Getting on the Tokamak bandwagon

Photos: AEC

Hirsch hopes to demonstrate that a fusion reactor is scientifically feasible.

The AEC wants to build fusion research devices like the Russian Tokamak

by Dietrick E. Thomsen

Research toward controlled fusion power has been proceeding for two decades in several countries. For a long time progress was slow and disappointing, but in the last two years its pace has picked up considerably. The problem is how to hold a high density, high temperature plasma, a collection of atomic nuclei (or ions) and separated electrons in a small space. It must be held long enough for the nuclei to start a self-sustaining process of repeated fusions that will produce the power.

In the last year Russian efforts in this line, with devices they call Tokamaks (SN: 11/6, p. 424), proved so successful that the United States Atomic Energy Commission has been persuaded to make a major alteration of its course. Before last summer Tokamak work had not been done in the United States; now the AEC is asking Congress for authority to build five machines modeled after Tokamak, and to do it as quickly as possible.

To contain a plasma, scientists must make a magnetic field so shaped as to produce a magnetic well, in which electrically charged particles will be trapped. Many different cavity field shapes have been tried in both straight cylinders and doughnut-shaped or toroidal containers. Tokamaks belong to the family of toroids.

The toroid family comprises, in addition to Tokamaks, Stellarators and multipoles. In a Stellarator the magnetic field is generated by electric coil windings entirely outside the plasma region. In multipoles metal rings that carry an electric current are added inside the plasma region to help form the magnetic field.

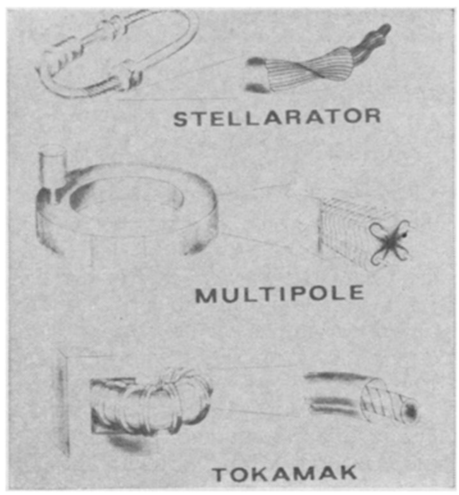
In a Tokamak the plasma itself carries a current that helps form the field. A plasma is an electrically conducting fluid since negative and positive charges are separated. The current in the Tokamak plasma is induced by making the plasma act like a secondary coil of a transformer.

American controlled fusion research has concentrated on multipoles and Stellarators; for the last 10 years the Russians have worked on Tokamaks. Since information in the field is exchanged without any secrecy, the division of labor was feasible and profitable to both sides.

Last summer the Russians announced that one of their Tokamaks had held a plasma of 50,000 billion particles per cubic centimeter at a temperature of 10 million degrees K. for 0.05 seconds. The temperature and density are near what would be required for sustained fusion and the time is about a tenth of the minimum and 10 times as good as any previous result.

In the autumn British investigators who went to Russia found the results were even better than claimed. They also found that the Tokamak plasma was exceptionally stable and well shaped. This result so sold the Americans on Tokamaks that they decided to drop Stellarators in order to accommodate Tokamaks within the budget of their program.

In a year when budgets for other scientific fields are down, some disastrously, the AEC is asking for a $2 million increase for controlled fusion research in its budget for fiscal year 1970, and Tokamaks are the reason.



Tokamak produces a stable plasma.

"If we had a lot more money suddenly," says Dr. Robert Hirsch, acting assistant director of the Commissions Controlled Thermonuclear Research program, "we would shore up the Tokamak program even more." After they had done that, they would invest in a few Stellarators too. Stellarators remain "one of the few possibilities," says Dr. Hirsch, but the Tokamaks are definitely top priority.

The temperatures, densities and confinement times of the Tokamaks cause fusion physicists to rub their hands with pleasure, but the real selling factor is their stability. "To make a thermonuclear plasma that will last a long time," says Dr. Hirsch, "the distribution of ions and electrons must be nearly in equilibrium, or Maxwellian"; that is they must have nearly equal energies instead of having clumps of hot ones interspersed among colder ones.

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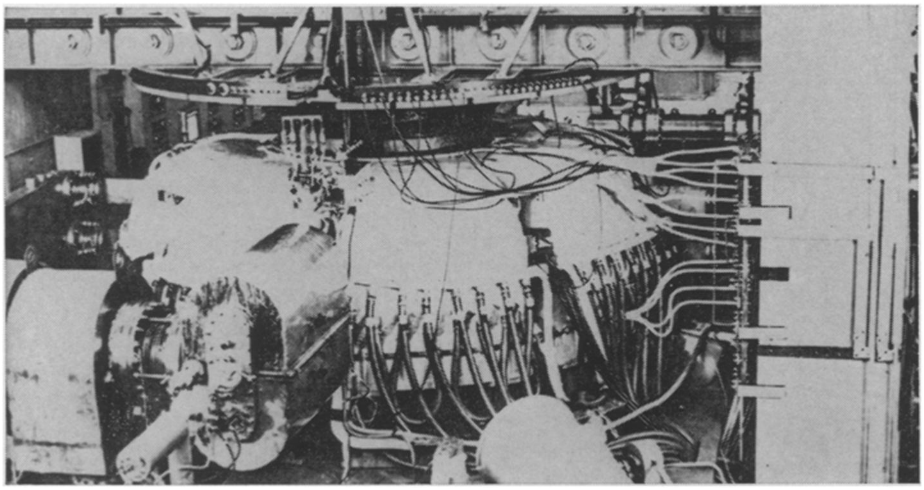

Excellent Russian results with the Tokamak have convinced U.S. scientists.

Plasmas do not usually start out in the Maxwellian condition, but they all tend to relax toward that state. One of the plaguing problems of fusion research is that on the way to the Maxwellian state, plasmas can develop instabilities that cause them to escape the magnetic fields and go to the wall of the chamber. Much research has concentrated on ways to suppress the instabilities. The exciting thing about the Tokamak plasma, says Dr. Hirsch, is that it had done whatever it was going to do on the way to the Maxwellian condition, had reached it, "and was perking along well."

The current flowing through the plasma was expected to be a major inhibitor of the plasma's natural tendency to attain equilibrium, and one purpose of the Tokamak experiment was to find out whether the current made equilibrium impossible. The Russian experiments have shown that the effect of the current is too small to prevent equilibrium.

Another Tokamak plus is that a Tokamak plasma has a circular cross section that is uniform throughout the tube. A Stellarator plasma has a triangular cross section that twists like a screw down the length of the tube, and this is bad for stability.

While the Russians were having their success with the Tokamak concept, American multipoles were recording equally exciting advances, and building on these also forms part of the AEC program. Dr. Tihiro Ohkawa of Gulf General Atomic in San Diego, Calif., used a multipole device to hold a plasma whose conditions of density temperature and confinement time were three times as far toward the minimum as the Russian results (SN: 11/1, p. 413).

"Multipoles," says Dr. Hirsch, "will not be useful as fusion reactors," although they are of great use in studying the physics of plasmas. The reason is that if a fusion reaction ever got going in a multipole it would vaporize the internal current rings and thus burn out the device. Dr. Ohkawa's next move therefore is to convert his multipoles into multiple Tokamaks, inducing the plasma to carry several spatially separated currents rather than the one current of conventional Tokamaks.

Physicists had worried that if anyone tried to induce more than one current to flow in a plasma, all the currents would snap together into a single one. They feared this would happen because there would be no material conductors to keep them apart. But Dr. Ohkawa has shown that two currents can flow simultaneously in a plasma, and he now plans to build a machine called Doublet (for double Tokamak) in which two currents will flow.

In a pilot Doublet, Dr. Ohkawa found that the magnetic interation between plasma current and the walls of the chamber kept the currents from snapping together.

Four single Tokamaks are included in the plans. They are a machine called ORMAK at Oak Ridge National Laboratory, one called ALCATOR at Massachusetts Institute of Technology, the conversion of the Model C Stellarator at Princeton University to a Tokamak and finally a Texas Tokamak at the University of Texas, for which the university is contributing $350,000, and the Edison Electric Institute $200,000 for instrumentation.

In testimony before the Joint Congressional Committee on Atomic Energy Dr. Hirsch stressed that the five machines were not competitive approaches to the same end. Each will attack a different aspect of the remaining problem: whether, as the densities, temperatures and confinement times in the Tokamaks are increased toward useful fusion power levels, the plasmas remain stable and approach controlled fusion as they are supposed to.

The Princeton conversion is a quick and inexpensive way to get a working Tokamak in the United States. The MIT ALCATOR will have a higher magnetic field than any other Tokamak; it will be able to go to 130 kilogauss, four times as strong as any field the Soviets have used. Soviet data give evidence that Tokamak performance improves with increasing magnetic field so the AEC expects ALCATOR to give higher energy and longer containment time. The Oak Ridge project will recreate the plasma of the Soviet Tokamak 3, but with higher magnetic fields.

The magnetic field in the Oak Ridge machine will be almost perfectly symmetric since it will be produced by a simple one-turn coil. The magnetic fields in the Russian Tokamaks have asymmetries—what Dr. Hirsch calls lumps—in them. The American physicists want to find out whether a Tokamak with a symmetric field will work as well since a fusion reactor with a symmetric field would be cheaper to build than one with a complicated, lumpy field.

Oak Ridge will also study the effect on confinement time of using different thicknesses of the plasma tube. The single-turn exterior coil can be removed and replaced with a larger one to permit increasing the diameter of the plasma tube.

According to theory, Doublet's two currents should multiply the ratio of outward pressure of the plasma to inward pressure of the magnetic field by 10. This multiplication should have a beneficial effect on the cost of building such a machine.

The Texas machine will be used to investigate new ways of heating plasmas to higher temperatures than can be achieved by the present method of using resistance to the plasma current.

Though years of hard work remain to be done, the Tokamak results have changed the attitude of plasma physicists from one of pessimistic caution to restrained optimism. "We're getting confidence in the physics," says Dr. Hirsch. "It's showing that nature is not standing in our way." Pessimists had feared that there was something in the physics of the universe that just would not permit controlled fusion to happen. Now, says Dr. Hirsch, it appears that the difficulties, though formidable, are technical rather than natural.

Dr. Hirsch hopes the world will see "power sent to grid" from fusion reactors by 1990 or 1995. By 1978 he hopes for enough progress to demonstrate that a fusion reactor is scientifically feasible, and he says: "If you want to put funds in, you could do it sooner." □