Shiva, Argus & Co.

India meets Greece in the mythology of the laser-fusion effort. If Argus sees all and Shiva creates, by 1998 we may have power.

BY DIETRICK E. THOMSEN

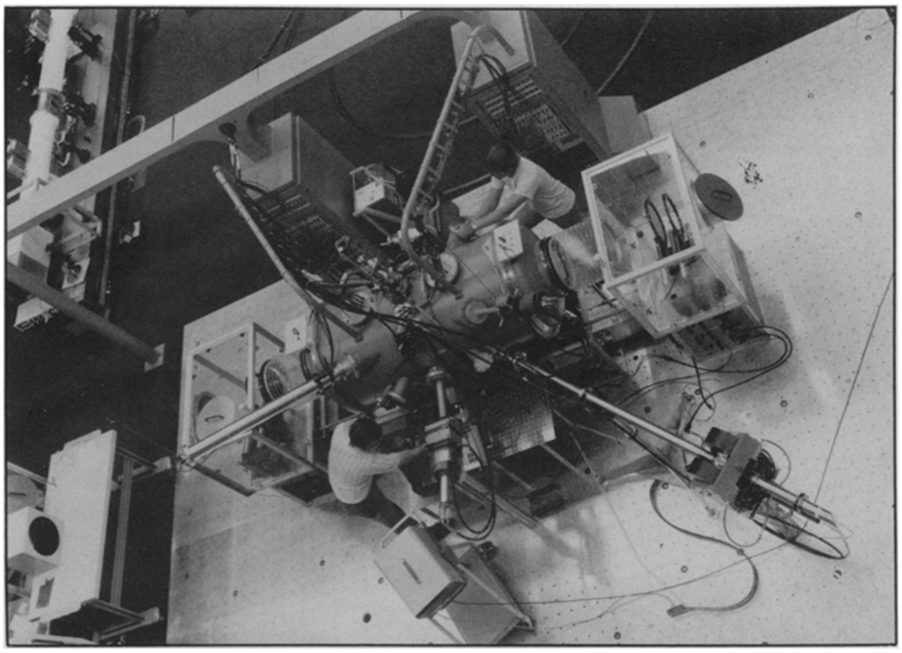
The building is almost finished. It has that expectant transitional air of waiting for the construction workers to move out and the scientists and technologists to move in. When the scientists and technologists finish what *they* are about to build, the now empty space will house what will be the world's largest laser-fusion experiment: the Lawrence Livermore Laboratory's Shiva.

It's a bit acrophobic to look into Shiva's target room from one of the upper levels of the building. The room is about four stories deep. In it will stand a complicated, tinker-toy-like, construction of steel tubing known as a space frame. In the center of the space frame will be the target chamber, an evacuated sphere 150 centimeters in diameter. In the center of the chamber will be the target, a microscopically small pellet of deuterium and tritium. In the implosion of the target, Shiva's designers hope and believe, this particular namesake of the destroying and restoring deity will perform, in a significant amount, the act of destroying and restoring known as thermonuclear fusion.

In one wall of the target room are 20 portholes through which will come the 20 beams of laser light that mirrors in the space frame will direct onto the target from all sides to produce the implosion. During the preliminary planning for Shiva there was a good deal of discussion and figuring over the question of how many laser beams was optimum. This, says Phil Coyle, deputy to the assistant director for lasers, led to the choice of the name. In Hindu mythology, Shiva always has as many arms as he needs to do whatever it is he sets out to do.

The laser beams will be produced by 20 chains of laser amplifiers running the length of the building and supported on an even more gargantuan space frame than the one in the target chamber. It will take a basement full of capacitor banks to supply the power for the amplifiers. In the capacitors the energy will build up until—zap—and 20 terawatts (20,000,000,000,000 watts) hits the target. At least that will be Shiva's first incarnation. An upgrade is already planned that will multiply Shiva's power by five or ten (100 to 200 terawatts).

All that is sometime in the future: Current plans see Shiva starting work at about the beginning of 1977 and the upgrade coming on line sometime in 1980. Right now, laid out on optical benches in another building is Shiva's two-armed predecessor, Argus. Argus is already the most powerful laser in the world. Its beams divide 2 terawatts of power, which is about twice the power generated by all electrical generating stations in the United States put together. Of course it does not produce this power steadily for hours as a generating plant does; it blasts it out in pulses that last less than a tenth of a nanosecond. So the energy requirement, though large, is not infeasible.



Illustrations: Lawrence Livermore Laboratory

Target chamber for the two-armed Argus is surrounded by diagnostic equipment.

Argus layout takes up a large room.

Argus's two arms will irradiate the target from two sides. It was preceded by two one-armed experiments, Janus and Cyclops. Before Argus was fully operational, when only one of its arms functioned, it irradiated a fuel-filled target that yielded 70 million neutrons, the largest number yet seen in a laser-fusion experiment.

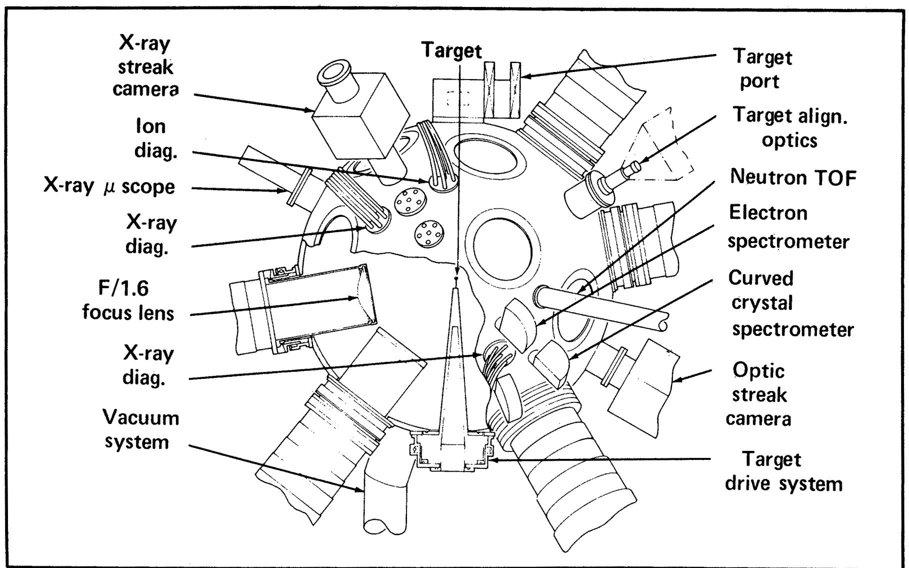
These neutrons bring up an important point. They can be taken as evidence that thermonuclear burn takes place in laser-irradiated targets. This is probably the most significant of a number of developments in the state of the art that have occurred since our last report on the Livermore program (SN: 8/17/74, p. 106).

During 1975, experiments at several U.S. laser-fusion laboratories (KMSF, Los Alamos, the University of Rochester and Livermore) yielded neutrons of 14 million electron-volts (14 MeV) energy in numbers ranging from a million to ten million. Neutrons of this energy are a characteristic by-product of the fusion of deuterium and tritium, the fuel combination being used. The occurrence of actual fusions in the compressed fuel pellets was therefore claimed by more than one experimental group. According to a report that Livermore's John Nuckolls, associate program leader for lasers, presented at the recent Ninth International Quantum Electronics Conference in Amsterdam, the Livermore people have experimental proof that their neutrons came, in fact, from deuterium-tritium fusion and not some other process.

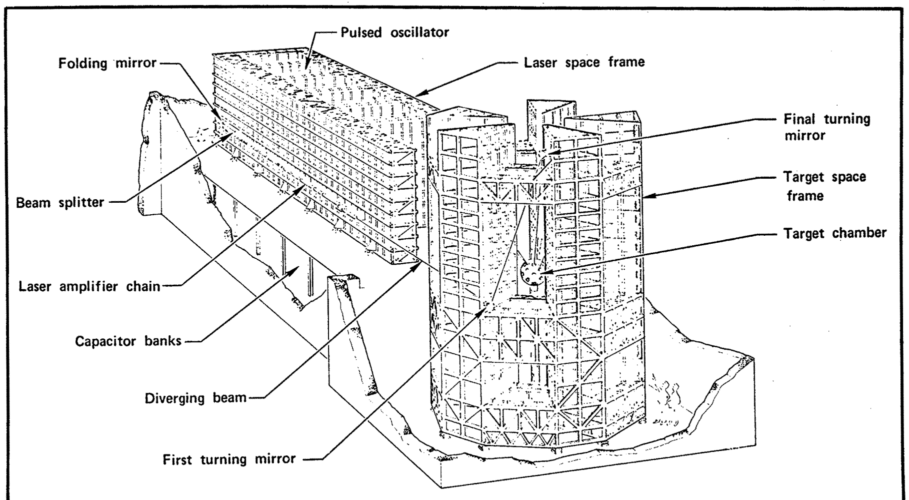
So now we can be reasonably sure that fusions do take place in laser-irradiated targets. The next question is whether there are enough of them. Is a laser system possible that yields as much or more energy from fusion than it takes to start the implosion? Such a condition is called scientific breakeven, and the various future steps in the Livermore program, Argus, a possible 10-terawatt version of Argus, Shiva and the future Shiva upgrade, are intended to march toward it.

Each step will be very carefully taken. Scientists want to know as much as they can find out about what happens in each experiment so as to enhance the chances of progress in the next step.

In the last year or two, Nuckolls reports, a number of technical developments, especially in the design and composition of the fuel pellets, have reduced the expected requirements for the ultimate achievement of laser-fusion power. The laser required for a one-billion-watt fusion reactor would have an efficiency of 1 to 3 percent, a wavelength between 1 and 2 microns, a power between 300 and 500 terawatts, an energy between 500 and 1,000 kilojoules and a repetition rate of ten pulses per second.



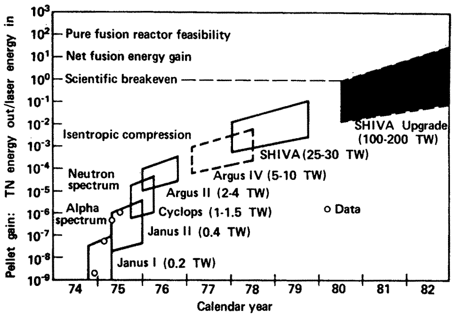
Shiva's target chamber shows attachments for 10 pieces of diagnostic equipment.



A cutaway impression of the Shiva building with space frames drawn in place.

The target chambers are fitted with many ports for measuring instruments, and the Livermore experiments place a heavy stress on "diagnostics," the determination of exactly what is happening as the light hits the target. The medical-sounding terminology goes back to the earliest days of fusion physics, and it seems particularly apt, because the number of parameters is large and their interrelations are complicated. The whole thing does bear an analogy to hospital studies that monitor a large number of complexly interacting symptoms in order to find out what is wrong with the patient. Only in this case, the diagnostics hope to find out what is right with the patient. The Livermore scientists want to know as much as they can

Such an apparatus is far from existing at the moment. The lasers used in all the experiments up to now and planned for Shiva are solid-state lasers in which the lasing material is glass doped with neodymium. This combination happens to provide the most powerful lasers now possible. Indeed improvements of glass technology promise to make them potentially more powerful. Even before Shiva is assembled, the Shiva upgrade is being planned. It will deliver 100 to 200 terawatts with up to 42 separate amplyfying arms. This can be done in the same building and with essentially the same geometry as the first version of Shiva, and that will mean a substantial saving in cost. With the upgraded Shiva, the Livermore scientists hope to demonstrate scientific breakeven (as much energy out of fusion as put in by the laser) by 1981 and possibly later even a net fusion energy gain



The experiments also have a time frame.

over the energy put into the system.

This is not, however, the straight road to a laser-fusion reactor. The glass in the Nd:glass elements has a tendency to heat and must be allowed to cool. This slows the repetition rate far below the optimum for a reactor. Nuckolls estimates that the Shiva upgrade could be fired only every few hours if the glass is allowed to cool properly.

The laser that will do the trick will most likely be a gas-dynamic laser, in which the lasing material is a gas that flows constantly in and out of the lasing chamber and can be efficiently cooled during the recycling process. But gas-dynamic lasers at the moment are fairly low power. The best of them are carbon dioxide lasers, but Nuckolls says those are unlikely to do the job because the wavelength of their light is too long. He mentions work on rare-earth lasers by Livermore's William Krupke as particularly promising. In fact, one current suggestion, according to Coyle, is to use the neodymium without the glass in a gas-dynamic setup.

At both Los Alamos and Livermore, a program of laser development is being pursued alongside the Janus-Cyclops-Argus-Shiva series of experiments, but with somewhat less emphasis. The strategy seems to be to use the most powerful available lasers (Nd:glass) to demonstrate the feasibility of laser-imploded fusion. Then a crash program to develop the most efficient and practical laser for an actual power generator will be fairly easy to sell to the political authorities who must make the funding decisions. Nuckolls predicts an experimental power reactor with a 300-terawatt gas laser producing 1 megawatt of power on the average by 1988, and a demonstration power reactor, one to which lights and appliances might be hooked, by 1998. □