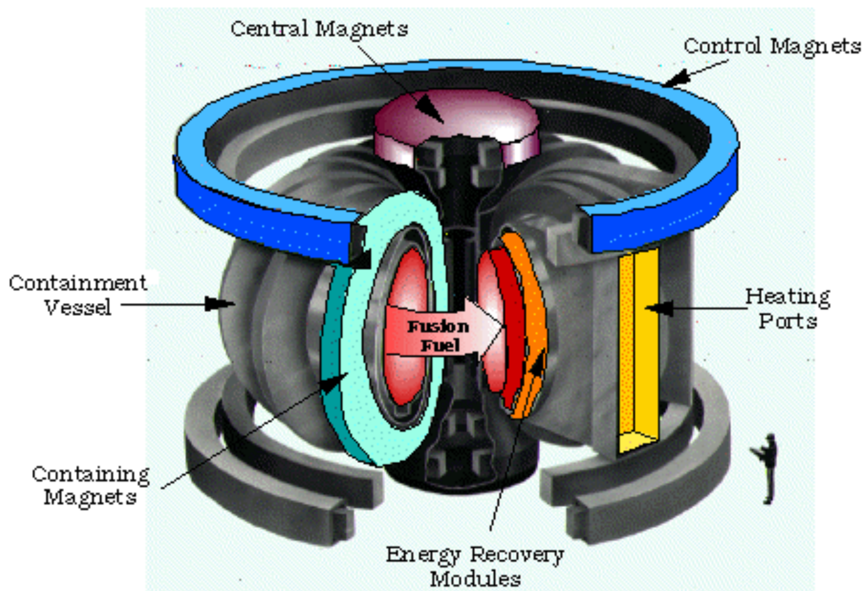
THE MIRROR:



The mirror

This method of confinement acts as a 'bottleneck' using magnetic field lines. As the plasma is confined to the field it is essentially trapped within it. Although some particles can escape at either end, it is possible to introduce another mirror to plug this gap. The field lines have peaks at either end and so a particle conserving energy and angular momentum converts its energy and motion parallel to the field into energy and motion perpendicular to the field. As the plasma is confined, it can be heated by using radio frequency heaters or ion injectors.

JET:



The JET (Joint European Torus) program is a Europe wide program of magnetic confinement fusion. Like the MEDUSA project, it uses what is called a Tokamak which is Russian for TOroid-KAmera-MAgnit-Katushka which means toroidal chamber and magnet coil. JET is a large Torus shaped chamber based at Culham near Oxford.

Its primary objectives are to study:-

- Plasma heating up to thermonuclear temperatures.
- Plasma behaviour at these temperatures.
- The interactions of the plasma with the chamber walls.
- The refuelling of the plasma.
- Exhaust waste and safety of the reactor.
- Control of any impurities within the plasma.

- Deuterium-Tritium experiments.
- Development for the International Thermonuclear Experiment Reactor (ITER)

The achievements so far are:-

- To construct the reactor on time and close to its initial budget.
- A record plasma current of 7.1 million amps.
- To reach the sort of plasmas needed in a fusion reactor.
- The temperature, density and confinement for a reactor. These were only achieved in separate experiments.
- Using Deuterium plasma, conditions for ‘break even’ (fusion power produced to equal plasma losses).

In addition to these achievements, JET produced 1.7 million Watts of fusion power for 2 seconds in 1991. This was done using a 11% mix of Tritium injected into the Deuterium plasma.

The parameters in these experiments were:-

- 3.1 million Amps of plasma current.
- 2.8 Tesla field.
- 200 million degrees centigrade heating.
- 2 to 4´1019m-13 plasma density.

This produced 6´1017 neutrons per second.

In 1997, a mix ratio of 50/50 Deuterium-Tritium was used in three months of experiments.

These experiments achieved:-

- 16 million Watts of fusion power.
- A ratio of fusion power produced to input power of 65%.

- There is a 25% reduction in the power needed to maintain the confined plasma.
- The process needed to breed Tritium for future reactors.

MEDUSA:

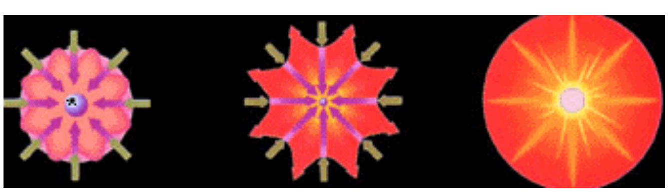
This is classed as a low aspect ratio Tokamak. Its major radius ranges from 10 to 24 centimetres and its minor radius from 6 to 9 centimetres. This gives it an aspect ratio of about 1.5. Other low aspect ratio Tokamaks have a ratio of about 3. Low aspect ratio Tokamaks have many advantages over conventional Tokamaks in that they produce a plasma that is more elongated, have a higher plasma current density, have a natural divertor for waste removal and are more robust. One main problem with these Tokamaks is the size of the central core. As it is small, only the Ohmic heating solenoid and the Toroidal field coils are passed through as they are needed. Although MEDUSA is only an economic tester for larger projects, it has had quite good success.

Some of these are:-

- Toroidal field strength of 0.45 Tesla
- Plasma current of 40 kiloAmps

Further research is in progress to Determine such aspects as plasma stability, high plasma current and sustainment.

BASICS OF INERTIAL FUSION:



Principle of inertial fusion

This process uses lasers to start the fusion reaction. Firstly a pulse of short wavelength laser light is split into several beams of equal intensity. These beams are amplified and by using mirrors and lenses are brought back together at a focal point. Placed at this point is a pea sized pellet of Deuterium and Tritium. As the pellet is illuminated from all directions with high intensity light, the outer coating of plastic or glass is very quickly ionised. This layer of plasma shoots outwards at a speed of about 1000 kilometres a second. Because of Newtons’ Third Law, an equal but opposite force contracts the inner core to more than 50 times it original size. This heats the pellet and increases its density enough for it to fuse.

The two types of laser that were used in fusion research were the Neodymium-doped glass and the Carbon Dioxide gas lasers. Both of these are Infra Red lasers and have a wavelength of 1 and 10 microns respectively. These lasers and others of longer wavelength heat the core of the fuel pellet before the plasma has chance to expand. This happens because suprathermal electrons travel through the outer coating into the core. This premature heating decreases the density in the core and lessens the chance of fusion to occur. This was avoided by developing lasers of shorter wavelength than Infra Red. This was achieved by growing perfect crystals and cutting them at precise angles to the orientation of the crystal lattice. The crystals when placed in front of the incident beam produce frequencies 2 or 3 times the input frequency. If a number of these are used, the wavelength of the laser is shortened by the same factor.

An experiment in France used two crystals of Potassium Dihydrogen Phosphate (KDP) with a laser of 1 micron to produce a wavelength with a reduction of a factor of four. When directed at a pellet it was found that it absorbed nearly all of the incident energy and no suprathermal electrons were detected. This was a massive breakthrough for inertial fusion energy especially with the fact that the most recent laser using Krypton-Fluoride can produce a beam of only 0.25 microns. The only downfall of using the frequency conversion crystals is that it takes up to a year to grow a crystal of 30 centimetres in diameter. Also in theory a large number of crystals could be used to keep decreasing the wavelength of the laser beam, but crystals that transmit light shorter than 0.2 microns are not yet available.

OMEGA AND NOVA:

The OMEGA program is much the same as the NOVA program. It consists of a number of laser devises which direct their beams at the fuel pellet. However in the NOVA experiments it uses what is called the Hohlraum effect to create great amounts of fusion energy. This process uses a Deuterium-Tritium pellet that is coated in a high atomic number material like Lead or Gold. When the lasers are incident on the pellet the outer layer converts the beam into X-rays which compress the fuel capsule.

The OMEGA apparatus can deliver more than 40,000 Joules of energy onto a target of less than 1 mm in size in less than 700 Pico seconds. This produces around 60 Tera Watts.

NIF (NATIONAL IGNITION FACILITY):

When fully developed this will house the most powerful Neodymium glass lasers in the world. It will be 50 times more powerful than the NOVA laser system. The lasers are split into 192 independent beamlets which are amplified to heat the pellet up to 50 million degrees centigrade. This will be sufficient to not only cause ignition, but will also produce a sustainable reaction.

NIF comprises of two different target mechanisms:-

DIRECT-DRIVE:- Where the laser beams are targeted at the Deuterium-Tritium capsule.

INDIRECT-DRIVE:- Used in the NOVA system the pellet will be coated in a heavy metal that produces X-rays and implode the fuel pellet.

NIF will be able to produce better results in higher density physics than have been achieved anywhere else. This will allow scientists to study the physics of stellar objects such as supernova as well as developing systems for future nuclear fusion reactors.

FUTURE PROPOSALS:

The JET Tokamak at Culham is being used as a research model for a future reactor called ITER (International Thermonuclear Experimental Reactor) which is research reactor being developed for a possible future nuclear fusion device.

Also at Culham is the START Tokamak. This is a spherical Tokamak that has a toroidal field supplied by a central column. It is about 2 meters by 2 meters in diameter and has an aspect ratio of 1.3. When working at full power it produces a toroidal field of 0.3 Tesla and a plasma current of 290 thousand Amps. It has been found that the plasma stability can be a factor of 10 or less than conventional Tokamaks yet produce the same plasma current.

Some interesting results are:-

- Confinement time is significantly better than conventional Tokamaks.
- World record energy efficiency has been achieved when using the neutral beam injection.

CONCLUSIONS:

It is clear that there are two distinct approaches to producing a feasible nuclear fusion reactor. Each one has been better and more powerful then its predecessor. All the right conditions are being met to produce nuclear fusion, however as long as the budgets are being split, neither group can achieve what they really intend to. What is needed is a definite proposals by governing bodies to fund these projects to get their full capability. The ITER approach is a very good example for this, but in the last few weeks budget cuts have hampered its development. It now has to be cheaper than what was originally proposed. Staff have lost their jobs and although they may find employment elsewhere it takes out of the project brilliant minds that helped develop it in the first place. Not a single scientist believe that viable nuclear fusion will be available within the next fifty years and if more cuts are to take place it will be even longer. It is very important I think that these programs be funded fully so that in the future when fossil fuels are running low we will have sufficient energy to fulfil our needs.

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