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REACHING FOR THE STARS

Deuterium is more abundant than oil shale, and it doesn't get your hands sticky. That's the rationale behind thermonuclear fusion: It's efficient (stars wouldn't use anything inefficient) and uses the most abundant fossil fuel of all. All it has to do is work.

There was once a certain romantic appeal about the idea of taking the process that produces energy for the stars (or for ordinary ones anyway) and putting it to Work in a controlled way in reactors on earth. Controlled thermonuclear fusion was going to be the energy source of the future. Then a lot of unforeseen difficulties arose, and the task came to seem more Herculean than Promethean. Romance tiptoed off stage.

It is now 30 years later. The world no longer has any choice nor much time for romance. There will have to be alternatives to the oil that will soon run out. And fusion still looks like a good bet to be an important alternative. From the middle of the Augean stables one can report that the floor now really seems to be in sight, and, in spite of a number of bad years at the budget table, fusion may still be there to supply a good part of our future energy needs. Although the people who work on it have yet to prove their basic principle --that more energy can be gotten out of any of their schemes than has to be put in to get fusion started -- groups in several laboratories are at work on designs and materials studies for future fusion reactors. When the great day comes they intend to be there with plans on file and perhaps materials in stockpiles, ready to call in the hardhats. They don't want to wait 15 or 20 years for a Marconi or an Edison to turn experiment into a practical device.

But will the great day come? Under heaven nothing is certain but death and political speeches. Fusion research has been heavily criticized for the years of work that have gone into it. The sort of people who make statements about "the country that developed synthetic rubber overnight..." are likely to complain about so little for so much. It should be pointed out that that little includes extensive knowledge of a branch of physics that was new in 1950 and almost completely, and disastrously, misunderstood. Edison's belief that tungsten would make a good filament for an incandescent lamp had behind it 100 years of research in electrical theory and in the strengths and physical constants of conducting materials. Today on the basis of what is known about fusion physics, reactors are already being designed. It is as if Edison looked over Ampere's shoulder. This time it may not take 100 years.

At the Lawrence Livermore Laboratory in California is a large hole in the ground that will be the foundation for the experiment that many hope will bring in the great day, breakeven day, for one of the varieties of fusion schemes, called inertial confinement. In any fusion experiment the basic problem is to make a plasma or fully ionized gas (that's easy), heat it to a temperature at which the nuclei begin to fuse, and keep it confined and dense enough for a significant rate of fusions. The last two criteria are what all the experimentation is about. Inertial confinement intends to satisfy them by taking a tiny pellet of fuel and zapping it from several sides with beams of light from a laser (or perhaps beams of energetic ions of some heavy element). The zap crushes the pellet, and the crushing supplies both heat and density. Fusions take place in the pellet for a short time, and then the energy they generate re-explodes the pellet. The total concept includes a continuous repetition of these miniblasts.

To torn this idea into a reactor, one starts with what comes out of the fusions in the pellet. If the fuel is a mixture of deuterium and tritium (and that, according to Wayne R. Meier of Livermore, is what everybody is working on now), the energy released in fusion is carried away by neutrons of 14.1 million electron-volts energy (80 percent) and alpha particles of 3.5 million electron-volts (20 percent). On the way out of the pellet the energies of the neutrons are degraded somewhat so that there is a spread of neutron energies coming out. Some of the lost energy comes out as X-rays, charged particles and other debris.

A fusion reactor has to be designed to extract energy from these things and at the same time suffer minimal damage from them. The idea from which design starts is that the succession of microblasts is to be confined in Some kind of chamber. It has been said again and again that a lithium blanket would be used to extract heat by slowing down and capturing the neutrons. In doing that it also breeds tritium for fuel. Deuterium is abundant in natural water, and no country with a coastline could be prevented by an OPEC or any other consortium from obtaining a supply, but tritium is rare and for the quantities needed must be bred.

Solid lithium surrounding the reaction chamber is assumed in most reactor plans, but Meier and his colleagues M. Monsler, J. Blink, J. Hovingh and P. Walker in their HYLIFE concept have opted for a fall or rather a rain of liquid lithium at a temperature of 500 Celsius. The first version of this concept called for a laminar flow of liquid lithium, an unbroken cylinder surrounding the area where the fuel pellet does its thing. Calculation indicated that the effect of the blast would slap the lithium against the inner wall of the chamber. Neither the disruption of flow nor the possible damage to the wall was wanted so the conception was revised to provide jets of lithium. The lithium is driven through a series of nozzles by a static head in a space above the interaction chamber, and the jets flow to the bottom where the lithium drains out.

Putting the lithium inside the inner wall instead of between the walls as other designs envision protects the inner wall from blast and radiation. While other designers have worried over the necessity for periodic replacement of the inner wall, Meier says here the inner wall is expected to last the life of the powerplant--that is, 30 years. For wall materials ferritic steels are favored--steels with no nickel and low chromium content, 2.25

percent chrome compared with 18 percent chrome in a typical stainless steel. Iron is neutronically inert. Bombarding it induces little or no radioactivity. That is not so for the common alloying elements.

The lithium is continually recycled. About five percent of it needs to be diverted to exchange heat with a liquid sodium circuit, which then goes to the boilers. Some of it, too, is continually processed for removal of the bred tritium and any other radioactive species it may have picked up.

Given a pellet gain, a ratio of fusion energy produced over laser beam energy delivered of 1,000 (and remember that a gain of 1 has yet to be demonstrated), Meier and his collaborators talk of producing a megawatt of electricity in one of these chambers. A single laser system could serve more than one interaction chamber on a given site. So could a single pellet factory. Meier says that as long as the fuel involves tritium, the pellet factory ought to be on the powerplant site. Tritium is radioactive and hazardous to transport.

There exists a technology and a procedure for handling tritium. A more novel hazard in this design is the handling of liquid lithium. It is corrosive. It is also inflammable on exposure to oxygen. Meier says the design contemplates running lithium pipes through an atmosphere of argon to prevent fires in case there should be a leak, in case of accident, however, shutdown would be easy. "If you lose the pumps [for the liquid lithium coolant] and don't want to heat the walls, just stop firing." It's not difficult to shut off a laser. The fuel pellets do nothing unless irradiated.

Liquid lithium as a coolant has been rejected after consideration by a Livermore group working on a reactor design for one variety of magnetic confinement device, the other main class of fusion experiments. According to Gustav A. Carlson, the difficulties of handling an electrically conducting fluid (which lithium is) in the strong magnetic fields deterred them. They now contemplate using gaseous helium as a coolant. It is nonconducting and neutronically inert, and its ability to do the job is known from gas-cooled fission reactors.

In fact, it was the difficulties of dealing with a conducting fluid in a magnetic field that nearly doomed fusion research a couple of times. A plasma is a conducting fluid, and so people had the idea of using magnetic fields to contain it. The type of magnetic confinement that Carlson and his collaborators are particularly concerned with, the magnetic mirror, was once a large part of the problem and may someday be a large part of the solution.

The idea of a mirror is simple. Take a volume with a low magnetic field in it and surround it with a high magnetic field. Whenever charged particles try to escape from the low-field space they will be bounced back by the high field. In practice it proves essentially impossible to set this up. If you make a solenoid (a long tube with strong magnetic fields at the ends so that the particles will bounce back and forth along the tube) you find that a lot fly out the ends anyway because the field lines don't close. Then it was found that a coil of special shape, a baseball coil or a yin-yang coil, produces a field of a sort that will hold a fairly dense plasma quite well.

The tandem mirror concept that is most popular at Livermore now is the combination of these ideas. A long solenoid is plugged at the ends with baseball or yin-yang coils. The ions in the dense plasmas in the plugs set up an electrostatic field that aids the magnetic mirror effect in containing the ions in the central solenoid. The fusion takes place in the solenoid.

With a 100-meter solenoid, says Carlson, you should be able to generate 1,000 megawatts of electricity by boiling water with helium heated by the fusions. But the ends of the device are the complicated part for the reactor designer. "We were calling for some very complicated technology in the ends," Carlson says.

The reason for that was the density of ions that had to be maintained in the plugs to make the electrostatic barrier. If the electrons in the plugs could be made very hot, they would improve the electrostatic barrier and lower the ion density requirement. But the electrons diffused from plugs to solenoid and back so the plug electrons could not be held at higher temperature than the solenoid plasma.

In about April of this year, B. Grant Logan came up with an idea for separating the electrons in the plugs from those in the solenoid. It involves a strong magnet coil at each end of the tube, and it permits the heating of the electrons in the plugs and all that follows from that. "I guess it has turned most of the tandem mirror program here on its ear," Carlson says.

They are hurrying to incorporate Logan's idea into all the tandem mirror experiments now operating or planned at Livermore, and they are incorporating it into the reactor design program, which evolves right along with the experimental program. It means simpler end technology, but more stringent magnetic requirements, which stretch the abilities of the best niobium-tin superconductor.

So it goes. These are two of many possible examples. When and if the day, of fusion comes, there will be a good start on methods for turning it into a practical power source. Will the day come? There is no guarantee. The development of synthetic rubber proves only that synthetic rubber can be developed. Other things have their own requirements.

DIAGRAM: A cooling downpour of liquid lithium at 500 Celsius surrounds the location (in the wide space between the liquid columns) where laser light will implode fuel pellets in Lawrence Livermore Laboratory's HYLIFE concept for a future fusion reactor.

DIAGRAM: Core of tandem mirror reactor. The central cell is 100 m long; the first-wall radius is 1.6 m. Continous neutral-beam injection maintains the end-plug plasmas. Plasma leakage from the end cells and solenoid is guided magnetically into end expander tanks containing direct converters. Advantages of this reactor design include a high Q (~5) and modular construction of the first wall, blanket, and solenoid magnet.

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By Dietrick E. Thomsen

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