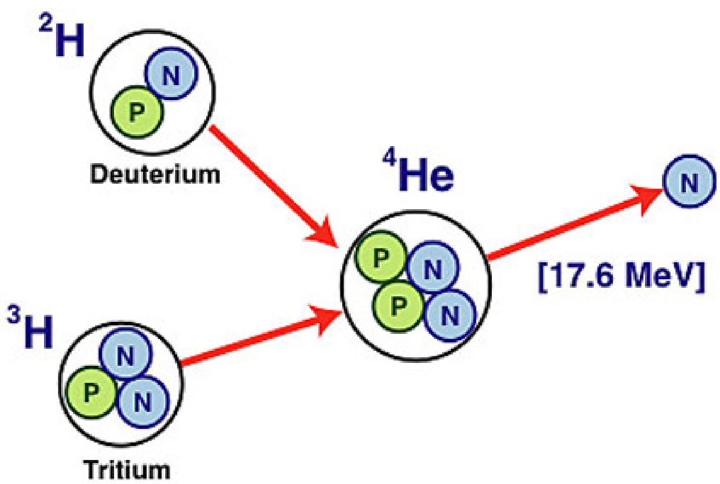
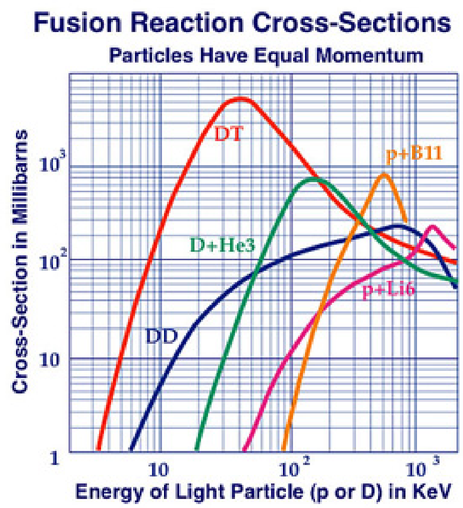
D-T Fusion Research

D-T Fusion: ITER, Tokamak, & NIF

As of 2008, the United States Department of Energy (DOE) and other U.S. federal agencies have spent approximately 18 billion dollars on energy devices using the fusion reaction between deuterium and tritium (D-T Fusion, below left). In this reaction the hydrogen isotope, deuterium (with one "extra" neutron) collides with the hydrogen isotope, tritium (with two "extra" neutrons), to form an alpha particle (a helium nucleus) and a neutron. This is a nuclear reaction: between them, the new alpha and the neutron possess 17.6 MeV (million electron volts) of energy.



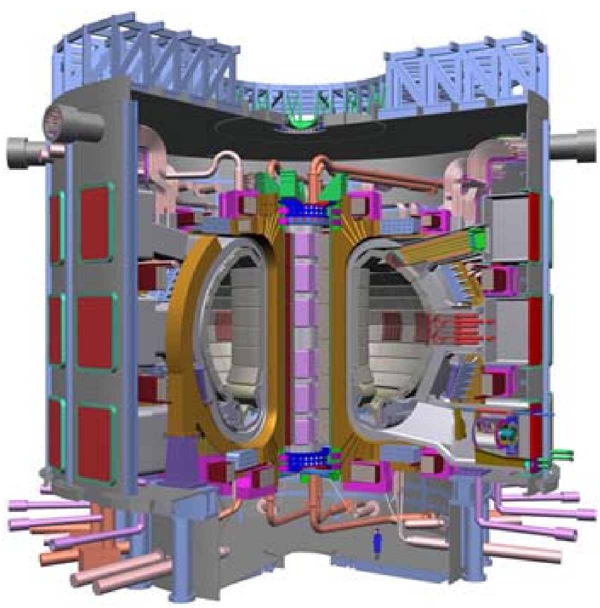


In the Fusion Reaction Cross-Sections graph (above right), the red DT (deuterium-tritium) curve peaks at about 40 KeV (forty thousand electron volts). This means that the optimum activation energy required for the DT fusion reaction is only about 40 KeV. The curves for the other reactions peak at much higher energies. The energy required to make the DT reaction happen is lower (in KeV) than the energy required for any other nuclear fusion reaction. Also, the height of the DT curve (Cross-Section in Millibarns) indicates that the deuterium and tritium isotopes "see" each other as being relatively large, compared to the isotopes in the other reactions shown. Thus, at the proper activation energy, this reaction is much more likely to happen than any other fusion reaction. DOE and many other entities pursue the DT reaction because it requires less energy to initiate, and because it is more probable. Unfortunately, there are several serious disadvantages to this reaction: 1) Tritium is both radioactive and expensive.
2) The neutrons released can harm living things and damage any other materials surrounding them. 3) The neutrons can make some materials radioactive.

At this time, the device preferred for making this reaction happen is the tokamak. The DOE, the European Union, Japan, Russia, China, and India are all part of the ITER program which is working on it. Their dream is that the tokamak will heat a plasma containing tritium and deuterium nuclei. The hotter these nuclei get, the faster they will move. When the plasma is hot enough, some of the nuclei will be moving fast enough to react when they collide. The energy of the newly produced, highly energetic helium nuclei (alphas) will be used to keep the plasma hot; and the energy of the new neutrons will be released to a lithium metal blanket which lines the tokamak. Water lines will run through the lithium. The hot lithium will heat the water to steam, and the steam will be used to spin turbines, which will spin generators to make electricity.

There is a substantial gap between the above dream and its fulfillment. For at least fifty years, the practical use of tokamaks and other DT devices to make electricity has been forecast to be, "about thirty years in the future." I can remember this projection from the early 1970s, when I first became seriously interested in fusion energy; and the projection is no different today: "about thirty years in the future." To be commercially useful, a controlled fusion reaction must produce more energy than the energy that was required to cause the reaction in the first place (the 40 KeV activation energy mentioned above). The point at which the energy produced exceeds the energy required is called "net power" or "break-even." Various organizations in different parts of the world have been working to produce "net power" nuclear fusion for about 50 years. Many billions of rubles, dollars, yen and euros have been spent on this endeavor, but no one has been successful yet.

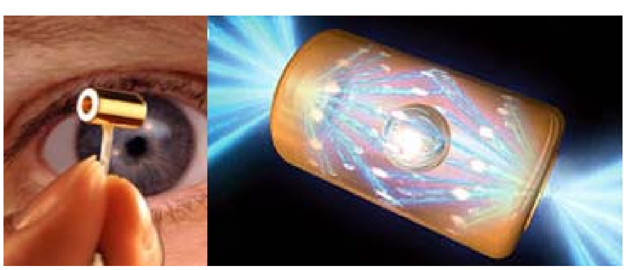
Many of the efforts have involved the idea of heating a plasma of deuterium and tritium gases until the nuclei fuse. When the heat of a plasma increases, the average energy (speed) of the particles increases; but there is an enormous variation in the energies of the individual particles within the plasma. This set of all the different energies of the particles in a plasma or a gas is called a Maxwellian distribution. Unfortunately, in the typical Maxwellian distribution, only a few of the nuclei have the 40 KeV of energy required to react; and all the other particles are just along for the ride. If the temperature is increased to the point where an adequate number of nuclei have enough energy, then other problems develop which can compromise the integrity of the containment.



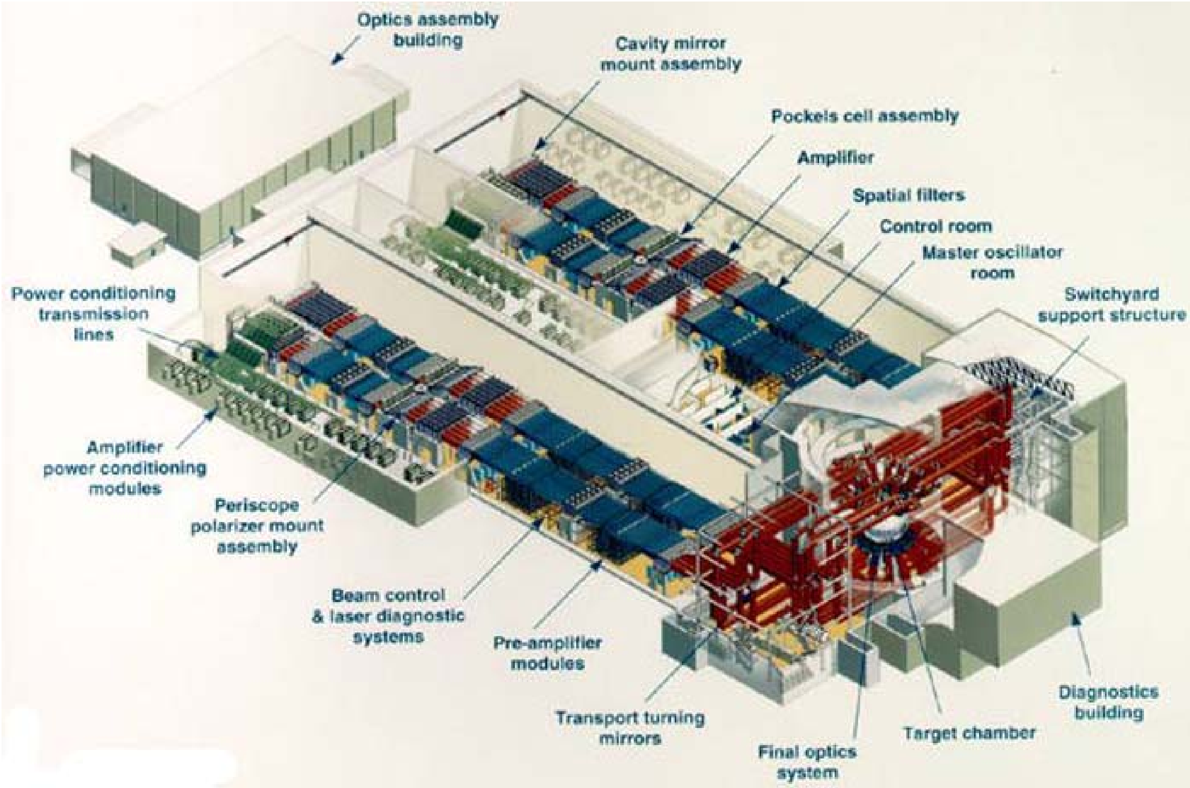
The tokamak was invented in the old Soviet Union by Andrei Sakharov and Igor Tamm. Some people jest pessimistically that the Russians "gave" the tokamak away to make sure that the Americans would never achieve practical fusion. Dr. Nicholas Krall, a top fusion researcher says, "We (U.S.) have spent $15 billion studying tokamaks, and all we know about them is that they're no damn good!"

The proposed ITER tokamak, to be built in France, is pictured on the right. To get an idea of the scale involved, notice the tiny little lab tech in the blue coat standing on the floor.

A somewhat similar fusion effort is the Stellarator, also known as the Wendelstein 7-X, in Germany. Both the Stellarator and the tokamak use a magnetic containment to control the fuel. A distinguishing feature of the Stellarator is the use of odd-shaped coils to manipulate the shape the plasma donut within the coils.



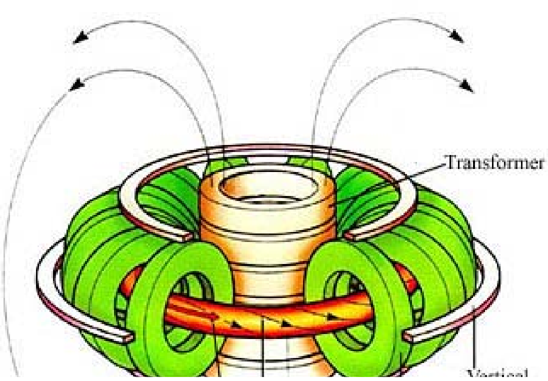
Yet a third major effort is the NIF (below) at Lawrence Livermore Laboratory. NIF uses many powerful lasers to heat DT pellets (left) to the point where fusion can occur.



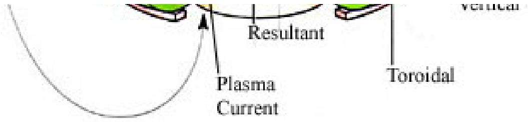
It is interesting to note that none of these multi-billion dollar efforts makes the slightest pretense of promising commercial viability. All three of them are essentially research endeavors. Everyone involved seems to agree that the projects may permit a lot of "good physics" to be done, and may well produce much interesting data. However it does seem fair to ask why this research merits the spending of many billions of dollars while the polywell project which could well reach "net power" in five years, has (as of 2008) been allocated about one ten-thousandth as much money.

How the Tokomak Works

Both the tokamak and the Stellarator use magnetic fields to manipulate the DT plasma. However the distinguishing feature of the tokamak is its "step-down" **Transformer**. The transformer's primary is the stack of beige coils in the center of the tokamak's torus (in the donut's hole below). The transformer's secondary is the ring of plasma – the orange skinny donut. An increasing current in the many-coiled primary induces a much-larger current in the single-coiled plasma "donut" secondary.



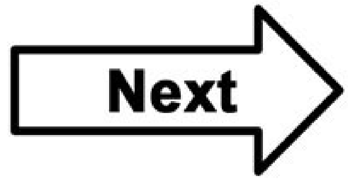
Two magnetic fields combine to produce the **Resultant** magnetic field (labeled left) that spirals helically around the tokamak's torus (orange skinny donut). This Resultant field contains and controls the plasma. The two magnetic fields that combine vectorially to make the Resultant field are: 1) the toroidal field, generated by the green **Toroidal** coils; and 2) the poloidal field generated by the orange **Plasma Current** in the torus. The **Vertical** coils (the large rings around the



outside of the tokamak, and above and below it), can create a vertical magnetic field for controlling the position of the plasma inside the torus.

The Transformer coils also cause “ohmic” (I2R) heating in the plasma, which contributes to raising its temperature. However, since the electrical resistance of plasma decreases as its temperature increases, the upper limit on the “ohmic” heating turns out to be about 20-30 million degrees Celsius, which is not high enough for fusion.

Thus it is necessary to further increase the temperature by three additional strategies: radio frequency heating, magnetic compression, and neutral beam injection.



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