# Latest Results Show Fusion Is Feasible And Economical

*Thermonuclear fusion has become front-page news in the past few weeks as a result of bold proposals from the Soviet Union and Japan for U.S. cooperation in a crash program to develop working fusion reactors in the next decade. In addition, Japan has kept a high profile for fusion at the Bonn meeting this week, stressing privately and in the West German press the importance of fusion research for meeting the world's energy needs.*

*In the report that follows, Charles B. Stevens of the Fusion Energy Foundation describes briefly what fusion energy is, what the major lines of research are, and what the latest research results tell us about its economic and scientific feasibility.*

*Mr. Stevens, director of fusion engineering studies for the FEF, is well known for his reporting work in the fusion field. A more detailed review of the status of fusion research by Mr. Stevens will appear in the August issue of the Foundation's magazine* Fusion.

The world effort to harness the virtually inexhaustible source of energy available from nuclear fusion reactions has achieved steady and rapid progress in the last several years, with a high level of international scientific collaboration. Most exciting, recent experimental results indicate that the demonstration of scientific feasibility — getting more energy out of the fusion reaction than is necessary to initiate it — may be weeks away. In the United States, Europe, Japan, and the Soviet Union engineers and scientists are now working on the basis of these latest laboratory results to produce a number of different designs for commercial fusion power plants that would be both economical and technologically feasible.

### *What is Fusion?*

Fusion is the chief source of energy in the universe. The fusion of atomic nuclei is the process by which all the heavier elements we know on earth were built up from the simpler, lighter elements. Fusion is the basic source of the huge energy output of stars and of the sun — sunshine.

In the fusion reaction lighter elements like hydrogen fuse and form the nuclei of heavier elements like helium, plus energy. There is a net energy gain because some of the end-product nuclei weigh less than the nuclei of the input fuel.

Man first duplicated the high temperatures and high densities needed to ignite fusion in the early 1950s with the detonation of hydrogen bombs. But the practical utilization of this type of fusion energy is limited politically by the fact that it requires an atom bomb to generate the necessary temperatures and pressures. Research into other approaches to igniting the fusion reaction were initiated in the 1950s but ran into major scientific problems, for example, around the confinement of the fusion

## Good News For The Fusion Budget

The U.S. fusion research budget was recently put into jeopardy by the attempts of Energy Secretary James Schlesinger and Deputy Secretary John O'Leary to axe fusion as an energy source. Now it appears to have weathered the crisis.

According to Washington sources in the Department of Energy, the fusion research budget for 1980 will be $500 million — enough of an increase to keep up with inflation.

John M. Deutch, director of energy research for the Department, told the *Washington Post* this week that he foresees commercial fusion plants in the United States by the year 2005. Although this estimate seems conservative to fusion experts like those at the Fusion Energy Foundation, it is a far cry from Schlesinger's recent comments that fusion would not be feasible until the end of the 21st century.

The other good news has to do with the Japanese proposal to President Carter in May to fund joint fusion research to the tune of $1 billion. Department of Energy sources report that a detailed memorandum has been received from the Japanese Embassy on the scientific aspects of the collaboration, and that a meeting is set for August to discuss policy.

The Japanese have proposed that in the first year each country will put up $100 million for the work in a number of projects. These projects range from ongoing mainline U.S. research — such as General Atomic's Doublet III in San Diego and Princeton's TFTR — to promising alternative lines of research that are not now funded in the United States, such as the stellarator and the Elmo bumpy torus. The Japanese also have on their list basic research in plasma physics, and work in areas like chemical processing that bear on fusion development. The Japanese have specifically noted that their fusion input is directed toward balancing the U.S. trade deficit.

According to department sources, both the laser office and the fusion office are enthusiastic about the proposal and are drafting positive replies.

reaction. These alternate approaches generally consist of directing relatively small amounts of intense electromagnetic energy onto minute amounts of fusion fuel.

### *The Two Basic Approaches*

There are two basic approaches in the confinement of the fusion fuel while heating it to ignition temperatures. The first is *magnetic confinement* in which relatively diffuse fusion fuel is insulated and trapped with magnetic fields. The second approach, *inertial confinement*, is similar to the hydrogen bomb approach: The fusion fuel is driven to high densities and thereby undergoes significant amounts of fusion before "blowing up." (To picture this blow-up, think of the ignition of gasoline in the cylinder of an automobile engine.)

Both approaches use the two heavy isotopes of hydrogen, deuterium (D) and tritium (T), which have the lowest ignition temperature of any fusion fuel, about 50 to 100 million degrees Celsius. In order for net energy to be produced — that is, more energy than that invested in confining and heating the fusion fuel — the hydrogen fuel not only must be brought up to the ignition temperature, but also must be maintained at a specific density for a certain period of time. This confinement condition is generally expressed as the product of the confinement time times the number of hydrogen atoms per cubic centimeter, and it is equal to about 30 trillion atoms per cubic centimeter-seconds.

### *Laser Fusion*

Inertial confinement, a relative newcomer to the fusion race, was initiated after the development of high power lasers and high-current-charged particle beams — electron and ion beam generators. The two largest lasers in the world that are carrying out fusion research today are the Shiva, a 24-beam neodymium glass laser at Lawrence Livermore Laboratory in California and the 8-beam carbon dioxide laser at the Los Alamos Laboratory in New Mexico. Shiva recently achieved a laser output of 26-trillion watts, and the 8-beam Los Alamos system reached a 22-trillion-watt output, more than twice the original specification of the 8-beam carbon dioxide laser design. (The 26-trillion-watt output, in one burst, is more energy than the total output of the entire world.)

Shiva has already produced a record number of fusion reactions, 1 billion, and is expected to produce a significant thermonuclear burn within the next year. To achieve a breakeven experiment will require upgrading Shiva to a 300-trillion-watt output, which could be completed by 1982.

Recent experimental tests and the surprising technological successes in the development of carbon dioxide gas lasers has led many scientists at Los Alamos to believe that carbon dioxide could go all the way to a commercial fusion electric power plant and do so in the 1980s — decades before all previous projections. The most recent results indicate that carbon dioxide laser light is absorbed just as efficiently as the shorter wavelength light from glass lasers. This is crucial, since it determines how efficient the laser beams are in inducing fusion.

Carbon dioxide lasers are also capable of achieving the minimal repetition rates and operating efficiencies needed for electric power plants.

The unexpectedly high power output of the 8-beam carbon dioxide laser means that the Los Alamos Laboratory can carry out crucial breakeven experiments in the near future, rather than having to wait until the 100-trillion-watt Antares carbon dioxide laser is completed in the early 1980s. In fact, Los Alamos scientists will begin to test laser fusion targets this fall that will demonstrate the key aspects of the dynamics of a breakeven experiment. In this way, they may achieve scientific feasibility without an actual breakeven experiment.

### *Electron Beam Fusion*

Researchers at Sandia Laboratory in New Mexico report that they have begun to resolve many of the scientific and technological questions involved in the electron beam approach to inertial fusion.

The first electron-beam-induced fusion was accomplished by the Soviet researcher L. Rudakov in 1976, and the Soviets are building a breakeven electron beam experiment, the Angara V, which will come on line in the early 1980s.

U.S. researchers at Sandia followed up the Rudakov results by producing electron beam fusion using a new type of target. Developed in collaboration with the Livermore Laboratory, the target uses induced magnetic fields to enhance the confinement of the fusion fuel. Fusion experiments with Sandia's new electron beam machine, Proto II, have just begun, and Sandia scientists report that they will have significant results to report at the Colorado American Physical Society meeting in the fall.

Reactor designers at Sandia have completed a number of experimental and conceptual studies that show that the path to commercial electron beam fusion is far more technologically feasible than previously believed. Briefly, their results are as follows:

*Transport of electron beams through laser-generated plasmas has been experimentally demonstrated. This would permit the electron beam generator to be placed a sufficient distance away from the fusion microexplosion so as not to be damaged.

*Methods to increase the repetition rate at which electron beam machines can be fired have been developed and have been found to be economically feasible for commercial power plants.

*A detailed, 100-megawatt electric prototype reactor design has been completed and would cost about $200 million to build.

### *Magnetic Confinement*

The most successful and most researched fusion device is the tokamak, a donut-shaped magnetic bottle designed by the Soviets.

In 1976, researchers working on the Alcator tokamak at the Massachusetts Institute of Technology reached the minimum breakeven confinement criteria of 30 trillion atoms per cubic centimeter-seconds at a temperature of about 10 million degrees. A follow-up experiment, the Alcator C, is now being fired up and is projected to get well beyond these minimum breakeven confinement criteria within the next year.

Additional methods of heating tokamaks to approach fusion temperatures are being explored on the original

Alcator, and recent results using microwaves appear to be successfully achieving this, in what is termed the lower hybrid mode. Further tests on the Alcator with microwave heating will receive a powerful impetus when a new 8-megawatt microwave generator, recently obtained from the U.S.

Alcator experiments with microwave heating were measured in thousands of watts, and 8 million watts of microwaves could bring Alcator plasmas into the fusion temperature range needed for reactors.

Scientists at the Princeton Plasma Physics Laboratory working on the world's largest tokamak, the PLT, also report recent successes. The Princeton PLT has successfully begun operation with neutral beam injectors for heating fusion fuel to fusion temperatures, and these experiments could demonstrate the most important scientific dynamics of fusion plasmas in tokamaks within the next few weeks.

These initial results will be publicly announced at the International Atomic Energy Agency meeting on fusion to be held at Innsbruck, Austria August 23.

### *Tokamak Reactor Studies*

Tokamaks have been severely — but unfairly — criticized as impractical candidates for commercial power plants. The critics say that tokamaks would lead to large, complex power plants that would be uneconomical and technologically difficult to perfect. However, the latest reactor designs based on the most recent experimental data demonstrate that this is not the case.

The most important of these designs is the University of Wisconsin Nuclear Engineering Department's NUWMAK tokamak, the latest design in the famous UWMAK tokamak series. Dr. R.W. Conn, leader of the Wisconsin group, reported recently that the NUWMAK design study demonstrates that "a medium field tokamak . . . can have high power density, a high degree of modularity, and moderate size." According to reports presented to the Santa Fe fusion technology meeting in May, NUWMAK would generate 600 megawatts of electrical power (a little more than half of the output of conventional nuclear fission reactors) with a power density of 10 megawatts per cubic meter.

The innovative features in the NUWMAK design are as follows:

*A single boiling water heat loop for driving the steam generator.

*The use of a solid lithium-lead eutectic for tritium breeding and thermal energy storage.

*The use of conventional copper magnets, together with superconducting magnets, to permit ready access to the reactor core for repairs.

*The modular cassette design of reactor components, creating economies in construction and repairs and permitting remote handling of reactor components.

*Overall, this design is a natural extension of the moderate field line of tokamaks such as the Princeton TFTR.

### *Fusion Economics*

Since the fuel for fusion is virtually free, the chief cost projected for fusion reactors that will produce electricity is the capital cost of building the reactors. Because of scientific uncertainties, the original fusion reactor designs in the early 1970s were based on building gargantuan 5000-megawatt thermal power plants the size of the Astrodome — obviously costly. However, the significant experimental and engineering design progress in the last few years has greatly improved these projected designs to the point that fusion power plants would be about the same size as existing fission systems and have capital costs in the same range as fission reactors.

In particular, the University of Wisconsin fusion engineering team has developed the NUWMAK, discussed above, which would be about twice the size of the Princeton TFTR experimental tokamak and would generate 660 megawatts of electricity (2000 megawatts thermal). Although the economic studies of NUWMAK's capital cost are still in process, it appears that the total capital cost would be close to that of conventional nuclear fission plants. Needless to say, this cost prediction demolishes one of the chief arguments used by the opponents of fusion development.

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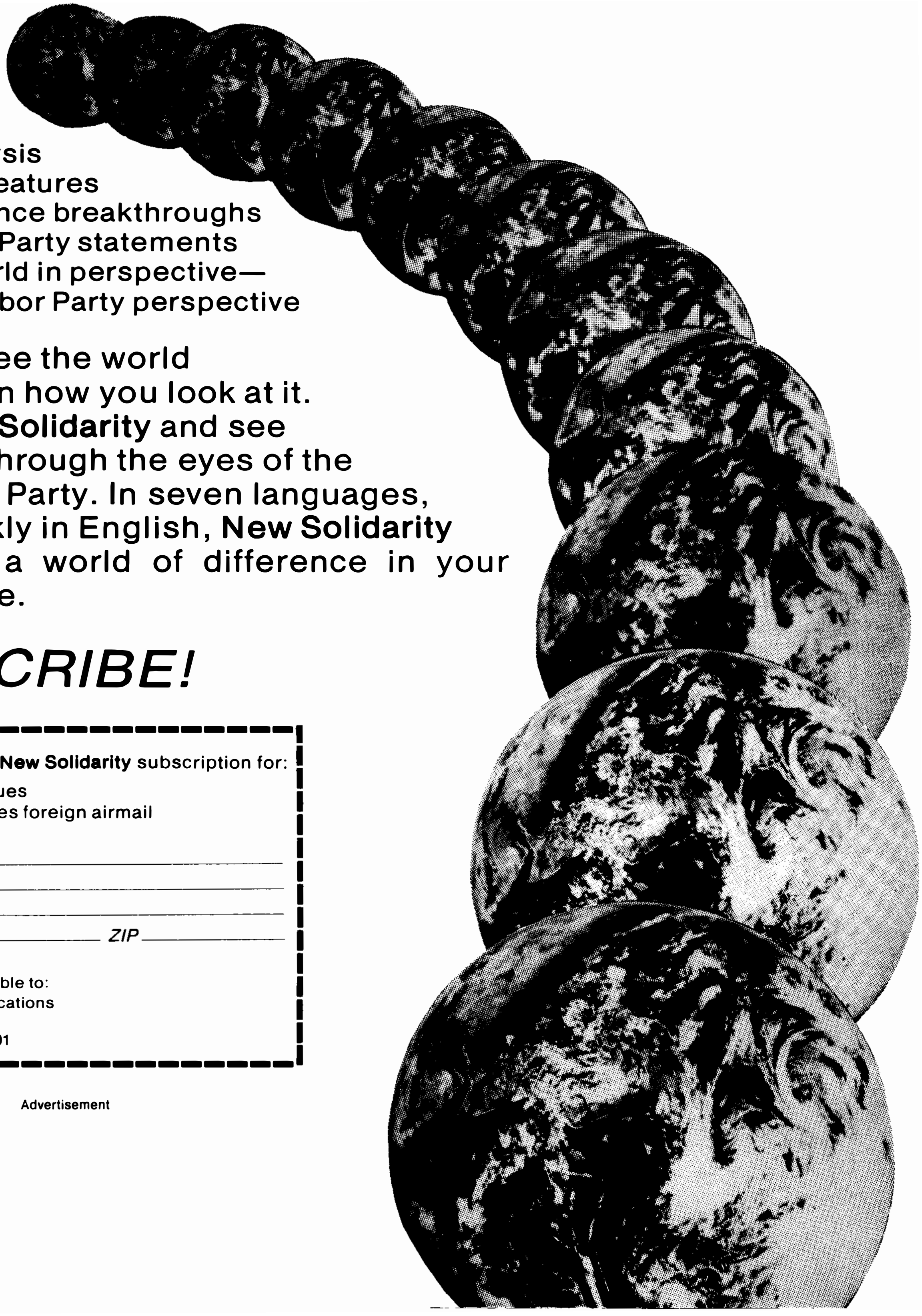

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