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Joint European Torus: a major advance for fusion

Although the U.S. is strangling its fusion effort, tokamak reactors are still possible by the year 2000. Astro-physics writer Albert Menez reports on the successes of the European JET program.

The tokamak remains the world's leading approach to harnessing the virtually infinite potentials of thermonuclear fusion reactions for the generation of cheap, clean energy. The tokamak may not eventually prove to be the best way to generate large outputs of electric power from nuclear fusion, but it is currently the only system that provides an immediate path to realizing large-scale "burning" fusion plasmas. Achievement of net energy-generating "burning" fusion plasmas is crucial for both further basic scientific advances and development of fusion engineering.

During the 1970s the United States became the undisputed leader in fusion research and development. But with the cutbacks initiated in the Carter administration and then continued by the Reagan-Bush administrations, that is no longer the case. As free-lance journalist Albert Menez documents in his article below on the Joint European Torus (JET), Western Europe has taken the place of the United States, with Japan close behind. The U.S. is now, at best, third. Even the Soviet Union maintains leadership in key areas, with the completion of their superconducting tokamak.

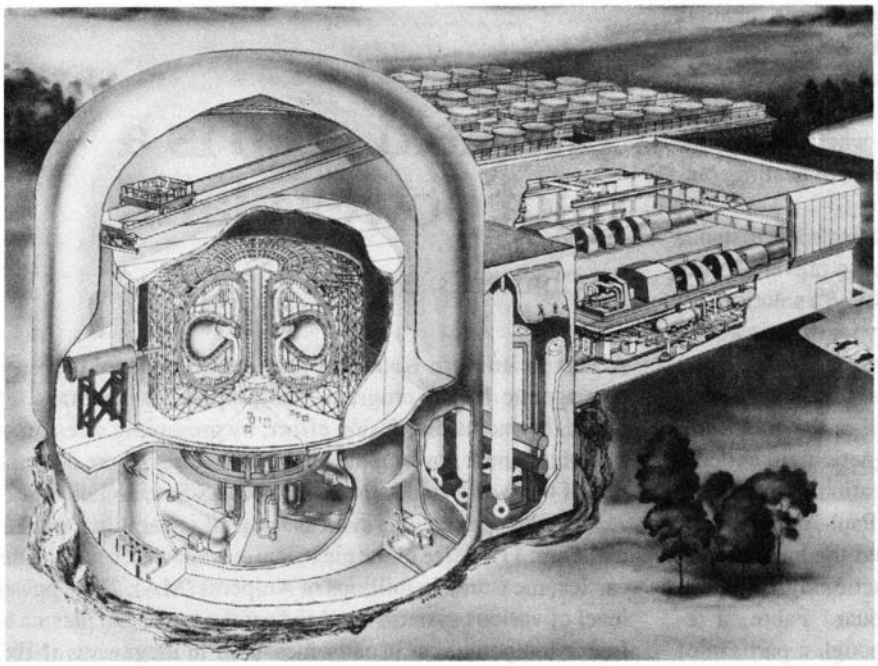
At the time of the first Geneva Reagan-Gorbachov summit in November 1985, the Soviets proposed that a joint effort be launched to build an International Thermonuclear Experimental Reactor (ITER) based on the tokamak. An international design team, which includes scientists from the United States, Soviet Union, Western Europe, and Japan, has been working on ITER plans since that summit. Now, the head of the Soviet fusion program, Academician Boris Kadomtsev, is proposing that this experimental stage be leapfrogged: Given the continuing progress in tokamak research, Kadomtsev thinks that the world should proceed to build an actual pilot power plant.—Charles B. Stevens

If we are to pursue continuing economic expansion in our industrial societies and the long-term development of the Third World, it is necessary to envisage an exponential economic growth, lest we watch these countries regress, bit by bit, to a point of no return. It is indispensable to extend our economic and technological activities beyond our terrestrial biosphere, and to have at our disposal a limitless and inexhaustible source of energy, in which the cost of exploitation is accessible to all, and not only to countries with secure fossil fuels or conventional nuclear energy.

With the present system of combining various energy resources (coal, oil, natural gas, and increasingly expensive offshore oil), it rapidly becomes clear that these cannot even sustain zero economic growth from 2015-20 on. Even then, such an energy mix would be for the almost exclusive profit of the relatively privileged countries that presently hold the keys to a world economic order which one day absolutely must be questioned. The massive recourse to conventional nuclear fission enery is more interesting; it is already providing France with nearly 60% of its energy production.

Traditional fission power always presents us with the extremely inconvenient task of extracting significant quantities of natural uranium, because only a small proportion, uranium-237, which makes up 0.7% of natural uranium, allows the characteristic chain reaction mode of energy production. Moreover, conventional nuclear power further presupposes the existence of vital infrastructure and an enormous effort to train a properly skilled work force. The extension of this mode of energy production to the Third World under large export contracts would be possible, but raises the question of the existing world economic order and of sources of financing, which brings us to the conclusion that the problem is, in fact, more political than linked to difficulties in technology transfer.

In any case, conventional nuclear energy should only be



Artist's conception of a functioning fusion power plant, using a magnetic confinement reactor. In 1974 when this picture appeared, the Atomic Energy Commission was predicting the first commercial reactors would be in operation by the year 2000.

considered a stage, and this includes breeder technology. Breeder technology allows us to economically utilize plutonium produced in conventional reactors, and, especially, to directly utilize uranium-238, which makes up 99.3% of natural uranium. This technology poses a safety problem, which is that it produces long-term radioactive waste, for which we need very rigorous storage systems. Nonetheless, the achievement of this technology is essential and its development must be continued.

Then there is controlled thermonuclear energy, also called fusion energy, the only technology that is able to ensure unlimited energy availability without the need to have considerable "primary" energy resources available. All that is required as "basic raw materials" is heavy isotopes of hydrogen, that is deuterium and tritium, from which it is possible to bring about fusion of the nuclei in order to obtain a concentration of mass, translating into a colossal release of energy, whether in the form of a deuterium-deuterium mix, or in a mix of deuterium-tritium....

The stars show us how

This controlled thermonuclear fusion is a natural phenomenon which occurs constantly inside stars, which has been completely explained and described by specialists in atomic and molecular physics laboratories attached to the great astrophysics observatories. The stellar fusion process naturally is being carried out with heavier and heavier elements, because the confinement and the necessary temperatures for nuclear fusion are achieved without difficulty in a plasma that is dense as a result of the fantastic gravitational force in the interior of these stars: This gravitational force constantly permits a counterbalance to the centrifugal pressure of electrons that come from the dissociation of nuclei located within these stars in assuring their equilibrium, and, similarly, allows the maintenance of the density and temperature of the plasma which are necessary for the fusion processes.

In order for man to achieve fusion, a number of research efforts using experimental reactors have been carried out, with the aim of maintaining their fuel at sufficiently great temperatures, densities, and confinement times, up to now with ambiguous, although often encouraging, results. For a deuterium-tritium mix, it is necessary to maintain a confinement temperature of 100 million degrees Centigrade and a density per confinement time of 100,000 billion nuclei per cubic centimeter and per second against 400 million degrees, and a much greater confinement time of a billion billion nuclei per cubic centimeter for a deuterium-deuterium mix. So far, two major paths have been explored in experimental reactors: rapid fusion by inertial confinement using lasers to compress the plasma; and slow fusion by magnetic confinement, which calls into play the whole system of complementary electric and magnetic fields.

Some interesting results have been obtained in the United States in inertial confinement by the Centurion/Halite program, but, more promising still, seems to be the research that has been led in Europe with magnetic confinement from the team in the Joint European Torus (JET) and its experimental reactor at Culham, U.K., financed by 14 countries.

Toward industrial use of fusion

Constructed between 1982 and 1983, the JET became operational in the course of 1984, and utilizes the tokamak system, which consists of using, as the vessel taking in the plasma and the mix confining it before fusion, a torus in the middle of which circulates a strong electrical current. From the fact that the plasma (ionized gas) is what conducts the current, it undergoes not only a phenomenon of heating, but, equally, a phenomenon of confinement.

Because it is necessary to keep this plasma some distance from the inner walls of the vessel in order to prevent a drop in temperature, the European specialists found a solution that had been used earlier and brought into play for this: a toroidal field produced by coils placed around the torus. For adjusting the form and position of this plasma, supplementary coils have been placed around the exterior wall of the enclosure, in order to obtain a complementary magnetic field called a poloidal field. According to a communication given before the Academy of Sciences in May 1990, Paul-Henry Rebut, director of the JET, had already presented the encouraging results of more than six years of the functioning European tokamak. During the same period, Edouard Fabre, a researcher at the Ecole Polytechnique, although a partisan of inertial confinement, had underlined how impressed he had been by the results attained by the JET.

The most recent information shows the considerable progress achieved by the Europeans in magnetic confinement. Certain basic problems have been resolved, including: Both the level of temperature attained as the confinement time (1.8 seconds!) and the density in the center of the plasma, parameters defined by the famous Lawson criterion, have been obtained. Unfortunately, so far, the JET experiments have not yet achieved all these criteria simultaneously and homogeneously in the different parts, corresponding to the energy discharges of the reactor.

In any case, the achievement remains fundamental, and it appears that the European physicists understood precisely what they must do and not do in developing further experiments that would be even more probing: The attempts conducted at JET between 1984 and 1991 have allowed us to specify that the deuterium-tritium mix used would often lead to the formation, in the middle of this plasma, of residual poles of helium curbing the chain reaction. They came up with the solution of adding magnetic fields designed to hold back this helium, to keep it distant from the plasma. Other modifications under way, consisting of utilizing beryllium tiles for the inside walls of the JET, ought to allow it to advance a further supplemental step toward efficiency. Thanks to the improved JET, to the French project Tore Supra, which uses superconducting coils to achieve the magnetic field, the Europeans are well on the way to achieving their goal in the realm of fusion research.

Now, with the projects for the Next European Torus (NET) and Intor on the table of decision-makers before they appropriate their budgets, the outline for an industrially usable fusion reactor is becoming clearer every day.

The next step is a pilot power plant

by Charles B. Stevens

Academician Boris Kadomtsev, scientific leader of the Soviet magnetic fusion program, has proposed to leapfrog the world thermonuclear fusion effort, by presenting a design of a pilot tokamak power plant as the next step. Where does the rest of the world stand, in the face of this Soviet challenge?

Two key parameters in measuring the capabilities of tokamaks are: 1) the size of the electrical current which the plasma carries, measured in millions of Amperes (MA); 2) the power level of various systems used to heat the hydrogen plasma to fusion temperatures, usually measured in megawatts (MW) of applied heating power.

The following comparison of international tokamak research efforts is taken from the September 1990 "Report of the Technical Panel on Magnetic Fusion of the Energy Research Advisory Board" of the U.S. Department of Energy.

"The Joint European Torus (JET), the largest tokamak in the world, operates with plasma currents up to 7 MA, ion cyclotron radio-frequency (ICRF) heating up to 16 MW and neutral beam heating up to 18 MW. JET has produced reactor level plasma parameters. . . . The Tore Supra, a superconducting toroidal field coil tokamak, has begun operation in France, along with a superconducting toroidal field coil tokamak, T-15, in the Soviet Union. The ASDEX tokamak in Germany continued to provide advances in enhanced confinement and current drive, and will soon be replaced by ASDEX Upgrade, a 2 MA tokamak dedicated to studying plasma-wall interactions. In Japan lower-hybrid heating was used to drive plasma currents of 1.5 MA in the large tokamak (JT-60) and, in the smaller Triam superconducting tokamak, lower hybrid sustained the discharge in steady state for more than 1 hour. JT-60 is current being upgraded to have an overall capability comparable to JET. . . .

"Both the European Community (EC) and Japan have operating tokamaks which are substantially larger and more expensive than the largest U.S. device (TFTR). Furthermore, both have funded major upgrades of their principal experiments—unlike the U.S. All three foreign parties to the International Thermonuclear Experimental Reactor (ITER) discussions have operating superconducting tokamaks, with the U.S. only now beginning to plan for such a device in the late 1990s. Thus, while the U.S. has contributed significantly to world progress on tokamaks in the 1980s, it will fall behind