MIRROR, MIRROR IN THE LAB

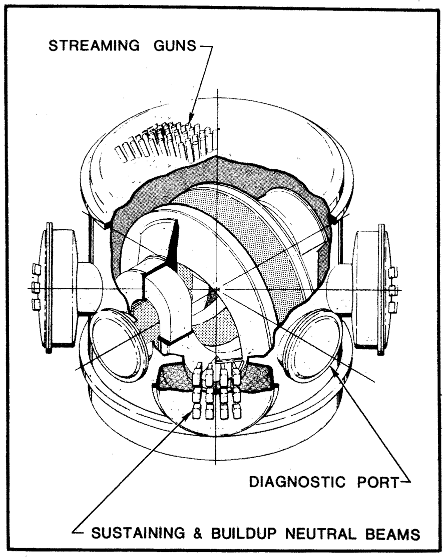
Magnetic mirrors show new hope of yielding future fusion reactors. Time will tell if they really are the fairest of all.

BY DIETRICK E. THOMSEN

The names are odd and don't convey very much: 2XII, now metamorphosed as 2XIIB; Baseball II, successor to just plain Baseball. They don't look like much that's recognizable, big, hulking, metallic constructions. The room that houses them with catwalks up, down and crosswise and all sorts of machinery resembles a steamer's engine room.

Up and down the stairs, across the catwalks. "These are the neutral-beam injectors." "This one just happens to be opened up today. You can see the middle of the field where the target for the laser beam will be. The laser beam will come from right over there." T. K. Fowler moves fast. And at the moment so does his experimental bailiwick, the Lawrence Livermore Laboratory's magnetic mirror program.

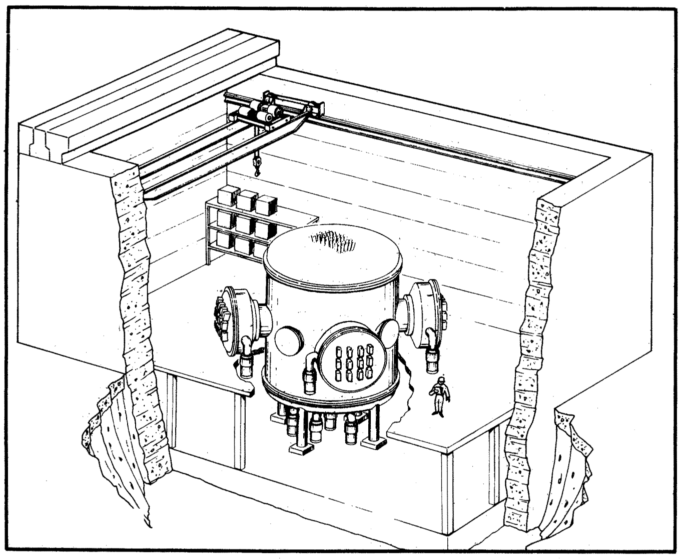
Magnetic mirrors are one of the current approaches toward controlled thermonuclear fusion. In the last year and a half, Livermore's current experiments have registered so many gains that the group of physicists and technologists involved are gearing themselves up to ask for something even bigger than what they now have, a project known—in a continuance of the tradition that names these things like creatures discovered somewhere by Star Trek—as MX. They hope they can build the experiment and the building to house it for $100 million or less.



Fowler & Coensgen/LLL

Proposed MX device: Next major step.

Up another ladder and across another catwalk, thinking of the 25 years already past, some of them years of numbing frustration, and of the 20 years the optimists estimate are still to come. If all goes well, sometime after 1995 thermonuclear fusion may be lighting our streets. There are, of course, other approaches than magnetic mirrors—and it's just a little amazing how close together are the ultimate power-reactor dates projected by proponents of each of them—but the magnetic-mirror people believe they have a significant plus. Magnetic mirrors, Fowler emphasizes, are likely to be the easiest to scale up from scientific experiment to power reactor. The others—tokamaks, pinches, imploded pellets—all will need significant technological alterations to become practical.



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MX in its shielded vault: Spurred by rapid recent progress in its magnetic mirror program, scientists at the Lawrence Livermore Laboratory would like to have the MX fusion device ready by 1981.

A tokamak, for example, is entirely surrounded by electromagnet coils that are absolutely necessary to it as a scientific experiment. But the energy that fusion releases will be carried away by energetic neutrons. How are you going to get them through the magnet coils to a place where they can give up that energy? It's easy to get the neutrons out of a magnetic mirror.

Those who approve of art following nature will be pleased to know that magnetic mirrors are one of nature's ways to confine a plasma. Nature's other prominent method, the self-gravitation of stars, is not available for laboratory use, though some of its features are paralleled in imploded-pellet fusion experiments.

Natural magnetic mirrors belong to planets. The earth has one; Jupiter has a huge one; Saturn appears to have one; Mercury has one, sort of. These are the trapped radiation belts. The particles in them, mostly protons and electrons, fly back and forth from pole to pole along the planet's magnetic field lines. The strengthening of the field that they feel as they approach the poles causes the particles to reverse direction. This continual bouncing is why it's called a mirror.

The planetary mirrors have excellent conditions for stability: Closed field lines, long flight paths, and low densities with small chance that particles will collide and knock each other out. And still they leak. Without constant replenishment they would not persist.

Laboratory plasmas have worse problems. They have to be hot and dense so that the nuclei that the experimenters want to fuse with each other—deuterium and tritium are most likely in the first incarnation of a reactor—will have a good chance of encountering each other and enough energy to overcome the electric repulsion between them and come together when the encounter takes place.

But dense, hot plasmas do not behave very tractably. Early in the game, experiments were plagued with a large-scale instability by which the whole plasma simply absconded from the field. This was countered by shaping the field so as to form a magnetic well, surrounding the plasma with an energy barrier that it had to climb to get out.

What seems to be the optimum field configuration for a mirror with a well is a rather odd, twisted-plane shape that is produced by magnetic coils shaped like

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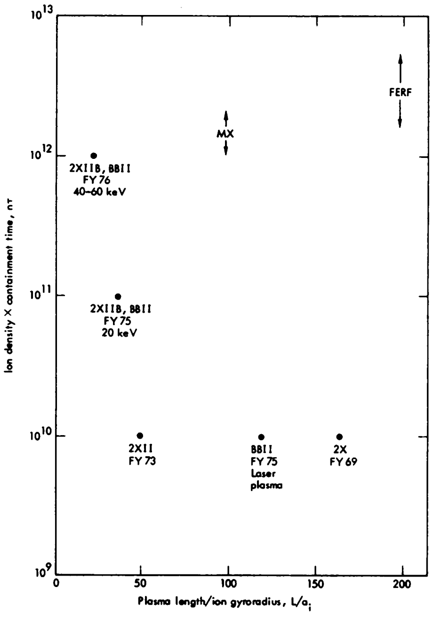
. . . Mirrors

the seams of a baseball—hence the name of one series of experiments. But even these fields do not have the advantage of planetary dipole fields: field lines that form closed curves. All the laboratory experiments can do is scrunch the field lines closer together at the edges. This does produce a mirroring effect, but it also leaves openings for plasma to escape. The escaping plasma carries away energy, which can be detrimental to the experiment as a whole, but in the spirit of using all of the pig but the squeal, devices to recapture that escaped energy and return it to the system as an electric current are under development.

Last but far from least, the plasma is still subject to what are called microinstabilities, small deviations from good behavior that can build like sympathetic vibrations in a bridge structure until they do real damage. What the experimenters would like is a quiescent plasma, one that behaves as closely as possible to the manner predicted by the theory of magnetic fluids.

A hot, dense, quiescent plasma sitting happily in its magnetic well for long enough to cook up a significant number of fusions. That's what they want. They have to start by getting something into the well. One way is to inject a fairly cool plasma into the well along the field lines. Early experiments then tried to build up the density and temperature of this plasma by pulsing the magnetic field and thus squeezing it. That didn't promise to give the kind of temperatures the experimenters wanted.

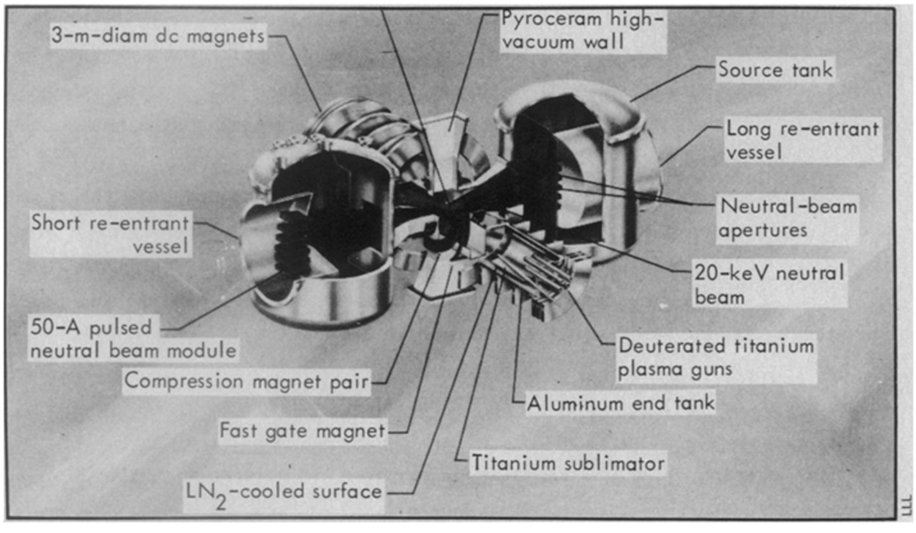
It began to seem better to regard this beginning plasma as a target plasma, and drive into it large amounts of new fuel, which, by colliding with the target plasma would increase both the temperature and density of the plasma. This has to be done across the field lines, and if you start with ready-made plasma, you quickly find out that mirrors work both ways: The charged particles bounce right back at you. It was necessary to inject neutral deuterium gas. This is arranged by first ionizing the gas so that it can be electrically accelerated, then supplying electrons to reneutralize it so it can cross the field lines. When it hits the target, it becomes ionized again and so increases both the amount and the temperature of the plasma present.



On the road to FERF: Rising capabilities.

At first the experiments could use only low-current neutral beams. They showed that neutral beams were a powerful means of raising plasma temperature, but density levels were reached where new kinds of instabilities appeared. If one could get to much higher densities, beyond this so-called "density gap," the plasma would again become fairly well behaved.

New methods for high-current neutral injection were developed in a collaboration between physicists from Livermore and its sister laboratory, the Lawrence Berkeley Laboratory. 2XII was rebuilt with 12 of these high-current neutral injectors and became 2XIIB. Meanwhile another method of increasing density is being tried in Baseball II. It includes both a new method of forming the target plasma, putting a pellet of solid fuel into the middle of the field and blasting it with laser light to make it into a plasma, and high-current neutral injectors.



The 2XIIB device: Its achievements have mirror people rubbing hands with satisfaction.

At the moment it is 2XIIB's recent achievements that have the mirror people rubbing their hands with satisfaction. F. H. Coensgen lists them in a presentation to the Energy Research and Development Administration that proposes construction of MX. Work with 2XIIB began in early 1975. By July of that year it had gotten densities of 1 to 3 × 10^{13} particles per cubic centimeter at ion temperatures of 13 kilo-electron-volts (the equivalent of 100 million degrees K), confinement times of 5 milliseconds and a Lawson criterion (the product of density and confinement time, by which some physicists like to compare different fusion experiments) of 7 × 10^{10}. The new techniques enhanced the stability of the plasma and by February 1976 the density had been increased to 1.2 × 10^{14} particles per cubic centimeter at a slightly lower temperature, 9 KeV.

This is getting up into a range that looks promising for fusion, and it makes the mirror people understandably gleeful. According to Coensgen these results make a pure deuterium-tritium burning mirror reactor look achievable. The mirror physicists would like to prepare for an experimental reactor of this sort to operate some time in the 1980s. It would be called the Fusion Engineering Research Facility or FERF.

The MX that is now being proposed would be the intermediate step between the current experiments and FERF. It would be a scaled-up mirror with superconducting magnets for greater field strength, lots of high-current neutral injection and plasma conditions and field configuration designed for enhanced stability.

Its initial goals would be a density of 10^{10} particles per cubic centimeter, an ion temperature of 50 kilo-electron-volts and a Lawson criterion of 10^{12}. This would serve to show that mirror technology would work on a large scale at temperatures comfortable for deuterium-tritium fusion and a Lawson criterion near what is necessary. It would be a prototype for FERF, which in turn would provide advance engineering data not only for a working mirror reactor but for other controlled fusion approaches as well. The hope is that if MX is approved, construction can start in fiscal 1978 and be finished by 1981.

And after FERF, maybe something we can plug into. That is, if progress goes on at the current pace. Plasma is still tricky stuff to work with, and the past has recorded many bad twists in the road as anyone who remembers the promises of the late 1940s can testify. Still we can hope; we can even believe and—keep our fingers crossed. ☐