Fusion energy ready for a new initiative

Dr. Stephen O. Dean, a leading expert in fusion energy, talks about recent advances in new approaches to achieving fusion, and the budgets required to make the breakthroughs.

Dr. Dean is the president of Fusion Power Associates in Gaithersburg, Maryland. He formed FPA in 1979, after a career in the Atomic Energy Commission, and serving as director of the Magnetic Confinement Systems Division of the Office of Fusion Energy in the U.S. Department of Energy. He was interviewed by Marsha Freeman on July 16.

EIR: The magnetic fusion energy program has taken a cut of at least $100 million over the past few years, and the laser fusion programs have virtually disappeared from the civilian Department of Energy budget. What is your general assessment of the status of the fusion program, at this point?

Dean: I think the fact that both programs had built facilities late in the 1970s and early in the 1980s has allowed them to continue to make very impressive progress in the scientific work in spite of the budget cuts, but all of the facilities now are underutilized. There's been a problem, of course, in upgrading facilities, and that will slow down progress in the future, but I'm hopeful that this downward trend of the last few years has hit bottom and that we're going to start seeing some growth again, in the future. I'm hopeful that this has just been a period of adjustment financially, and that in the long run, fusion will still be an important, fairly large government program and may even get some growth again.

EIR: What have been the major results and milestones in the fusion program over the past year or so?

Dean: At the Princeton Plasma Physics Laboratory, they achieved 200 million degrees in the Tokamak Fusion Test Reactor, which was a record for tokamaks, and actually it's the kind of value that's required in their atttempt to achieve breakeven over the next year. I don't even know if it's been announced yet, but there's just been the achievement of a 6% beta, where beta is the ratio of the plasma pressure to the magnetic field pressure, and in the tokamak, beta has always been fairly low. One needs to get to about 10% for a commercial reactor, and the best we've been able to do was about 4.5% before. Now, at GA Technologies [in California], in the Doublet device, they've gotten about 6%, and they're encouraged by that. They hope that they'll get it up even higher.

[In addition] there have been a couple of experiments that aren't fully conclusive, but suggest that we'll be able to drive a current in the tokamak with radio frequency waves that would allow the tokamak to run steady-state all the time, instead of having to be pulsed. That would be very important for commercial activities.

EIR: Where are those experiments being done?

Dean: Some of them were at the Massachusetts Institute of Technology, some of them were at Princeton, and some were in Japan. We have a major experiment getting set up now to test that further at Lawrence Livermore Laboratory, where we have moved the MIT tokamak out to Livermore. We're setting it up alongside the free electron laser facility out there. We're going to drive currents in that machine at a higher density using the microwaves that are generated by the free electron laser facility. There's a lot of intense work on trying to figure out how to convert the tokamak concept, which is the most successful concept, from a pulsed machine to a steady-state machine. All the theory and all the experiments suggest that there are several frequencies that could be used and there are tests going on around the world to try to demonstrate the kind of currents that one needs.

All of that looks pretty good. The international community has agreed to work together to design the next machine. That's encouraging also, because it shows that everybody is now focusing on a real engineering test reactor in the program. A few years ago, those kinds of things were casual studies, but now it seems like a serious plan; that there will be one or more engineering reactors built in the 1990s and, of course, these are essential to have before one could design a commercial reactor.

There are some new back-up facilities. There is a new reversed-field pinch facility that's under construction at Los Alamos National Laboratory, and there is a new field reversed concept being constructed at Spectra Technologies in Seattle. So there's vigor not only in the mainline tokamak program, but also in some of the back-up concepts. Of course, what we've lost in all of that, is our entire magnetic mirror program, and that was a result of these budget cuts.

EIR: The mirror program, especially at Lawrence Livermore Laboratory, had a large commitment of federal funds, and had built some very large facilities. What is the staus of the mirror program, how is it different from the tokamak design, and where should the program go?
Dean: The government has decided, right or wrong, that they're going to phase out all mirror research in the United States. They stopped the Livermore work first, and now they're going to stop the university work at the end of this fiscal year. If there were enough money, you certainly would not want to do that, especially after you'd made all of those commitments. On the other hand, you take the amount of money you've got, you try to place your bets on things with sufficient resources to allow something to make progress, and that's what's been done. I guess I think that was a tough decision, but was probably the best decision that could be made under the financial circumstances we were in. If it's possible at some future time, if the budget can get up another $50-100 million—it probably would have to take a $100 million increase in the budget, in order to rejuvenate a mirror program—I think that we could do it.

The mirror concept has certain attractive features, for commercial reactors. Its geometry is nicer from a mechanical engineering point of view, but the physics is much more difficult than these toroidal concepts, and it was lagging in its progress. I'm not sure how hard it will be to make the mirror concepts actually work. I think what may happen eventually, is that the facilities that were built for mirrors at Livermore may be converted to do other things so those facilities are still there, and if there are funds and interesting ideas, they might get rejuvenated for some other purpose.

At the moment it doesn't look like the mirror concept itself will make a comeback in the near future. The Japanese still have a vigorous mirror program, and maybe they'll carry the ball for the next five years. If it looks good over there, we can justify getting back in it.

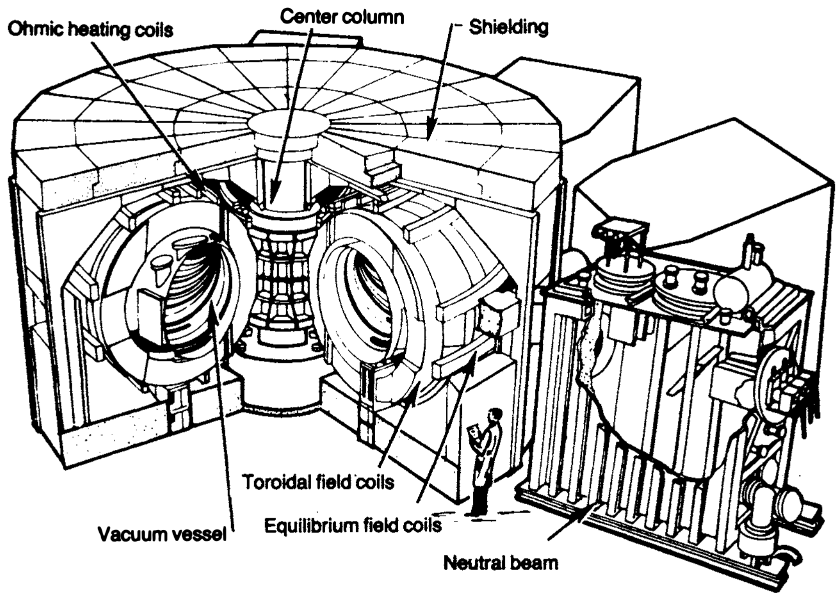
EIR: Have the Japanese continued to make progress in their mirror program or have they encountered the same physics problems as researchers in the United States?
Dean: They've come up against some of them, and they were a little behind anyway—their facilities aren't quite as big as the one we had just built—so the answer is that they've made some progress on some of those problems. The interpretation of data is always tricky, and without comparable tests elsewhere, it's always going to be difficult to make sure these things are done right. They certainly haven't solved [all] the problems of the mirror, but they've gotten some interesting results, and partially solved some of the problems of the mirror.

EIR: One of the most interesting potential applications for the open-ended mirror fusion design, is the work being done at the University of Wisconsin Fusion Technology Center, on fusion propulsion for spacecraft. Although putting any kind of device into space adds to the constraints, such as making it as light as possible, whereas on Earth the weight would not matter, it is also possible that a space-based fusion propulsion system might be more forgiving, in terms of efficiency, and other parameters that would be important for baseload power. What do you think of the fusion propulsion work?
Dean: I think that that concept is correct, that the application is easier, in many respects, at least from the testing point of view and the physics point of view, than to make electrical power on Earth. I think the magnetic mirror concept could possibly be adapted for that, even if it couldn't be adapted for commercial electric power. I think it would be worth pursuing.

Of course, the Department of Energy is not motivated to support work for fusion propulsion. They don't use that as a criterion to decide to run a magnetic mirror program. If NASA and the Department of Energy could think of it that way, I

Dr. Stephen O. Dean

FIGURE 1
Schematic of the TFTR tokamak



The Tokamak Fusion Test Reactor, the largest construction project in the U.S. fusion program, became operational on Christmas Eve 1982. Shown are the various coil systems that produce the magnetic field configuration that spirals around the plasma in the tokamak, containing it. The TFTR recently achieved 200 million degrees, a record for tokamaks, and the kind of value required in their attempt to achieve breakeven over the next year.

Source: *Fusion* magazine, January-February 1985.

think it would be a good justification for running a small mirror program to test some of those kinds of concepts out. There never has really been a fusion propulsion program in this country, per se. There have been just been a few studies now and then by people, but there's never been a funded, focused program to look at fusion for propulsion, and to carry out experiments. Maybe it's time for somebody to start a serious program to do that.

There is a small study funded by the Air Force that I think is going on now, to evaluate some of that, and if it comes out good, perhaps the Air Force, or the Air Force with NASA, might take over some of these mirror facilities and keep the work going. I don't think at the moment, that the Department of Energy would do that, unless somehow or another they could get extra money specifically for that purpose.

EIR: Perhaps the Strategic Defense Initiative Organization would be interested as well, since the launch of the Soviet superbooster, the *Energiya*, has taken away the U.S. monopoly on advanced launch systems.

Dean: I think that one problem is that fusion propulsion is better suited to deep-space missions than to near-Earth orbit propulsion and SDI people don't have as much interest—or maybe they don't have any interest—in deep-space propulsion, at the moment. They're looking for practical things that can be used reliably, efficiently in near-Earth orbit. They do have some interest in orbiting power plants, or anything that could make a large amount of power in a short amount of time, and it's possible that some of these things could be adapted for that, but tokamaks could be just as good or better for [power production] than the mirror, so it's not clear that [fusion propulsion] uniquely benefits the mirror program.

The Air Force has a range of interests, and they are interested in propulsion. They have a small team, I think at Edwards Air Force Base, that has a small program in advanced propulsion ideas. They're looking at fusion because they haven't looked at it for a number of years. But deep-space propulsion does have a lower priority than the near-orbit propulsion.

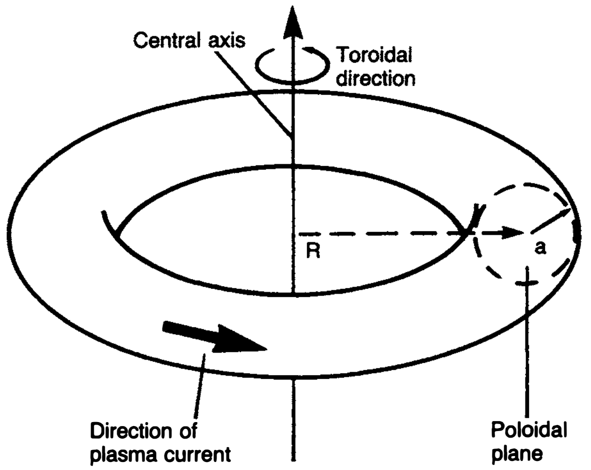
The advantage to fusion propulsion is that it gives a very high specific impulse [fuel efficiency at high exhaust velocities] and hopefully, with a relatively low weight of fuel, you can get vehicles up to extremely high speeds. The real advantage is when you're going on really long trips. The shorter the trip, the less the advantage of fusion propulsion, versus various other kinds of propulsion.

EIR: I understand that there are a number of newer experiments in concepts different than the mainline tokamak or mirror programs, which look interesting. Could you describe them, and what their advantages might be over the mainline fusion designs?

Dean: The general feature of these, is that people are trying to get the same amount of power in a smaller apparatus than the tokamak might do. Another feature of some of them is to remove the hole in the donut. The tokamak is a donut-shaped

FIGURE 2

Tokamak magnetic confinement configuration



Source: *Fusion* magazine, October 1980.

machine and it has equipment, hardware, that goes down inside the hole in this donut, and so the geometry is not that attractive. There are people who want to figure out how to make a plasma that doesn't have this donut shape, because it may simplify the engineering. The driving force is getting the size of the machine down, which is another way of saying, getting the power density up. The reverse-field pinch, which is being built at Los Alamos National Laboratory, is the place where most of that work is going on now, and there is a $72 million facility being built there. They've just arranged with the TVA [Tennessee Valley Authority] to get a large generator that was purchased originally for a nuclear power plant that they're now not going to build. It's being sold to DOE and it's going to be used to power this new $72 million facility. It is supposed to come into initial operation in 1990 and then it will be upgraded in 1992. If all that works, then by the mid-1990s this concept should be able to produce plasmas comparable to the best that we have in tokamaks today, in facilities that are cheaper and have a higher density.

EIR: How is the reversed-field pinch different from the tokamak?

Dean: If you look at it simply, in many ways it looks the same because it's a donut in its shape, so it does still have those disadvantges. But the main advantage is that it makes all, or most of its own magnetic field by the current that's in the plasma, whereas in the tokamak you have to provide most of the magnetic pressure by having superconducting magnets, or other kinds of magnets around the plasma. That means that the plasma itself is able to be run at a higher density, so you can get the same amount of power in a smaller object than you can from a tokamak.

Unfortunately, this system is a very dynamic system, so it's a little harder to see how you would make it steady-state, but they do have ideas to test on how to make it steady-state. It doesn't require auxiliary heating. In the tokamak you can't get it hot enough by just running a current [through the plasma]. You have to put in extra power, using either radio frequency or neutral beam accelerators. But in this device, just by running the current in the plasma itself, you can raise it all the way to ignition—at least that's the theory. So it should be more efficient and [there should be] less equipment required to get the plasma ignited than in the tokamak. Its disadvantage is that its power density is so high, that we'll have more problems of the materials holding up and the vessel holding up than we have in the tokamak. Because it's a stronger pulse, it will have more thermal fatigue-type problems than might be present in a tokamak. Those are some of the engineering problems that will have to be solved if that concept is going to compete.

EIR: I understand that there is also a new program at the Naval Research Laboratory.

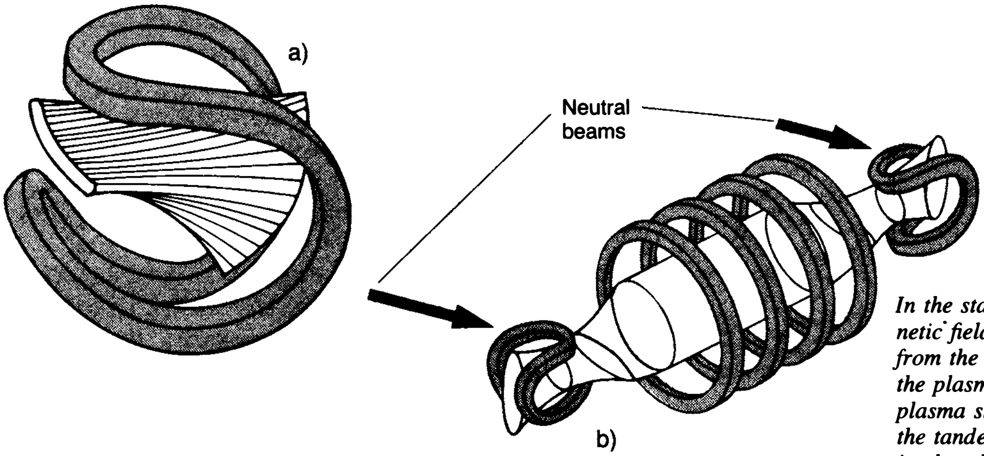
Dean: That is at a very early stage but if it works it could be extremely cheap, and it is very simple. It's just a matter of taking a deuterium-tritium mixture [the two fuels for fusion, isotopes of hydrogen], cooling it down until it's bascially frozen, and it becomes like a slush, a frozen slush, like a snow cone. You put pressure on it and extrude it out from a tiny hole in an electrode and you make a small wire between two electrodes. Then you put a million amperes [of electrical current] or so down down through this solid deuterium-tritium fiber and that current raises the temperature of all of that fuel up to ignition conditions. You make a very small, fat burst of fusion energy that way. It's very simple, very cheap.

There are tests in progress to try to prove that it works, [and if it does work] then you could make a small fusion plasma very inexpensively. Less work has been done on how you would make a power reactor out of that, because it is a very small object, so it doesn't make a lot of energy per pulse. You'd have to make many, many pulses, and the electrodes, at the moment, are fairly close to the plasma, so they'd become damaged. So how you'd convert this into useful power is not quite clear yet, but it does seem to be a way [to create] a fusion plasma for study, which could be used for testing purposes, or engineering tests, and it's conceivable that somebody may figure out how to make a reactor out of it.

EIR: Are there other new ideas that have just come up in the past year?

Dean: Actually, most of these ideas are not new. This idea for making a high density pinch has been around for 20 years, but only since people thought of making it in a frozen fiber instead of some type of a gas, has it seemed to work. The

FIGURE 3
Magnetic mirror configuration



In the standard mirror machine, **a,** *the magnetic field strength increases in all directions from the machine's geometric center, where the plasma is stably trapped. However, some plasma still escapes out the open ends. In the tandem mirror,* **b,** *a standard mirror cell is placed at each end of a cylindrical solenoidal cell. The plasma is then "end-plugged" by the electrostatic forces of the two mirrors.*

Source: *Fusion* magazine, October 1980.

other kind of very interesting "hot" concept—and again it's not that new, but the progress in that area is pretty recent—is what they call a field-reversed plasma, or a spheromak plasma where, as I mentioned before, you are able to take the hole out of the middle of the donut, and make a plasma that is essentially spherical in shape.

That's nice because now the plasma is more localized and you can put all of your equipment around it rather than having to have your equipment go down through the middle of it. There is a new experiment being built at Spectra Technologies in Seattle. The fundamental work was done at Los Alamos and Princeton on the spheromak concept, and I think those have a lot of promise, but they are in an early stage, and require a lot of fundamental work yet on a small scale before you can really assess the potential.

EIR: It is interesting that this experiment is being built at a private company. Is it with internally generated company funds, or is the Department of Energy supporting it?
Dean: It was partly [company funds] before, but it's now supported by the Department of Energy. They won a competition, where Los Alamos was in the competition, and this company was selected.

EIR: What has been the effect of the contraction in the fusion budget on the companies who have been working in this area? Your company, Fusion Power Associates, is an industry association.
Dean: Opportunities for industry participation have been drastically reduced. Some of the big companies that have been in fusion and had an established position, are still quite strongly supported, like GA Technologies, and KMS Fusion. But the companies that were depending upon sub-contracts to help build facilities, or to operate small programs—most of those programs have all but disappeared. But we're hopeful that with some of the new facilities, that we hope are going to be built in the next few years, industry opportunities will start to grow again. For example, there's a new large multi-hundred million dollar tokamak that was put in for authorization in this year's congressional budget called "CIT" for Compact Ignition Tokamak at Princeton, and if that project moves into construction next year, there should be a lot of opportunities for industry to participate in the project.

EIR: What has been the impact of the budget cuts on personnel—both people working in the programs, as well as university students working on their degrees, and graduate work in fusion?
Dean: I think there's been an effort to take most of the money out of the mirror program, and most of that money was hardware money, or money that was going to be needed to operate the large new mirror experiment at Livermore, so there's been an attempt to minimize the effects on the universities. The second place where money has mostly been taken out of, has been in the long-range technologies. That has impacted the industry a lot, and it has impacted the universities that were working on some of the longer-range things, like materials, systems analysis, reactor studies, and

things like that. In terms of plasma physics research in the universities, I think the impact has been minimal.

EIR: Dr. Gerald Kulcinski, from the University of Wisconsin Fusion Technology Center, mentioned to me a few months ago that up until the past few years, the best and the brightest science students in the universities were going into fusion research. In the recent years, however, he observed that these top students were going into lasers, and other fields that were more related to the research on the SDI.

Dean: I think that's true. I think in terms of personal choice, of where the students are going, they see [as more promising] the areas where there seem to be more career opportunities than in fusion, so the students themselves are not going into fusion the way they were several years ago. In some of the technology areas that are funded through the engineering departments, their budgets have been cut, and they are having a harder time finding support, not only through university research contracts but also in terms of the fact that the engineering opportunities in the programs, and in the laboratories where they might go to work afterwards, have been cut back. In the physics departments, I think the impact has been less severe but there has been some impact. They try to keep the university programs somewhat insulated from these big budget cuts. . . .

EIR: Until the early 1980s, the United States certainly had the worldwide lead in magnetic fusion energy research. How does the United States fare now, compared to the Japanese, European, and Soviet fusion programs?

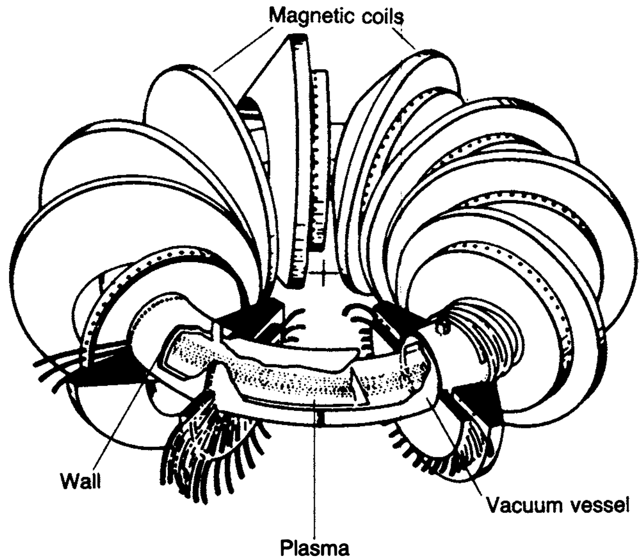
Dean: I think it's pretty clear that over the past five or six years, whatever lead we had has disappeared. The Japanese and European programs are fully competitive in size and progress with the U.S. programs. If you look at the actual budgets, which I am going to publish a graph on in my newsletter, the European program has financially overtaken the U. S. program in the last five years. The European budget is now as large as the U.S. budget, whereas previously it was about half the U.S. budget. The Japanese budget is about the same as the U.S. budget, whereas five or six years ago, the Japanese program was more like a quarter of the U.S. budget. So both of those groups have facilities and skilled people who are fully competitive with our facilities and our best people.

It's less clear what's been happening with the Soviets. I think in the early 1980s the Soviets slowed down dramatically, and a lot of their facilities got bogged down in construction. But they do seem, in the last couple of years, to be making a strong rejuvenation in the program. There are new facilities being rapidly constructed in the Soviet Union, and I think they are again giving fusion a high priority.

EIR: What effect do you think the recent developments in higher-temperature superconductivity might have in the fusion program?

FIGURE 4

Reverse-field toroidal zeta pinch



The donut-shaped (toroidal) vacuum vessel and magnetic coils for the ZT-40 are shown diagrammatically in this figure, representing an earlier design from the one referred to by Dr. Dean. The distinctive feature of the ZT-40 is the configuration of strong plasma currents that confine the plasma in the volume indicated by the dotted lines within the vacuum vessel. This uniquely efficient plasma confinement results from the reversal of the magnetic field that occurs near the wall of the torus.

Source: *Fusion* magazine, March-April 1985.

Dean: It potentially could have a major impact on the cost of fusion power, in terms of the cost of electricity. The big question is, how long will it take to take these laboratory demonstrations, and convert them into engineering materials that can be used to construct large objects, like magnets? I think nobody knows the answer to that yet, but there are optimists and pessimists in the [fusion] community.

EIR: Where will the major application for superconductivity be in fusion?

Dean: The major application in fusion would be in making the superconducting magnets that we use. The temperature that you have to run those at is a major factor in what kinds of refrigerators you have to buy, and what the cost of keeping the magnets cold is.

EIR: What would the economic impact be, in the cost of electricity?

Dean: In a power plant, about half the [capital cost] has nothing to do with whether it's fusion, or fission, or coal. So there's 50% that you can't impact with this discovery, at all. Of the other half [of the capital cost], probably about a quarter may be the [fusion superconducting] magnet system and the refrigerators that go with that. It's about a quarter of 50%, so probably about 10-15% of the total plant cost is involved in the magnets. But that's not really what you want to know, because there you're talking capital costs, and it could turn out that these new superconductors might have a higher capital cost for the magnets. You don't really know what the cost will be, because that's involved in the manufacturing process. What [the breakthrough in superconductivity] will impact is the operating cost of the plant once it's built. Day in and day out, the magnets have to be kept cold, and if you have to keep them near absolute zero, that's a big cost. If you can keep them near room temperature, that's a smaller cost. What you have is a continuous savings over the entire life of the plant and that impacts the cost of electricity, more than it impacts the capital cost of the plant. We don't know enough about these superconductors yet to really calculate what that potential impact might be.

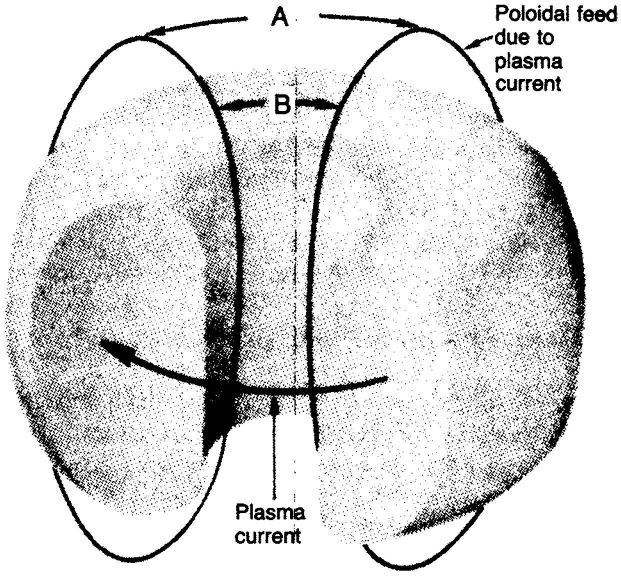
EIR: The United States does not have a fusion facility in construction that has superconducting magnets. We do have the magnet test facility at the Oak Ridge National Laboratory to test superconducting magnets, but is there any plan to use them in fusion experiments?
Dean: In the 1990s we have a serious chance to build an engineering test reactor as an international project, and we would be participating in that. That is the only definite, if you can call it definite, plan that we have to build a facility that uses superconducting magnets. Then, of course, the real impact is when you get to commercial power, and you are building demonstration reactors.

EIR: The Soviets have planned to build a superconducting magnet fusion experiment, which I understand had gotten bogged down.
Dean: That's the T-15 and it's still being built, and it might be finished soon. I don't know the latest date, but I think at the end of this year, or early next year, it's supposed to be finished. It's been delayed so many times, that I think we'll believe it when we see it.

EIR: Are there any other programs internationally that plan to use superconducting technology in their fusion programs?
Dean: There is a facility that is under construction that is almost finished in Caderache, France, called the Tore Supra, which is a major superconducting tokamak. It's probably going to out-perform the Soviet machine by a mile. A very sophisticated machine.

EIR: When is that machine scheduled to come on line?
Dean: I think next year. . . . It's a European-funded program. The United States is participating in it. We're sending some equipment over there and it will be, in part, an international project, although it's basically a European project.

FIGURE 5
Diagram of the plasma configuration in a spheromak



The spheromak can be smaller and more efficient than the tokamak because it uses the electric currents within the plasma itself to generate the confining magnetic fields. This eliminates the need for external copper coils.

Source: *Fusion* magazine, March-April 1985.

EIR: Is there anything else you would like to add?
Dean: I didn't mention inertial fusion [including laser fusion]. I think that they've really come on strong. I feel that the program is now at a stage of scientific understanding comparable to magnetic fusion. Recently, there was an experiment at Lawrence Livermore Lab where they achieved a convergence ratio, which is the ratio of the initial radius of the [fuel] pellet, to the final radius of the pellet. They got that ratio up to a value of 35. This is the ratio of how much the pellet is compressed, as it is hit [with a laser beam]. You have to compress it in order to ignite it. They got to a value of 35, and you only need to get to about 40 for this kind of pellet, in a commercial laser fusion reactor. They're very excited about that.

The filling pressure of the fusion fuel [into the pellet] was low, so they didn't actually get a high compression of fuel or ignition, or anything like that. It was just a test of stably compressing the pellet shell. I think it portends the fact that they will be able to stably reach the kinds of spherical compression they need to get. To actually ignite the pellet, they'll need more energy in the laser, but that program is making really good progress.