mal and mechanical stresses which will take their toll, especially since most fusion reactors are based on cyclical designs which mean that these parameters will be changing over time.

While many of these effects can be theoretically extrapolated from existing experience gained with nuclear fission reactors, the only certain way to test the full and combined effects is to recreate the same environment that will be found in a fusion power reactor itself.

Recent advances in the experimental performance of the plasma focus indicate that this device could be capable of generating these required conditions at a cost ten times less than other alternatives.

The Stevens Institute submitted a design to the March, 1988 San Diego International Energy Agency Workshop on Requirements for an International Fusion Materials Irradiation Facility for an advanced plasma focus Compact Accelerator Plasma Target (CAPT) system that would meet the requirements for fusion reactor materials development and testing.

The experimental results from plasma focus experiments over the past several decades demonstrate that this compact device has some of the best scalings for producing fusion so that it would be possible to reach levels required for reactor materials R&D with a relatively small system. Recent advances have significantly improved these already good scaling laws.

For example, Stevens Institute researchers have developed a technique involving the introduction of an electric field distortion during the breakdown and initiation phase of the plasma focus. This field distortion is caused by the introduction of a knife edge near the insulator end of the focus. The field distortion leads to the generation of a much more tightly packed moving plasma current sheath which, in turn, leads to a tenfold increase in fusion reactions produced when the plasma pinch forms. The field distortion has also eliminated plasma focus misfirings and creates conditions in which the lifetime of the insulator at the breech of the coaxial electrodes is increased by a factor of 100 to 1,000.

Repetitive modes of operation have been also demonstrated ranging from up to 1 million shots per second down to 2-10 large-scale shots per second which combine trains of many plasma sheaths to form one final pinch plasma.

Professor Vittorio Nardi of Stevens presented to the Workshop the latest experimental results, which demonstrate that a compact 10-million-watt neutron output plasma focus could be constructed at costs many times lower than other proposed devices.

Dr. Nardi reviewed a two-stage proposed program. A $20 million dollar demonstration facility could be constructed and tested within 3 years. It would consist of a 1 megawatt, .5 million joule plasma focus. The final facility would cost about $100 million and be completed within 4 years; and would be a 5-megajoule plasma focus with a 10-megawatt neutron output for testing fusion reactor materials.

Interview: Winston Bostick

Near-term uses of the plasma focus

Dr. Winston Bostick of the Stevens Institute of Technology in New Jersey is the world's leading pioneer in plasma focus research.

EIR: Could you outline what some of the near-term applications of the Plasma Focus are?

Bostick: One of the most promising is the creation by fusion with elements of Z greater than 1--that is, a higher atomic number than 1--specifically, carbon and nitrogen, the creation of radioactive isotopes, short-lived, which can be used in tumor tomography. It's called PET: positron electron tomography. These isotopes up to now are created by cyclotrons, but now the plasma focus can do it more economically, and it is basically much more efficient, because the plasma focus uses a very hot plasma target. The target and the accelerator are all really one very small volume, where there are very high magnetic fields and very high electrical fields generated. And the deuterons are accelerated and contained in these high magnetic fields, and the plasma focus does all of this. . . .

EIR: How quickly could this application of the plasma focus for positron electron tomography be developed?

Bostick: It could be developed very quickly. You see, the technology is already developed for the use of these isotopes, as manufactured by the cyclotron. The plasma focus, which would cost perhaps only one-tenth of what the cyclotron costs, would be much easier to operate and could be installed in many, many hospitals, which would make it possible for every medium-sized hospital to have a plasma focus machine to generate these isotopes; and tomography for locating cancer, locating tumors, especially tumors in the brain, would be available for every one of these hospitals. The technology for imaging has already been developed, but the role of the plasma focus would be to make these isotopes available in a much more universal and economical way.

EIR: How soon could that be done, if you had the funds to go ahead?

Bostick: The machines already are in a laboratory state; we should package them and make them so that a trained hospital technician could learn how to use the machine; and this, and the packaging of the machine for commercial sale, could probably be accomplished in six months to a year, and the machines could be put on the market and manufactured, almost as rapidly as the market would develop.

EIR: How many hospitals, approximately, have the cyclotron technology right now, for producing radioisotopes? Just a handful?

Bostick: Yes, I would say a handful. I could name a few: Johns Hopkins; the University of California at Davis; I don't know about the University of Chicago: They had one once, but whether they are still using it for this purpose I don't know. And there are a few others scattered around. The cyclotrons for this are now being manufactured in Sweden, as they are simpler than the laboratory cyclotrons that were used. . . .

EIR: About how much do the cyclotrons cost?

Bostick: As I understand it, their cost is something over a million dollars.

EIR: And you say that the plasma focus has the possibility of being as low as maybe one-tenth?

Bostick: $100,000, $150,000 something like that.

EIR: So that would make quite a bit of difference--it would make an order of magnitude decrease in the capital cost.

Bostick: Of course, the cost of the imaging is still presumably as high; but as the cost of the whole machine comes down, the market increases tremendously, you see, and that opens up a whole new level of hospitals that can get into it. Instead of just a handful of hospitals that can use it, the number of hospitals will go up into the thousands. And that, of course, would then bring the imaging cost down, because they would be able to mass-produce them.

EIR: What are some of the medical applications of PET?

Bostick: Well, for the location of tumors in various parts of the body, the compound is injected into the bloodstream, and it is such a compound--containing the short-lived radioactive isotope--that it would be preferentially absorbed by the tumor. And then, the gamma rays which come out are counted in coincidence--the gamma rays that come out from the positron electron annihilation, come out always along the same line, but in opposite directions. And there is a battery of counters, which sense this incoincidence. And after a short time, the computer synthesizes this, and shows the location of the tumor, wherever it may be in the body. As I understand it, it is especially effective in locating and describing the extent of tumors in the brain.

EIR: So, therefore, they use very short-lived radioactive materials, in order to minimize the amount of residual radioactivity left in the body.

Bostick: That's right; these half-lives are, some of them in the seconds, others in the few minutes. Which means that in a matter of a few hours, the patient is essentially free, again, of radioactivity.

EIR: Now, if you're dealing with really short half-lived radioactive isotopes, or radiochemical isotopes, is there any advantage to the plasma focus as far as processing the elements into a form that you would inject them?

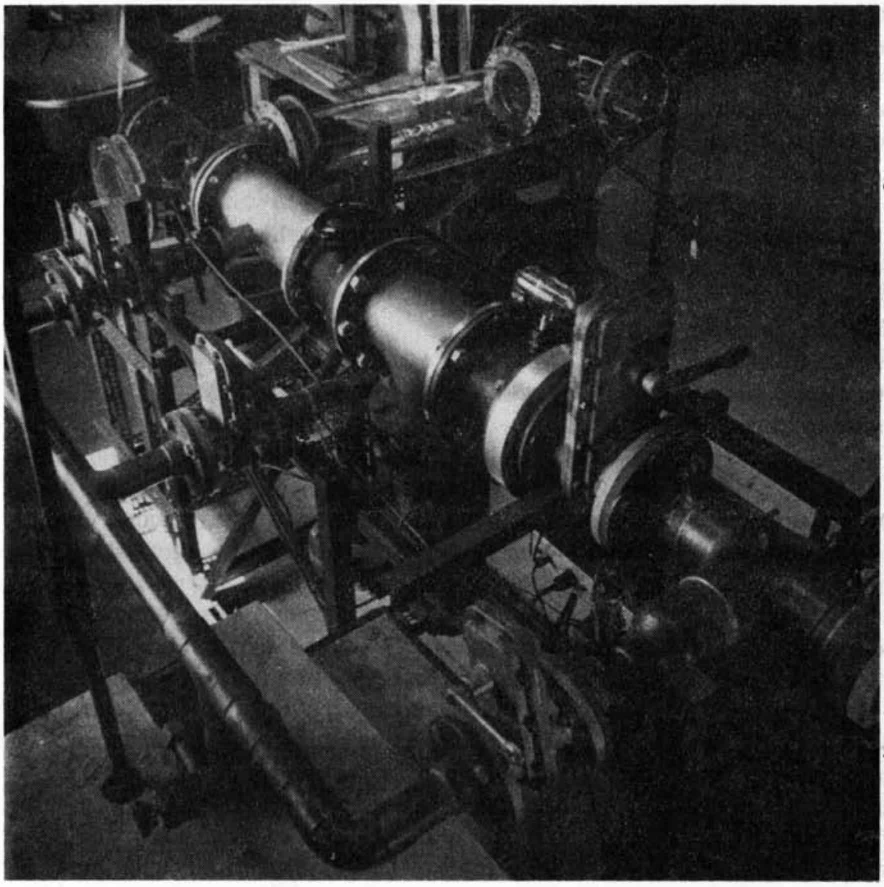
Bostick: Yes, because with the plasma focus, for example, if we wish to make a radioactive isotope out of deuterium on carbon-12, which gives us, as I recall, nitrogen-13, the technique is to have the radioactive isotope appear in gaseous form. And it would be pumped out of the plasma focus vacuum chamber, and absorbed in the appropriate solution, very quickly. If a cyclotron is used, the radioactive isotopes are generated in soli targets, and the target has to be dissolved, and then the chemistry has to start there. The chemistry can be done more readily with the plasma focus, because the radioactive isotope is in gaseous form in the beginning. It is the same way for the reaction of deuterium on nitrogen, which gives, as I recall, oxygen-15. This, again, gives a radioactive isotope which is in gaseous form, and which is more readily usable, as it can be done more simply and more quickly than it can be done when it is produced in a solid target.

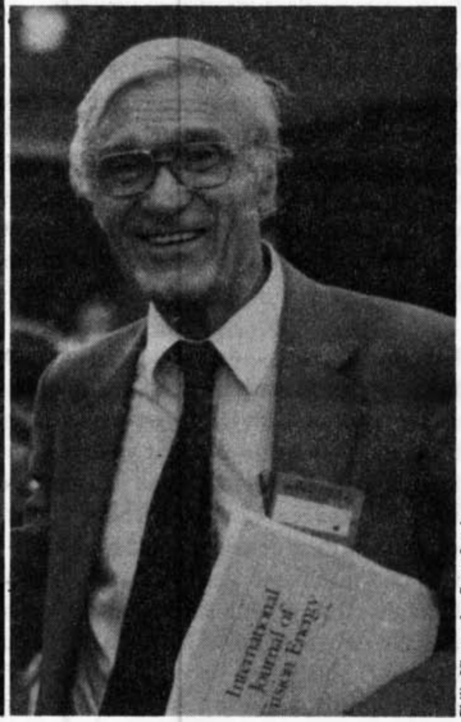
EIR: Why does the plasma focus have such an advantage? Here we have an accelerator; maybe you can explain what the advantage of the plasma focus is.

Bostick: With a cyclotron, the deuterons are accelerated and then are shot into a solid target. And most of those deuterons are used, not in producing radioactive isotopes--most of them just spend their energy in ionizing the solid target, heating it up. They come to rest in the target, and only a small fraction of them produce the nuclear reaction. Whereas, with the plasma focus, the deuterons, which are accelerated with very high electric fields in the presence of a high magnetic field, are being accelerated against other--in this particular case, carbon, if the deuterium is doped with methane, or if it's doped with nitrogen--you've got the reaction of deuterium on carbon or deuterium on nitrogen. The deuterons pass by the nitrogen or the carbon nuclei many, many times; all of them are contained in the same nodule of hot--I shouldn't say hot plasma--deuterons that are being accelerated. And the target is ionized and the electrons are very energetic. So very little energy of the deuterons is spent in an ionization process; almost all of their energy is available for making the nuclear reactions.

EIR: So plasma focus, you would say, is much more efficient?

Bostick: That's right. The plasma target and the accelerated deuterons are all part of a very intimate package. And it is all at high energy, and none of the expensive high-energy part





The laboratory plasma focus at Stevens Institute in New Jersey, and plasma physicist Winston Bostick. The plasma focus could produce radioisotopes for perhaps as low as one-tenth the cost of a cyclotron, says Dr. Bostick.

Philip Ulanowsky; Stuart Lewis

of the deuterons has to be expended in heating up something like a solid target.

EIR: So, first of all, the plasma focus would cost less for an initial unit; and what about in terms of energy supplies? That is, average power needed to run it?

Bostick: Well, because of that, the average power is less. Of course, the power needed for these machines is not a primary consideration. But all the components of the plasma focus are smaller, more compact. . . .

EIR: Well, maybe we should get some idea of that. When I have an accelerator and a solid target, that sounds like something where I am going to have at least scores, if not hundreds, of cubic centimeters over which the beam is traveling and going to a target. How big is the region in which the plasma focus is producing these radioisotopes?

Bostick: It's a fraction of a cubic millimeter.

EIR: A fraction of a cubic millimeter!

Bostick: That's right. A millimeter on the side would be a cubic millimeter; it's a *fraction* of a cubic millimeter. The plasma nodules where the plasma in the magnetic fields are highly concentrated, and where the electric fields reach high values, are in very small volumes.

EIR: So therefore the actual power density that the plasma focus is operating on, is much greater than that of the accelerator?

Bostick: That's true.

EIR: How do you get that high-power density in plasma focus?

Bostick: Well, nature has a way of energy-densification in these discharges of current, where the current goes up to a large fraction of a mega-amp, and nature decides what to do with it. It turns out that the minimum free energy in such a medium, is for the plasma to concentrate in these nodules and not be smeared out in a Maxwellian-Boltzmann type of distribution. It looks as if it defies the second law of thermoydynamics, and in a sense locally, it certainly does. Nature makes these concentrations of energy in the elementary particles--which also, we believe, at least I believe, to be minimum free-energy concentrations--entities, so to speak, plasmoids. Well, the elementary particle is similar to the plasmoids which form in the plasma focus. And they are minimum free-energy concentrations which form, just as droplets of water, or bubbles, are always spherical. Because the surface forces are such that the positive surface forces which produce a sphere, which has the smallest amount of surface for a given amount of volume. And that is a minimum free-energy configuration, just as we think that the elementary particle, and also the plasmoid that's involved in the plasma focus, is a similar type of concentration.

EIR: In other words, you are taking advantage of the plasma, to get a miniature accelerator, with much higher fields than what could be withstood by ordinary materials?

Bostick: Nature planned this all by herself! When the plasma reaction was first discovered, nobody expected that this was the process that Nature had in mind. Theoreticians were, for the most part, very much surprised to see that this actually happened.

EIR: Now, I know that you are one of the pioneers in the fusion research program, and although with fusion we are usually dealing with hydrogen--fusion of heavy hydrogen--however, you mentioned that you are actually doing heavy ion fusion, such as with carbon and nitrogen.

Bostick: The big tokamak machines are struggling to get the energies of their deuterons, and eventually it will be deuterium and tritium--to get the average energies up to a few kilovolts. The plasma focus gets the deuteron energies up into not only the tens of kilovolts, but into the hundreds of kilovolts! This makes fusion with nuclei of Z greater than 1, quite possible, because this higher energy can overcome the Coulomb barrier--that is, it makes it easier for deuterons to penetrate the Coulomb barrier, and so these reactions with carbon and nitrogen, with Z equals 6 for carbon and Z equals 7 with nigrogen, occur in very great number--no difficulty in getting them to do it--because nature is so efficient in doing this type of acceleration, and also in containing the particles with these very high magnetic fields. So this opens up a whole new vista for the controlled thermonuclear program, because we don't have to deal with deuterium and tritium alone, which represent Z equals 1. Now, this really offers wonderful opportunities. You see, the tokamak machines are like dinosaurs, or like elephants--they are so large and ponderous, that they can't get more than one or two feet off the ground at once! Whereas the plasma focus is like a grasshopper, that can jump many times its own length in one jump.

EIR: Do you see any applications of the plasma focus to fusion research?

Bostick: Oh, indeed, indeed. Because two of the very great drawbacks of fusion with deterium and tritium, are: one, the fact that many neutrons are generated. The generation of neutrons makes the metals that are used for constructing the device radioactive; and this induced radioactivity will have to be handled. It's not as vicious a radioactivity as the end products of the fission reaction, but nevertheless, this is one thing that has to be contemplated. And the tritium inventory has to be very great, and that has certain health hazards. That's one difficulty.

The other is, that the first wall of the tokamak fusion reactors, will have to take such a bombardment of energy from the neutrons, that the search for materials that can take this, is going to be difficult--even the simulation in order to make a test of materials, is going to cost hundreds of millions of dollars, perhaps a thousand million dollars, in order to just make a machine that will be able to test the materials for withstanding this kinetic energy that they have to absorb from the neutrons.

EIR: How soon could plasma focus actually do something about that?

Bostick: Well, if we have gotten these reactions with carbon and nitrogen with no difficulty, it means that if we use proton on boron, then we have a perfectly clean reaction. No neutrons; the only energy we get out is the energy and the alpha particles that result from this reaction. And what will happen then, is that we don't have any bombardment of anything by neutrons; the shielding necessities that we have, are tremendously reduced. Indeed, aside from the high-energy electrons that may produce some x-rays, which can be stopped with lead, the shielding of the machine, as far as personnel is concerned, becomes very simple. And with all of the energy going into charged particles like alpha particles and electrons, it's quite possible to make an electrical scheme in which this energy can be converted directly to electrical energy, without having to go through the Carnot cycle with a steam engine.

EIR: Would it be possible to use a plasma focus to generate neutrons to test materials for deuterium-tritium fusion reactors?

Bostick: Oh, indeed, indeed. The plasma focus is, I would say, one of the leading contenders, in the last analysis probably the most economical contender for this. But of course, there are great vested interests in other schemes, which are promoted by the authors of these other schemes; and it becomes something of a political football, instead of a merit contest. But the plasma focus is certainly one of these contenders. But we might say that the era of clean fusion, and much simpler fusion, with smaller power plants, which can be experimented with much more easily, is in the offing with this higher-z-element fusion. And boron-11 and protons, look to be the best way. There is plenty of boron on the surface of the Earth, and of course protons can be made a dime a dozen, with hydrogen. So, this is a much simpler, much cleaner scheme, and with efficiencies--if we can make schemes for direct conversion of electrical energy--perhaps efficiencies of 80% or 90%, instead of something like 30% or 35%, which is the best we can expect when we are using the Carnot cycle with a lithium blank, which will have to be done with the tokamak machine.