Fusion-fission hybrid reactor

The next step in nuclear energy technology

Scientists and business representatives at the second U.S.-USSR Fusion-Fission Reactor Symposium held at Princeton University from Jan. 22 through 26 agreed that the fusion-fission hybrid breeder reactor is the next step in nuclear energy technology development.

Dr. Woldenhauer of the Washington Public Power Supply System said that utilities like the one he represents could not wait for fusion to have an impact on the energy production system. He called for an international effort to implement a two-phase immediate term program to, first, work out a detailed overall plan for hybrid development and, then, to initiate experimentation.

Dr. G. Shatalov of the Kurchatov Institute in Moscow demonstrated how a developed world economy in the year 2020 could be based on nuclear energy fueled by the fusion-fission hybrid. Of his projected 100 trillion watts of total energy capacity, about 12 times the current world capacity, 30 to 40 percent could be met by nuclear energy, 6-8 trillion watts of which would be from fusion hybrid reactors. The remainder of the nuclear energy component of total production would be made up by 15-20 trillion watts from conventional nuclear fission and 9-12 trillion watts from fast breeder reactors.

France, private sources say, is looking seriously at the hybrid concept as the next major nuclear technology area to be developed. They recently, successfully launched the SuperPhenix liquid metal fast breeder reactor into commercial production.

Should the United States show a commitment to a global expansion of nuclear energy capacity on a scale commensurate with the potential availability of fuel supplies from the hybrid breeder — a political commitment that would have to be linked to a reorientation of U.S. policy commitments away from London and toward the European Monetary System — the U.S. economy would receive a tremendous and necessary shot in the arm. Industry could expect large-scale orders for high-technology specialty materials and equipment — an area of production in which the U.S. excels.

But presently, the Department of Energy's policy is to foster solar energy development and other environmentalist alternatives to nuclear energy, putting the nuclear industry on the defensive. That policy has bred in energy executives attitudes ranging from hesitation to skepticism about even considering innovative ideas for possible implementation.

And leading members of the fusion research community are split over the tactical efficacy of adding the research and development of new ideas like the hybrid into their beleaguered programs. Cut to the bare bones by the U.S. Administration, the research budget barely funds already established fusion programs, let alone the new research ideas that are necessary to the vitality of the overall fusion effort.

The United States has relinquished its early lead in the fission breeder program, centered mainly at Clinch River, Tenn., to France. At this point, the U.S. should probably license the SuperPhenix fast breeder from that country. But the U.S. still has the lead in fusion research. Applying the highly skilled manpower pool, trained in the liquid metal fast breeder program, to the hybrid program, could accelerate the timetable for fusion-fission hybrid breeder development.

Why the hybrid?

There are two basic reasons why leaders in science and industry are supporting the immediate development of a fusion-fission hybrid.

First, the hybrid provides what Peter Fortescue of General Atomic referred to at the November Conference on an Acceptable World Energy Future in Miami Beach as "a plateau of usefulness" for the application of fusion energy well before the realization of pure fusion reactors. The hybrid will fill a critical role in world energy supplies in the next two decades and it will also provide important engineering tests for future fusion reactors.

Second, the hybrid is a very attractive answer to the question of providing cheap fuel. One hybrid can fuel from 5 to 20 conventional nuclear power reactors. In fact, in the initial phase, it may be most useful to think of fusion-fission hybrids not as electricity providers, but as fuel factories generating just enough energy to keep the reactor core going.

At the center of the device is a plasma produced by some magnetic or inertial confinement configuration. As generally conceived, a relatively modest rate of fusion takes place in the core area, producing an output of high-energy neutrons from the deuterium-tritium fuel undergoing fusion. The neutrons then pass out of the fusion plasma region and enter a blanket composed of so-called fertile material such as uranium-238 or thorium-232, substances that can be fissioned but cannot support a fission chain reaction. As a result of bombardment by the neutrons, the material in the blanket is transformed by the neutron absorption into heavier elements, fissile materials that can be separated out and used as fuel in fission reactors.

There also may be a certain amount of fission induced in the blanket, so that the hybrid operates directly as a power reactor in addition to breeding copious amounts of fuel for other fission reactors. Finally, the blanket also can contain lithium, which interacts with the neutron flux to breed tritium, one of the fuels for the basic fusion reaction.

The demand for nuclear fuel

Although there is disagreement on the time scale involved, authorities in the field of energy production agree that there definitely will be a need for nuclear fuel bred in reactors — either fission breeders or fusion-fission hybrids — if nuclear fission reactors are to continue as a significant source of global energy production. How soon this need will occur depends entirely on which projection one chooses for the expected world growth rate in the use of nuclear fission plants to generate electricity.

Dr. Shatalov's projection falls between the optimistic scenario developed by the author and his collaborators and the pessimistic assumptions in studies done by the International Atomic Energy Agency and the World Energy Conference. Both the optimistic and pessimistic projections of nuclear growth show that given the now available uranium and the expected new discoveries, the world will not be able to guarantee fuel supplies for the lifetime of nuclear plants dedicated toward the end of the century unless nuclear fuel is bred.

The hybrid as an energy multiplier

A pure fusion system must satisfy stringent requirements to be considered as a power reactor. If it is running on deuterium-tritium fuel, it must operate well above the ignition temperature of 44 million degrees Kelvin in order to sustain the fusion burn, and the product of plasma density times confinement time must be well beyond the breakeven condition of 30 trillion seconds-nuclei per cubic centimeter in order to produce net energy. The fusion-fission hybrid relaxes these conditions because the energy associated with the output neutrons from the fusion reactor can be greatly multiplied before it finally appears as heat or electricity.

In a typical fusion reactor, the fuel mixture of the two heavy isotopes of hydrogen (deuterium and tritium) fuses, producing the nucleus of a helium atom, called an alpha particle, and a neutron. Four-fifths of the energy produced in the reaction is carried away as the kinetic or motional energy of the neutron (14.1 MeV) while the remainder (3.5 MeV) stays with the alpha particle.

If fissionable uranium or plutonium is introduced in the blanket, the energy enhancement is on the order of 200 MeV per fission reaction, making possible a significant increase in the total energy output of the reactor (and at the same time relaxing the conditions for plasma breakeven). If each fusion neutron were to cause one fission, the energy outputs would be increased by more than a factor of 14. By multiplying the number of neutrons that bombard the fissile material, it is technically feasible to get an energy enhancement factor of 35 or more.

To turn the fusion-fission hybrid into a fuel factory, the blanket region would be used primarily as a breeding region to provide fuel for fission reactors, instead of as an energy producer. The mode of operation is neutron multiplication, followed by neutron absorption in a fertile material, creating new fuel that is then removed from the fusion reactor. The energy multiplication still occurs, but the conversion to electricity or process heat takes place at another location — the fission reactor that receives the fuel.

Some hybrid history

Surprisingly, the fusion-fission hybrid concept is almost as old as both branches of nuclear energy, and the hybrid history is now coming full circle.

The possible feasibility of the fusion-fission hybrid for breeding large amounts of fissile material was one of two main reasons that fusion research remained classified by the Atomic Energy Commission until 1958. The second reason was the theory that there might be a special, quick path to breakthrough in fusion research that would give one nation strategic control of the fusion power source. As the story goes, the development of controlled fusion proved to be more difficult, the rapid development of fission reactors in the 1950s provided easy access to fissile material.

Ironically, the reversal of the status of these two earlier considerations has brought the hybrid to the fore again: Fusion research in many areas has progressed dramatically during the 1970s, bringing the conditions for hybrids immediately in sight. At the same time, nuclear growth is beginning to outstrip existing fuel resources, making a new fuel source a necessity.

One of the first proposals for a hybrid based on the deuterium-tritium fusion reaction and conversion of uranium-238 to plutonium was put forward in 1953 in a report by F. Powell for a team at Lawrence Livermore Laboratory, which included Edward Teller.

In 1955, Lawson and others at Harwell in England proposed a similar hybrid configuration; and two years later, Barrett of Knolls Atomic Power Laboratory proposed a hybrid based on the Princeton stellarator. The more modern era of hybrid design and evaluation began in the early 1960s with experimental studies of the interaction of 14-MeV neutrons with uranium.

This was followed with the publications beginning in 1965 at the Massachusetts Institute of Technology and the Oak Ridge National Laboratory of detailed computer studies of the nuclear reactions and their products in more fully specified hybrid designs.

Hybrid concepts

A number of hybrid concepts have been proposed, which depend on both magnetic and inertial confinement fusion reactions to drive fuel production. Generally, the simple plasma configurations are considered as viable hybrid candidates, even though they are recognized as inappropriate for pure fusion energy production.

Concepts ranging in complexity from pure fuel factories to various combinations of energy and fuel production have been proposed by Lawrence Livermore Laboratory, the Bechtel Corporation, and by study groups working at General Atomic, the Massachusetts Institute of Technology, and several Soviet laboratories.

Depending on the complexity of the device, cost estimates for commercial production range for $500 million to $2 billion, the latter about double the cost for present fission reactors. Fuel and electricity production costs are expected to be comparable to if not cheaper than present costs.

Nuplexes

Since the early days of nuclear energy development, the idea of integrated agricultural and industrial production facilities based on central nuclear energy facilities — the nuplex — has been under discussion. Combinations of conventional, high temperature, and breeder reactors, both LMFBR and hybrid, can provide an integrated thermal and electrical energy supply for domestic and industrial use, while producing and reprocessing fuel for use on the site and in other locations. With sufficiently large groups of diverse types of reactors, entire new cities can be built.

At this time, most of the technology for fission-based nuplexes is available and construction could begin immediately, if the investment were made. The fusion-fission hybrid reactors provide a transitional technology from pure fission nuplexes to potentially pure fusion nuplexes at some later date.

How soon?

Given the Department of Energy's current timetables, a commercial demonstration hybrid reactor could be in operation in the mid-1990s. With an aggressive program, however, this time scale could be significantly accelerated so that a demonstration reactor might be on line by about 1990. In fact, researchers at Princeton have estimated that a crash program based on a tokamak (magnetic confinement fusion) core could produce a demonstration model by 1985. And Edward Teller forecast at the Miami conference that his brute force tandem mirror hybrid could be ready for commercial introduction in 15 years.

Whichever hybrid design is chosen for demonstration, the construction of an operating fusion-fission hybrid would provide a nice basis for celebrating the 40th anniversary of the original U.S. hybrid proposal.

— John Schoonover