Fusion power is now in sight for the 1990s

by Paul Gallagher, Executive Director, Fusion Energy Foundation

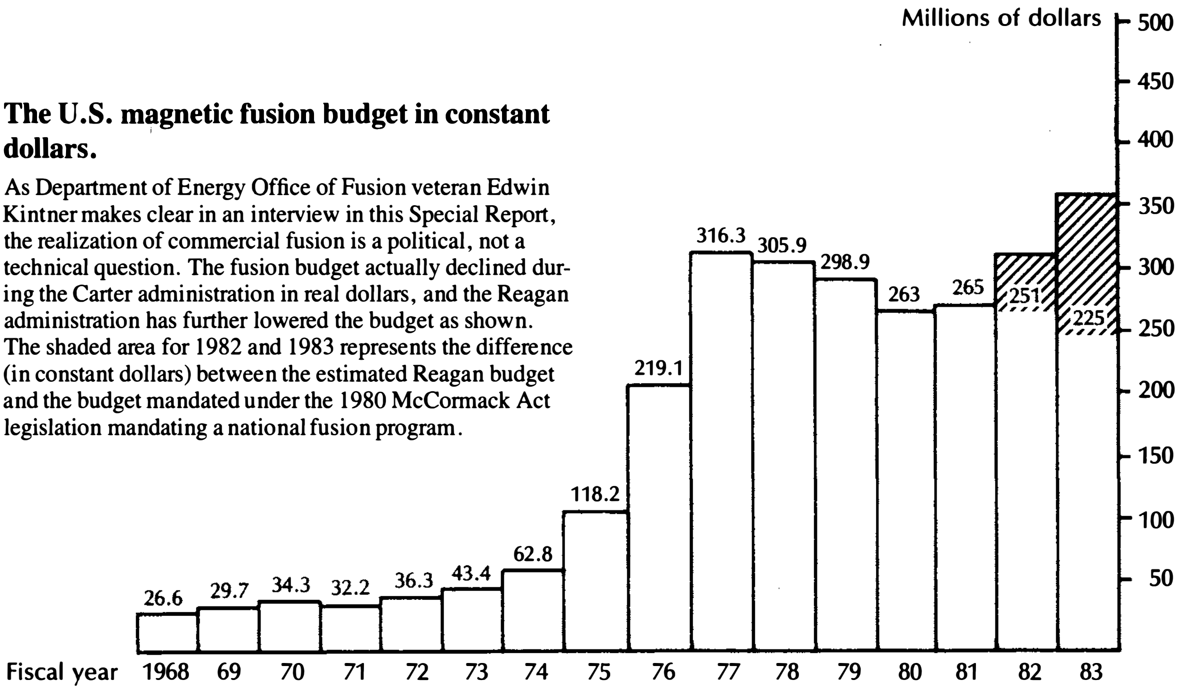
The International Conference on Plasma Physics and Nuclear Fusion is convened by the International Atomic Energy Agency only once every two years, and the ninth such conference, held in Baltimore Sept. 1-8, brought together nearly 1,000 of the world's leading plasma physicists and fusion laboratory experimentalists. The delegation from the Fusion Energy Foundation released a special issue of *Fusion* magazine at the conference, proposing that commercial fusion energy could be brought five years closer, to the middle 1990s, by exploiting the promise of polarized fusion fuels, one of the most-discussed, and least reported, ideas in the international fusion community since April.

The potential of polarized fusion fuels was just one of the recent advances in fusion energy research and development discussed at the IAEA conference. As Department of Energy veteran Edwin Kintner elaborates in an interview in this report, these achievements demonstrate definitively that commercialization of fusion power in the near-term future is a political, not a scientific, problem. The nature of the problem is perhaps best expressed in the recent announcement by President Reagan's Science Advisor, Dr. George Keyworth, that the government's present strategy will not achieve commercial fusion until 2050. Under the rubric of budgetary austerity, this policy not only contravenes the Magnetic Fusion Energy Engineering Act of 1980, which mandates a $20 billion national expenditure over 20 years to achieve a commercial prototype reactor by the year 2000. It dooms the United States to permanent energy shortage and industrial decay, at the very point that this nation's scientists have proven that there exist no scientific or technological barriers to fusion development by continuing to achieve results in their work—even under conditions of increasing funding restraint.

Early this year researchers at Princeton and Brookhaven labs predicted that deuterium-tritium and other fusion fuel mixtures could be magnetically polarized (spin-aligned) and would *stay* polarized even in the enormous heat of a fusion reaction. This would double or triple the reaction rate, and produce engineering advantages in controlling and directing the reaction and designing the reactor, considered of even greater importance than the enhanced reactions themselves.

The U.S. magnetic fusion budget in constant dollars.

As Department of Energy Office of Fusion veteran Edwin Kintner makes clear in an interview in this Special Report, the realization of commercial fusion is a political, not a technical question. The fusion budget actually declined during the Carter administration in real dollars, and the Reagan administration has further lowered the budget as shown. The shaded area for 1982 and 1983 represents the difference (in constant dollars) between the estimated Reagan budget and the budget mandated under the 1980 McCormack Act legislation mandating a national fusion program.



Fusion, September 1982

The prediction passed accelerator tests at Brookhaven, and when word of the potential came to FEF from Dr. Bruno Coppi of MIT, the Foundation began an immediate and aggressive canvassing effort with scientists and the press, to "break the story" as it had the now-famous 1978 Princeton Large Torus breakthrough in achieving record plasma temperatures.

It took a letter from Dr. Hans Bethe of Cornell to Reagan Science Advisor George Keyworth, however, to produce the first discussion of a testing program for the new breakthrough under fusion reaction conditions, nearly two months after FEF began its campaign. But the scale and breadth of the test program is still vague.

Low-risk conservatism and lack of engineering drive has become the hallmark of the once-dominant U.S. fusion program under Keyworth. Keyworth has made it clear, most recently at Magnetic Fusion Advisory Committee meetings, that his indefinite postponement of fusion is rooted in acceptance of the collapse in worldwide energy growth caused by the economic depression and monetary crisis. The Science Advisor told the MFAC meeting that the world "does not need a new energy source by the end of this century."

Under conditions of continuing world economic collapse, Keyworth is correct. But the alternative program to permanent global depression and the holocaust of Third World depopulation that will come with it—the debt and monetary reorganization and "great projects" infrastructure development program proposed by *EIR* founder Lyndon H. LaRouche—requires energy. Break the stranglehold of the collapsing International Monetary Fund over the credit supplies of the developing sector, restart capital goods production for export in the developed nations, and the world economy would suddenly manifest a demand for electrical energy growing so rapidly as to surpass fission growth capabilities *including fast fuel breeding* within 30 years. By then fusion reactors will have to be in widespread commercial use.

The Japanese challenge

At the IAEA conference, only the Japanese representatives made a presentation describing a timetable and engineering prospectus for future developments leading to a commercial fusion prototype. The continuing emergence of the Japanese program toward world leadership in fusion is described below, in the article by Marsha Freeman on Sept. 8 presentations to congressional hearings by the leaders of the Japanese and European programs.

Also included in this Special Report are an interview with Dr. Stephen Dean, head of Fusion Power Associates, by Dr. Steven Bardwell, and excerpts of *Fusion* magazine's special issue on the potential of polarized fusion fuels. The FEF has announced plans to circulate this issue of *Fusion* in 200,000 copies, as part of its campaign to enlist the U.S. citizenry in reviving the nation's fusion program. This campaign was announced at a public FEF meeting during the IAEA conference. All mission-orientation has been withdrawn from the U.S. fusion program, Bardwell told that meeting. The breakthrough of polarized fusion fuel could "give us a second chance" to move aggressively toward engineering fusion development, he concluded, perhaps five years earlier than any previous government's estimate.

Edwin Kintner: 'Achieving fusion is a problem of politics, not technology'

Edwin Kintner was the director of the Department of Energy's Office of Fusion Energy until January 1982 when he resigned, citing the extreme problems developing in the program as a result of Office of Management and Budget interference. Kintner had, before coming into the program, some 30 years of experience in the development of nuclear technologies, and had been project director, under Capt. Hyman Rickover, of the Nautilus program which developed the first working nuclear power reactor, as an engine for submarines.

Kintner was interviewed for EIR *by Fusion Energy Foundation Director Paul Gallagher, immediately following the International Atomic Energy Agency conference on fusion Sept. 1-8 in Baltimore, at which he spoke on prospects for fusion at a meeting organized by the foundation.*

EIR: You told the FEF session in Baltimore that fusion energy research and development efforts in the United States and elsewhere are continuing to progress in demonstrating technical capacities for fusion power. What are the important new developments, as of this conference?

Kintner: There were a number of very satisfying advances reported at this conference..
the 4.6 percent beta [plasma pressure] from the Doublet III [tokamak at General Atomic in San Diego]. You remember that just a year ago there were theories, and some experimental evidence from the ISX-B at Oak Ridge, that 2.5 to 3 percent was going to be the limit of beta. Many people were quite concerned about that. Now we have information that there is no such limit, and we have not yet seen any reason to believe these machines have reached their limit. This is another one of the major parameters in fusion, as represented by the tokamaks, in which it now appears we can be reasonably confident; we know we can do it in temperature, and we know we can do it in beta, within the ranges that are required for a power reactor. . . .

Another result most gratifying to me is the initial success with the TMX [tandem mirror machine, Lawrence Livermore Lab] Upgrade. I've felt for some time that one of the most important contributions I've made to the program is to get a serious program started on the mirror design side, and the TMX itself did what it was supposed to do: increased the confinement in a tandem mirror by a factor of ten over a simple mirror. The TMX Upgrade was supposed to improve this by another factor of ten; in initial operations they have done this by a factor of three, and there is no reason in their minds why they should not continue to improve.

Another important advance, known before but reported in Baltimore, was the operation of the superconducting magnet for the MFTF-B [Mirror Fusion Test Facility], which is by far the largest and most powerful superconducting magnet in the world. It got up to full power with no difficulties.

Now those were in addition to the ones discussed at the FEF meeting, with the polarization of ions to increase cross-sections [rates of fusion reactions], and the other advantages which take place from that. So I think it's been a period of steady and important fundamental progress. . . .

EIR: You also said, despite this progress, if I quote you correctly, that the United States "may have already blown it," in the effort to commercialize fusion. What did you mean?

Kintner: What I said was that one of the most important questions of fusion was not technical at all. That is, whether or not a program requiring as long a time, and as many resources as fusion, could be organized on a political and social basis, in a *directed* way. I felt we had done that, were on the verge of doing it, with the Buchsbaum recommendations of 1980; and I think that what has happened now, the change that has taken place in the program, is not just a matter of money; it is a matter of loss of forwardness and cohesion along a line. The people who are "saving money," don't realize how hard it will be to get the program back on the track, so it has priority as a program; they simply don't understand it.

EIR: Of the two mandates of the McCormack Act [the Magnetic Fusion Energy Engineering Act of 1980] which the Department of Energy has since renounced—aiming at a specific timetable for commercialization of a fusion reactor; and the immediate development of a Fusion Engineering Device—are these the aspects of current policy which have had the worst effect on the program?

Kintner: Yes, they are. I would, perhaps, put them in different terms. The program has come to the point, from a physics point of view, where it is necessary to accelerate the engineering, to match the physics, so that it is possible to know, in ten years or so, whether fusion is practical, and how much good it can be expected to provide.

Now, that is not going to be possible. Until a systems-integrating device like the FED is built, the understanding on the engineering side won't be there.

The other significant aspect of the Magnetic Fusion Engineering Act which is going to be dead or on the back burner, is that of getting industry involved in a serious way in working on fusion development. . . . I'm talking now, for example, about setting up the Center for Fusion Engineering in an industrially oriented mode, and building it as primarily an industry-oriented activity. Those are going to fall by the wayside, and industry is going to lose interest. These corporations are not going to put their best people or their resources into being small-job shops, for a few million dollars a year, to the national laboratories.

EIR: The President's Science Advisor, Dr. George Keyworth, and other officials of the White House Office of Science and Technology Policy, speaking in public, have alleged the unreadiness of certain scientific aspects of the fusion program for the development of engineering.
Kintner: That may be, but within the community [the outlook is optimistic]—for example, the summary on magnetic confinement progress to the Baltimore IAEA meeting which was delivered by Harold Furth [director of Princeton Plasma Physics Lab], was very forward in tone. I do know that Ron Davidson . . . says that we are making good progress, that there are still questions we haven't answered, but we're moving, and moving well. I don't think the question is that we're not ready. The question is will we support it? I'm prepared to let people have credit for saving money, but I don't think they ought to simultaneously take credit for being experts in what the program needs to get ahead.

EIR: How did the program solve major problems during its past five years, while you were director?
Kintner: There were several things indicative of what now needs to be done on the engineering side. One was started before I got there, and I followed through. That was to organize the tokamak program as a program, with a flagship—the TFTR [at Princeton]—and a number of smaller ships, like Alcator A and B, PDX, ISC, and Doublet—all of which had a role to play to increase the base of technical knowledge and insight which would culminate in the TFTR and the JT-60 [Japan] experiments. That's what I mean by a *program*.

Now underneath that, of course, there were another substrate of experiments for the development of information, and development of the theoretical base, the setup of the Institute for Plasma Physics at the University of Texas, and so forth. What we did in addition to that, and this *was* something I had a great part in, was to create a mirror program, with the MFTF and then MFTF-B as the flagship of the mirror system, and devices like Terra, and the TMX Upgrade, and the Tandem Mirror at TRW, and the program at Wisconsin, so that there were a number of different machines, feeding information into this central, flagship of the MFTF-B. And that's what I mean by a program.

We attempted to have other physics experiments intended to fill in the matrix of physics in the plasma fusion and magnetohydrodynamics field. We couldn't do all those we would have liked to do, but with the machines that we had, and the program we laid out, both toroidal and magnetic, within ten years we would have had a significant body of knowledge contributed to science.

On the engineering side it's a similar thing. You need the flagship—namely, the Fusion Engineering Device, with the objective to make significant fusion energy and extract it—and then under that, there have to be additional development devices which produce the special information of one kind or another, such as the FMIT [Fusion Materials Irradiation Test Facility], and the Large Coil Project, and so forth. You [NASA] could have done all the tests in the world, with rockets, and guidance, and monkeys, and so on; but unless that program had had the objective of sending a man to the Moon and bringing him back, it would have wasted 50 percent or more of its efforts. And that's why you need programs, and you need clear targets.

EIR: From the technology-development standpoint, can the current fusion program be compared to important points in fission development?
Kintner: There is not a Stagg Field [the first atomic "chain reacting" pile] kind of step. There is not an STR-Mark I [submarine power reactor] stage for fusion. The rational approach, if one accepts that fusion development is an important human goal, is that when you get to the point that you can design and build, with confidence, a machine that produces significant thermonuclear energy, the next step is immediately to do that; and you continue the physics development which allows you to make more refined judgments with regard to power reactors.

As soon as you start this process of designing and building a systems-integrating device, then you have to lay out, on the engineering side, the developments which will support the design and construction of that machine. If you then do that, if you carry it out well, you will then end up with two types of insights. One is in physics, with regard to the best way of confining a plasma in a magnetic field, and the knowledge of how efficiently, in how small a machine that can be done. You also have a body of knowledge, then, with regard to the engineering; the magnets, the materials, the safety aspects, handling. Putting those two together, then, you are at a point where you can make an assessment about what the program can do in the future.

I studied the Apollo Program, and the Manhattan District program, the naval reactors and the breeder program, and I've tried to find a parallel. But they aren't there. Fusion development is a special kind of challenge.

EIR: The Nautilus program, in which you were involved, was the first breakthrough to power production with fission.

What kind of problems had to be solved to do that, and how fast was it done?

Kintner: There were tremendous problems, and they were so many, and so difficult, that the people involved were quite often discouraged, and quite often surprised. These problems ranged from just not knowing the physics in power reactors, nor the stability of power reactors under loads, nor the materials with which to make the fuel elements, nor how you would be able to inoculate high-speed, high-power motors, pumps, and gears with water lubrication, nor even the simplest question of how you would be able to shield or weld the primary systems. All those problems were solved; the prototype was running in three years; the ship was at sea, and running at full power and full submergence depth in five years.

Now I'm not saying that you could do that with fusion. I'm only saying that so far, it seems to indicate that the same sort of attitude is rational, and that the principles that were enunciated, which I saw come true in the naval reactors program, are valid in fusion: Nature works best for those who work hardest for themselves.

EIR: The U.S. fusion program has been, until recently, the largest. How do the other major national, and international efforts, in the case of the European program, stand, and what rate of progress are they making?

Kintner: At least for the moment, they're making good progress. Good results came out of ASDEX, in Germany. There are good results coming out of Japan, and I think that the Soviets' work on the T-15 Tokamak is doing well. I think that at least for the moment, the results of the Beckerts Committee indicate that technological development in Europe is going to happen, and the same thing is true in Japan.

But my sense of the matter, with both the Japanese and European systems, is that there may come in those countries a reflex action from the downturn in the U.S. program. Their building up recently, in the JET [Joint European Torus] and JT-60 [Japanese Tokamak] programs, came from the impetus of the United States' acceleration since 1972. They're not going to continue full bore if the United States does not.

EIR: What do you think the impact of the program has been, over the last decade, on the training of physicists in the United States?

Kintner: There has been a significant body of bright young people trained and brought into the program. It is inevitable that they are going to continue to produce good results, whether in the fusion program, or outside, in other physics activity. That is a permanent, lasting contribution of the program, absolutely. There is still, and I think will continue to be, an impulse in people to see, in something like fusion, an intellectual and moral challenge, and it will draw to it worthwhile young people who will train themselves, and eventually make major contributions.

Polarized fuel: the that could move up

Nuclear fusion has been called the ultimate energy source. Using the same energy generation mechanism as the stars, nuclear fusion produces energy more intensely, at higher temperatures, and in more different forms than any other form of energy known. The fuel for fusion is the various light elements, hydrogen and helium being the most important.

The fuel cycles most attractive for fusion energy generation are:

deuterium + tritium→ helium-4 + neutron
deuterium + deuterium→ helium-3 + neutron
deuterium + deuterium→ tritium + hydrogen
deuterium + helium-3→ helium-4 + hydrogen

The common ingredient in all these fuel cycles is deuterium, a doubly heavy form of hydrogen that occurs naturally; approximately 1 out of every 6,000 hydrogen atoms has a deuterium nucleus. This isotope of hydrogen shares all the chemical properties of normal hydrogen but has different nuclear properties. The energy attainable through the deuterium-deuterium cycle from a quart of water is equivalent to

TEMPERATURE REQUIREMENTS FOR FUSION BREAKEVEN*
in degrees Kelvin

Fuel Cycle	Unpolarized	Polarized
D-T	100,000,000	80,000,000
D-D	350,000,000	220,000,000-300,000,000
D-He^3	700,000,000-1,000,000,000	400,000,000-500,000,000

*Assuming standard tokamak conditions for density-confinement time.

Courtesy of Fusion magazine

research discovery fusion's timetable

that produced by 300 gallons of gasoline. It is estimated that there is enough deuterium in the ocean to last 100,000,000 years at 100 times the present rate of energy consumption!

The rate at which a given mixture of fusion fuels will "burn," or fuse, is determined by the temperature of the reactants, the density of the fuel mixture, and, scientists have only recently stressed, the magnetic alignment, or polarization state, of the fuel. The accompanying table summarizes the conditions that must be achieved in a standard design of a fusion reactor using each of these fuel cycles. The temperature conditions listed combined with density conditions would result in what is called a breakeven plasma; that is, a fuel mixture (at these temperatures in an electrically charged, gaseous state called a plasma) that returns as much energy from the ignited fusion reactions as was required to create ignition conditions.

A new degree of freedom

The primary approach to achieving the required temperature and density conditions uses the electrical properties of the plasma fuel itself to contain and heat the fuel with magnetic fields. Since the electrically charged fuel nuclei are deflected by a magnetic field, a *force field* can be created that insulates the fuel from the cold (that is, room temperature) containment vessel. A toroidal magnetic field configuration, the tokamak, is by far the most advanced design for such a fusion device.

The use of polarized fuel adds a new dimension, a new degree of freedom, to the quest for fusion energy. Previously, only the temperature, density, and closely related quantities could be varied in tokamak experiments to achieve fusion ignition. It was known that the actual fusion reactions that occurred were overwhelmingly those between particles with the appropriate magnetic alignment, or spins. In the case of a conventional, unpolarized fuel, as many as half the collisions took place under unfavorable alignment conditions, and so only rarely resulted in fusion. The use of polarized fuel, on the other hand, creates a situation in which almost all the collisions between fuel nuclei occur under favorable conditions of magnetic alignment and, depending on the fuel cycle, increasing the *net* reaction rate by a factor between 1.5 and 2.5.

Using known techniques, the spins of the fuel can be aligned, and the auxiliary heating of the plasma (accomplished with beams of fuel particles) can also be polarized. The resulting mixture of polarized fuel provides the optimal conditions for ignition. However, there is one serious problem—a problem that seemed so overwhelming that scientists had not considered the possibilities of polarized fuel for many years: In the extreme temperatures and external magnetic fields of a fusion plasma, would not the polarized fuel quickly lose its state of higher organization as each particle underwent millions of collisions?

At first sight, the answer to this question seems to be an emphatic yes. But the more recent analysis done by a group at the Princeton Plasma Physics Laboratory (J. Kulsrud, H. Furth, and E. Valeo) and one at Brookhaven National Laboratory (Maurice Goldhaber) demonstrated that neither of the two mechanisms thought to depolarize the fuel would in actuality do so. First, it had seemed obvious initially that the collisions that result in the fusion of nuclei would also, when fusion did not occur, result in the disruption of the magnetic alignment of the colliding nuclei. However, a simple calculation done by these scientists showed that by far the predominant kind of collision, a collision governed by the electrostatic repulsion between the particles (called a Coulomb col-

Tokamak beta values

Machine	⟨B⟩ %	B (KS)
ASDEX	.5	22
JFT-2	3.0	15
PDX	3.0	9
ISX	2.2	9
T-11	2.8	8
D-III	4.7	6
Tosca	0.5	5
Reactor needs	≥5	50

Source: Dr. Harold Furth, Princeton Plasma Physics Laboratory

The efficiency of use of magnetic field in a fusion reactor—measured by the ratio of plasma to magnetic field pressures—determines the ultimate power density of the reactor. This efficiency, called beta, has been a major object of research in the magnetic confinement fusion program. Shown here are the highest achieved values of beta in existing large experiments. ASDEX is a tokamak in West Germany, JFT-2 a Japanese machine, PDX a large experiment in Princeton, ISX a toroidal device at Oak Ridge National Laboratory, T-11 the largest Soviet experiment, D-III the world's largest tokamak at General Atomic Corp (in San Diego), and Tosca an Italian machine. The recently reported beta of nearly 5 percent achieved on the D-III is very close to that necessary for a commercial reactor. ⟨B⟩ represents beta and B represents magnetic field.

lision), cannot disturb the magnetic alignment of the nuclei. That is, this physical interaction does not affect the magnetic spin properties during the collision.

Second, it had also seemed obvious that the strong and rapidly changing magnetic fields that occur in a plasma would themselves act as random polarizers and rearrange the polarization of the fuel in a very short time. But detailed calculations of the effect of these magnetic fields on the magnetic alignment of the nuclei showed that they, too, were incapable of affecting the direction of spin of the fuel. The scientists summed up their results in stating that the depolarization time of a fusion plasma is much greater than the ignition time; that is, a fusion plasma at ignition conditions will burn a long time before it depolarizes.

These theoretical arguments are currently being tested in laboratories in the United States and other countries and the experiments should be completed by early 1983. There is almost complete confidence in scientific circles that these experiments will confirm the following hypotheses:

(1) Polarized fuel enhances reaction rates of all fuel cycles, in bulk plasma as well as in individual collisions (an already demonstrated fact). These enhancement factors are:

D-T increases by a factor of 1.5
D-D increases by a factor of 2.5
D-^{3}He increases by a factor of 1.5

(2) The depolarizing mechanisms in a fusion plasma, specifically Coulomb collisions and magnetic field fluctuations, are too weak to depolarize the fuel on time scales less than the ignition time.

Applications of polarized fuel

The advantages of polarized fusion fuel fall into three different areas: (1) the enhancement of reaction rates and relaxation of ignition requirements; (2) the ability to control reaction products and tailor energy forms; and (3) the possibility of using advanced reactor designs and energy extraction techniques.

(1) *Enhanced reaction rates.* The enhancement of the reaction rates for all fusion fuel cycles dramatically changes the timetable for realization of fusion energy for commercial production of electricity. The most aggressive projection for the large-scale application of fusion for electricity production is that of the Japanese. Their fusion research project is planned to operate a commercial prototype fusion reactor, producing 150 megawatts of electrical energy, by 1993. This prototype reactor would then be scaled up to a reactor for export by the year 2000. This aggressive schedule has been confirmed by numerous U.S. government and private studies, which have stated unequivocally that the world's fusion effort (with the exception today of the Japanese project) is limited by funding, not by technology.

This fact was recognized by the U.S. Congress in October 1980 when it passed by an overwhelming margin the Magnetic Fusion Energy Engineering Act of 1980 (the "McCormack Bill"), mandating an accelerated U.S. program with the goal of achieving a commercial prototype reactor by the year 2000. This act has not been enforced, and the funding for the U.S. fusion program has actually been cut since the passage of the bill.

With the advent of polarized fuel, this already medium-term projection for the realization of fusion is significantly speeded up. Estimates are that the relaxation of plasma conditions made possible by the increased reaction rate of polarized fuel would enable a prototype reactor to be built before the end of this decade, and a commercial reactor to be built seven to eight years after that.

The plasma conditions in the next generation of fusion experiments would be very close to those required for a fusion reactor. These machines (the TFTR at Princeton, and the JT-60 in Japan, both scheduled for completion during 1983) were designed to be breakeven machines for the conventional D-T fuel cycle. In addition to achieving the plasma conditions necessary for ignition of D-T, they were to be modified after several years of operation, to actually burn this fuel.

With the development of polarized fuel cycles, however, this experimental program could be modified to shorten considerably the initial plasma demonstration period, and to proceed much more quickly to the actual ignition testing. Since the machine would now be operating not merely in the ignition range, but actually with plasma conditions similar to those in a reactor, the engineering schedule could essentially skip over one stage of experimentation.

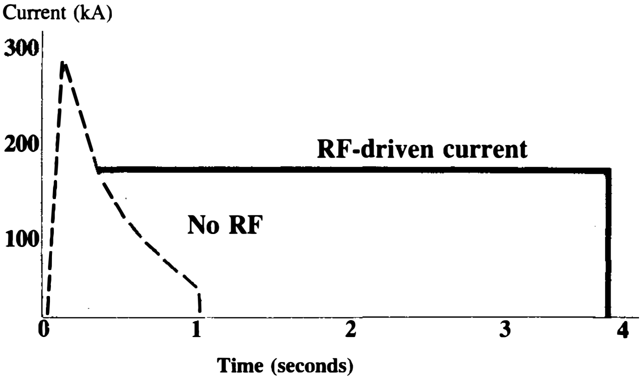
Based on previous considerations, fusion scientists expected that TFTR would be followed by an engineering device (the Fusion Engineering Device, or FED) and, only after that step, a prototype commercial reactor would be built by the year 2000. However, by using polarized fuel and modifying the next generation of experiments—TFTR and the JT-60—it may be possible to move directly into a commercial prototype by 1995, conservatively speaking.

This speed-up in the possible experimental program leading to fusion would obviously be possible in all branches of magnetic fusion, not only in the tokamak schedule described above. The magnetic mirror machines, which have shown remarkable progress in the past several years, would also be accelerated, as would be the whole family of more speculative devices. With the plasma conditions so much easier to achieve, it is quite possible that the engineering advantages of some of the alternative approaches to fusion would compensate for their present inability to achieve the ignition conditions for conventional fuels. Thus, the Elmo Bumpy Torus, the reversed field pinches, and the stellarators—all of which have significant engineering advantages over tokamak designs, but have not as yet demonstrated a comparable ability to control a heated fusion plasma—might leapfrog the tokamak for a second-generation polarized fuel burner.

(2) *Control of reaction products*. The most significant engineering challenge posed by fusion development is that of perfecting materials capable of withstanding the intense bombardment by neutrons from the fusion reaction. These neutrons cannot be controlled by the magnetic field (because they are not charged) and so are absorbed in the containment vessel and shielding blankets of the reactor. Indeed, the main factor limiting the technologically achievable energy density in a fusion reactor is the inability of conventional materials to withstand bombardment by energetic neutrons. The main advantage of the so-called advanced fuel cycles, especially the D-^{3}He cycle, is that they should theoretically produce fewer neutrons and, correspondingly, more charged particles.

However, conventional advanced fuel cycles are able to deal with the neutron problem in only a partial way because of the systematic inability to control the fusion process itself. Present-day fusion energy is frequently referred to as *thermonuclear* fusion since it is usually assumed that the fusion reactions take place in a random way in a randomized plasma—a condition that is called *thermal*. Polarized fuel changes this condition in two essential ways. First, the products of the fusion reaction (the ^{4}He particles and the neutrons of the fuel cycle reaction products) are produced in a *preferential direction* out of the fusion reaction.

"Current drive" in Princeton Large Torus



Source: Dr. Harold Furth, Princeton Plasma Physics Laboratory

A significant engineering draw-back of the tokamak as a commercial power producer has been the necessity for inductive current generation in the machine. The tokamak depends for stability and heating on the existence of a very large current circulating in the machine, which must be induced at the start of the discharge. Scientists had long assumed that this current could only be restarted with a repetition of the original induction cycle resulting in an inherently pulsed operation mode for the tokamak. The mechanical and thermal stresses from pulsed operation created a number of serious engineering problems that had dimmed the attractiveness of the tokamak. But results reported in the last two months show that the current in a tokamak can be sustained for many seconds using powerful radio waves. This technique, called radio frequency (RF) heating and current drive, offers the potential for a steady-state mode of operation for the tokamak.

Second, the kind of fusion reactions that occurs can be controlled by the polarization. Consider the case of the D-^{3}He fuel cycle. In a plasma consisting of this fuel mixture, it is clear not only that the D-^{3}He reaction will occur, but also that the D-D reaction will occur. With conventional fuels there is no way to control the additional reactions. With polarized fuel, on the other hand, a whole new degree of freedom is introduced into the fusion process that enables us to control to a large extent not merely *when* the fusion reaction happens, but *what* reactions happen.

Since the basic nuclear physics interaction involved in the fusion process is enhanced when the spins of the species to fuse are oppositely directed, consider the result of igniting a D-^{3}He plasma in which the deuterium nuclei are polarized in one direction and the helium-3 nuclei in the other direction. The D-^{3}He reaction will be enhanced. This is desirable because the D-^{3}He reaction produces no neutrons. On the other hand, the D-D reaction will be suppressed (since all the deuterium nuclei have the same polarization). Thus, we can separate the two cycles using the polarization of the nuclei and eliminate almost entirely the neutron production of this cycle.

(3) *Advanced reactor and energy conversion*. Fusion, like fission, is not a single technology, but rather a succession of increasingly complex and flexible machines and techniques for energy production in all its aspects. Many engineers project, in fact, that the greatest impact of fusion energy will be not in the production of electricity but rather in the production of synthetic fuels, cheap process heat, and intense beams of high-energy particles. The use of polarized fuel has a dramatic impact on each of these longer term applications of the fusion process, an impact that depends on the uniquely ordered and controllable form in which the polarized fuel produces energy.

The second and third generation of fusion devices projected on the basis of conventional (unpolarized fuels) were all chosen for their attractive engineering and maintenance features and for their flexibility in the production of different forms of fusion energy. These reactor designs include:

(a) The reversed field pinches. These machines make use of the plasma's inherent ability to create and sustain its own magnetic field. They are among the most efficient producers of plasma magnetic fields and so require small (and easily manufactured) field coils.

(b) Mirror machines. The mirror machines (tandem mirrors, the Elmo Bumpy Torus series, and so forth) all use variations on electrostatic confinement and linear magnetic field variations to produce a fusion plasma that has many advantages over a conventional tokamak plasma.

(c) Spheromaks. These machines resemble a smoke ring generator, and they create a self-structured, toroidal plasma that needs no central support. The engineering advantages of a simply connected chamber (one with no hole in it) have generated great enthusiasm for this relatively new machine.

Stephen O. Dean: 'Nuclear fusion is ready for the engineering stage now'

Dr. Stephen O. Dean is the president of Fusion Power Associates of Gaithersburg, Maryland. He was in government service with the Atomic Energy Commission, the Energy Research and Development Agency, and the Department of Energy for 17 years, and held the post of director of Confinement Systems Division of the Office of Fusion Energy in the U.S. Department of Energy until early 1979. Dr. Dean was interviewed for EIR *by Steven Bardwell.*

EIR: At the International Atomic Energy Agency's Ninth conference on Plasma Physics and Nuclear Fusion in Baltimore during the first week in September, new results in tokamak physics were reported. Will you summarize what you see as the most important developments?

Dean: I think this meeting was particularly interesting in that advances were reported on problems which the tokamak was perceived to have by some people, on issues associated with whether they would make attractive commercial reactors, specifically the problems of raising the power density in these machines and, secondly, finding a means of running them in a continuous, (rather than pulsed), mode. I think the most important and impressive results were the ones reported by General Atomic. They reported 4.6 percent beta, [the critical determinant of commercial power density in a fusion reactor] which is about twice what the previous record had been, of about 2.5 percent.

I think the importance of their result was not just that it was a higher number but that the earlier experiments seemed to be showing some kind of saturation or beta limit. General Atomic went well beyond the values at which the other experiments were saturating with modest amounts of input power. They still have a couple of megawatts reserved there so they may go up even further, and they have now reached values which are about what's needed to build the fusion engineering device. This is still somewhat short, in my opinion, of what will be used in a commercial reactor, but even within a factor of two of what I think would make a very nice, reasonable, compact and high-powered type of tokamak, the conventional type of tokamak.

EIR: Were these in the ballpark of what was predicted for noncircular cross-section machines like the D-shaped Doublet III at General Atomic?

Dean: Nobody really knew what kind of beta values would be reached in these various machines. The power that's available for these machines is sufficient in the long run to run the machines up into the 10 to 15 percent range. We don't have full power on any of the machines yet, so we haven't really gotten to those values. I think in terms of expectations this is consistent with the original expectation for this amount of power input, but it is beyond what most people thought was going to happen in view of the saturation factor that was being observed elsewhere. I feel that for those reasons the General Atomic results bode well for continued progress toward a higher power density plasma. They also saw evidence that the non-circularity of the plasma was in fact contributing to enhanced plasma conditions and hence confinement, and I think there again it was the first time we have seen definite results that show the advantages of non-circularity.

In addition, on the question of continuous operation, results from MIT, where they showed lower hybrid coupling of radio frequency waves into the plasma at higher density, show that perhaps we can drive the currents in tokamak by non-inductive means so that we could imagine perhaps eventually a steady-state tokamak or one which doesn't require pulsed transformers. This has important engineering implications.

EIR: At this meeting I noticed there were a number of results relating to the question of lower hybrid heating, ion cyclotron resonance heating, and other radio frequency heating. Can you give any idea of the relative significance of these?

Dean: I think what these results show is that only in the past couple of years have we started to seriously investigate putting large amounts of radio frequency power in a variety of frequencies into plasma. We've almost always simply used neutral beams for heating. Now, all over the world, we're starting to see the effect of putting large amounts of radio frequency power at various frequencies into the plasma. I think without exception we are finding better conditions as we do this. I don't know what frequency we'll eventually choose in a reactor, but I think the significance is that we may have a variety of possibilities. If it doesn't work well at one frequency, we'll be able to use a different frequency. We'll be able to tailor the plasma to behave in a variety of ways.

EIR: There are two results of other magnetic confinement machines which generated considerable interest at the IAEA meeting. One is the progress of the mirror machine, and the other is the dramatic change in the assessment of the significance of reverse field pinches.

Dean: The mirror experiments I think presented a nice step forward in demonstrating that in the larger tandem mirror we are able to enhance confinement time by something like a factor of three beyond that in the smaller tandem mirror, which of course was itself a factor of a couple above what had been achieved in simple mirrors. So, the mirror program, as we make the machines bigger and change their design, is showing the ability to enhance the confinement and reduce the end-losses.

We don't yet have a full demonstration of thermal barriers, and this is the objective of the mirror program at Lawrence Livermore Laboratory during the next six to eight months. At that point we will be able to make an assessment of what a real tandem mirror reactor will look like. Right now we don't have sufficient fundamental data to verify our assumptions on thermal barriers. But that should all clear up in the next year, and certainly I think we are going in a positive direction. . . .

On the reverse field pinch, we've had the emergence, as a surprise in the last year, of a fairly small experiment doing considerably better than it was designed to do, for reasons which weren't predicted in advance and aren't fully understood but are quite dramatic. One of these is the "dynamo effect," in which the plasma seems able to continue to exist because of its own dynamics in a confined state, independent of what we're doing to it from the outside.

EIR: I was impressed by the statements of Dr. Donato Palumbo, the head of the European Community's fusion program, and Dr. Shigeru Mori, the head of the Japanese fusion program, on their continued optimism on the prospects for commercial fusion development and on the broad-based commitment that they've made to fusion research. They reported on a number of impressive experiments. How do these programs fit together with the prospects for progress in the United States?

Dean: I think that it's clear that both the Japanese and the Europeans are now committed to fusion as a development program, as opposed to just a research program. They both have program plans that lead to power reactors; both seem to have a more reliable financial commitment to carrying these programs out than we have in the United States. . . . Palumbo said, for example, that he has a five-year budget and he knows that his available funds will not be less than specified in this budget during that entire five years. . . . This gives him the ability to plan his program with some confidence. Mori stated that in Japan, fusion was elevated a few years ago to what they call a national project, and that means that it's not something that is played around with in the budget every year. It means that the country is committed to funding it at the levels required to carry out the objectives of the project and those objectives are quite ambitious.

I think that both the Europeans and Japan have their programs on a par with, at least, and maybe somewhat more aggressive than what the United States has, even though I think Americans could still argue that we are turning out more interesting results by and large. This is more because we've put more commitment in the past rather than where we stand today. The new European and Japanese machines are comparable to or maybe bigger and better than our TFTR, and they are clearly organized to go the rest of the way.

However, I don't think that there is any likelihood that Japan and Europe will break into the lead in terms of building a power reactor several years before the United States. I think that they are not quite confident of themselves to run away from us in that regard.

EIR: You have alluded several times to the uncertainties and the fluctuations in U.S. political commitment to fusion power. In the last year, budget cuts have hit the inertial confinement programs even harder than the magnetic confinement programs, although both areas have suffered cuts in real dollar levels of funding. Will you hazard a guess as to what the future funding profile for U.S. fusion research and development might be?

Dean: I am optimistic that things are beginning to improve. I think that it is typical of a new administration that it comes in not knowing what it likes and doesn't like, or liking some things and not having heard of other things. Fusion was one of those areas of ambiguity, and we suffered in the first year of the Reagan administration. But our situation will improve in the third and fourth year as the administration gradually becomes aware at the highest levels what a good program fusion is, and how much it has to benefit in its international activities by pushing fusion. Fusion has a very good reputation internationally, at the highest levels of government in Europe and Japan, and that information is filtering back to the United States' system through the State Department and other channels. There are many international meetings on technology going on right now, and fusion keeps coming up as the example of a good program, well managed, in which there is something to benefit from pushing. This is starting to have an effect on the attitudes of the administration. . . .

So I am optimistic that things are slowly but steadily improving. And there is one thing that I would like to add. Consider the invention of the laser: the laser could have been invented in 1910 by Western man, instead of 1960. And the new developments in polarized fusion could have been realized when the fusion program was started 25 years ago, but they weren't. This and many other things are starting to bubble up now because people are thinking about the program and they will all become incorporated as the program evolves. Fusion still needs much improvement before we can credibly claim that this technology is going to produce electricity more cheaply than coal or nuclear power. But I think what we definitely don't want to do is to wait until all these things sort themselves out at the laboratory level before moving ahead with machines that produce large amounts of fusion power. By moving ahead as quickly as possible, we will put ourselves in the position to really start to learn of the more interesting potentials of the technology, its power handling, and its impact on the engineering.