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Laser Fusion: An Energy Option, but Weapons Simulation Is First

Offi and on for almost 20 years now, the United States and the Soviet Union have professed interest in signing a comprehensive nuclear test ban treaty. But if the two superpowers do eventually come to terms on a comprehensive test ban, a remarkable and rapidly evolving new technology may, in important ways, help both sides circumvent it.

The new technology is laser fusion, a technique for creating miniature thermonuclear explosions by hitting pellets of hydrogen with converging laser pulses of enormous power. Over the past few years laser fusion has been widely hailed, both by the press and by its developers in the national laboratories, as a potential shortcut to one of the ultimate objectives of nuclear research—cheap electric power from thermonuclear fusion. Although there is no question about the sincerity of these hopes, it is not generally understood that the immediate practical objective of the government's $68 million laser fusion R & D program is to devise a laboratory technique for simulating nuclear weapons explosions. Indeed, there is a body of opinion—though generally not shared by the national laboratories—which holds that weapons simulation may be the only practical application for laser fusion in this century.

According to weapons authorities, laser fusion promises "orders of magnitude" improvement over present methods of simulation for two distinct but related purposes. First, bursts of radiation from large but controlled "microexplosions" triggered by laser could be extremely useful in testing the effects of weapons radiation on satellites, warheads, and other military hardware packed with delicate electronics.

Perhaps more important from the arms controller's point of view, weapons experts expect laser fusion to become an extraordinarily valuable experimental tool for studying basic "weapons physics" and, in conjunction with increasingly refined computer simulation codes, for developing new warhead designs.

Under any circumstances, laser fusion thus promises to save a great deal of time and money now spent in setting off bombs under the Nevada desert. Some scientists involved in the program say, in fact, that laser "target shooting" experiments in the past few months have already begun to benefit the weapons program by helping to refine the design codes. Thus, quite literally, laser fusion is emerging as a new means of bringing nuclear testing indoors—a prospect that seems all the more attractive in the context of a test ban.

"People go around town saying this is an energy program, but that's something that came along only after energy research got popular," Major General Edward B. Giller, the chief of national security in the Energy Research and

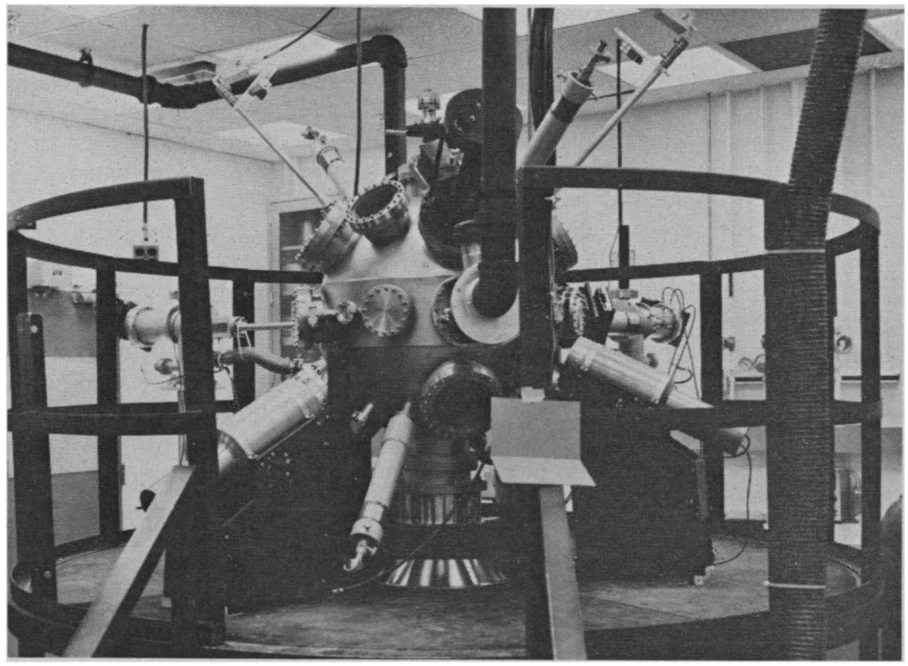
Development Administration (ERDA) said in a recent conversation. "What we're doing now, developing basic laser technology, is equally applicable to military and civilian aspects. But really, this is a military program and it always has been," Giller continued.

"It would be a very useful thing to have in a comprehensive test ban. . . . It would keep the weapons labs busy for 5 to 10 years anyway."

Neither Giller nor others involved in the program who echo his hopes for laser fusion look on its simulation potential as contrary to the spirit or intent of a test ban. For instance, Charles Gilbert, the deputy director of ERDA's division of military applications, said that, while simulations might help maintain the momentum of weapons research, "new weapons designs cannot be based on laser fusion experimentation alone. Development tests as well as proof tests will be required to field new weapons with a credible deterrent value." Another authority was less absolute on this point, however. "I wouldn't like to [deploy a new weapon without proof testing], but you never know. I mean, you never go to completely new designs. You only refine old ones."

It is clear, however, that any thought of deploying a new weapon that had been tested only by simulation methods would rouse an intense debate in military circles.

The Soviet Union, in any case, has mounted an even larger laser fusion program than that of the United States, and France is pursuing the technology as well, all apparently with the same applications in mind. As a matter of prudence, Giller says, "Even if you have a test ban you can't just shut down the laboratories and send everyone



Target chamber of a laser fusion test device built by Sandia Laboratories in New Mexico for weapons simulation research.

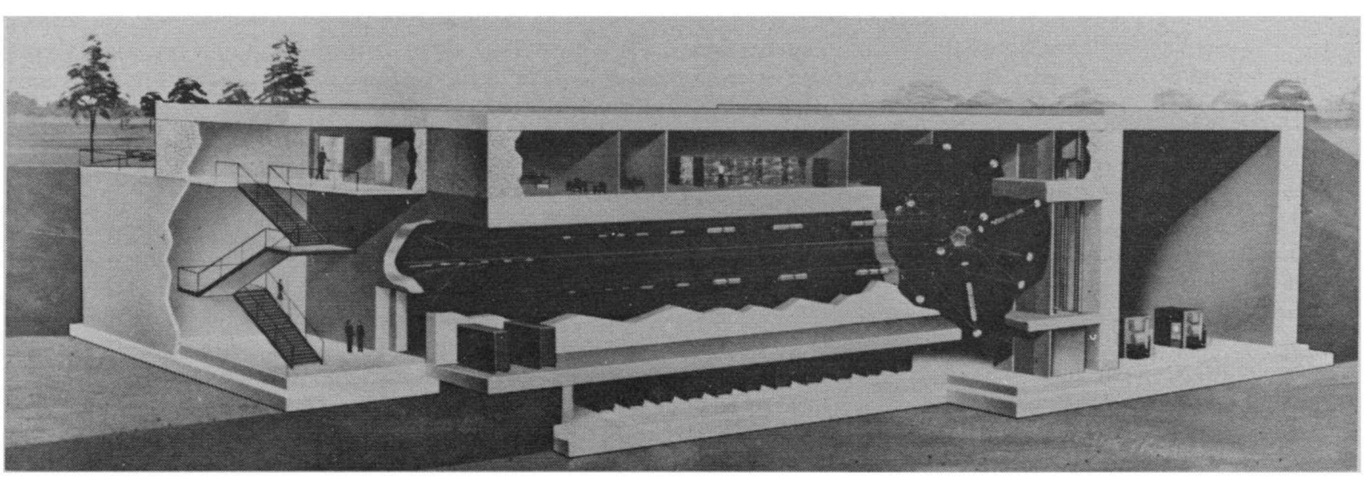
home in hopes that nothing new pops up on the other side. At least not until you have real disarmament."

No one seems to disagree that weapons simulation will be the first application for laser fusion; opinions divide as to whether this may be its last.

Last September the Atomic Energy Commission convened a special review panel to provide an outside perspective on the technology's future. The panel, headed by the venerable former director of research for General Motors, Lawrence R. Hafstad, came to some starkly conservative conclusions about the possibility of an economical laser fusion power plant.

While favoring "aggressive development" of laser fusion technology, the panel said that "there is great question that an economically practical arrangement can be developed" for producing electricity. Each of several possible civilian and military uses of laser fusion posed its own set of formidable problems, the panel's report concludes, but the application with the fewest difficulties seems to be weapons simulation.

Basic laser fusion systems, as they are currently envisioned, consist of anywhere from 2 to 12 glass or carbon dioxide lasers aimed symmetrically at a single point in a spherical target chamber. Simultaneous pulses lasting less than a nanosecond converge on a target pellet which can either be mounted at the intersection point or dropped through it. As a laser pulse hits the pellet, its surface layers explode outward while reaction forces implode the remainder of its hydrogen fuel, compressing and heating it to the point of



Schematic of a 10-kilojoule laser fusion facility being built at Lawrence Livermore Laboratory. Beams converge on target chamber at right. The $25 million facility may eventually be used for weapons effects testing.

thermonuclear fusion. (Use of electron beams in place of lasers may also be feasible. This is being studied mainly at Sandia Laboratories in New Mexico.)

Experiments conducted in the past 2 years at Livermore and the Los Alamos Scientific Laboratory, among other places, have produced miniature fireballs. But their output of x-rays and neutrons suggests that the thermonuclear "burn" has thus far been more of a smolder.

"What we're seeing is like touching a match to damp wood," one scientist said in an interview last year. "We see smoke but not fire."

The Hafstad panel said no physical problems had been identified that would prevent these experiments from leading to practical power production. But such a system, in the panel's view, would require each target pellet to emit 75 times more energy than the megajoule of laser light that goes into it. Even then, up to 45 explosions each second would be needed to generate power on a commercial scale. In contrast, a practical weapons simulation system would require a much smaller gain and a repetition rate of perhaps only three or four shots a day. Ports mounted in the walls of the target chamber would let radiation impact on hardware being tested.

To appreciate the weapons establishment's enthusiasm for such a device requires some understanding of the special difficulties of a business that, when stripped of its complicated ethical considerations, is revealed at heart to be a most arcane and expensive branch of physics.

It involves, weapons physicists point out, experimentation with materials at extreme physical conditions currently found only in the centers of stars and in bomb explosions. Moreover, carrying out physics and engineering experiments deep inside a mountain or thousands of feet underground in mined-out chambers of rock, as is the case at the Nevada Test Site, is ponderously slow and exorbitantly expensive. Since the Limited Test Ban Treaty was signed in 1963, prohibiting tests everywhere but underground, the United States has spent roughly $175 million annually to conduct 10 to 20 explosions a year at Nevada. In the fiscal year beginning this July the testing budget will go up to $210 million as the laboratories race to beat the March 1976 cutoff date for tests larger than 150 kilotons proposed last year as part of the Threshold Test Ban Treaty.

"People think we like to go out in the desert and shoot off bombs, but that isn't true," says one nuclear effects expert who has spent many years doing precisely that. "A test can take a year or more from conception to detonation, and they're usually oversubscribed with experiments. It's hot, you get sand in your relays, and things don't always go as planned. Believe me, it's no picnic."

A physicist whose involvement has centered on weapons design, not effects, emphasizes the difficulty of gathering data under these conditions: "Nothing survives in the thermonuclear environ-

Laser Fusion Report Plays Down Power Potential, Play

The early hopes that laser techniques could provide a shortcut to fusion power have faded, and noted scientists have said that the government's laser fusion program is being oversold as an energy project. But the official Washington attitude remains sanguine. The first high-level review of the laser fusion program, released by the Energy Research and Development Administration (ERDA) in mid-March, recommended that it receive broader support, especially for research in universities and private companies. But the report made the point quite clearly that of all the possible applications of laser fusion (see accompanying story), commercial production of electricity was the most dubious.

The usefulness of laser fusion for electricity production depends on achieving what is called a high pellet gain, that is, a high return on the laser energy deposited in a fuel pellet from the fusion microexplosion that results. Using reasonably optimistic estimates of the efficiencies that might be expected from the various components of a laser fusion power station, the report found that a gain of at least 75-fold would be required for a practical power plant. The evaluation of the technical status of laser fusion concluded that "A pellet gain of 75 . . . may not be attainable under practical conditions. But the possibility is important enough to warrant aggressive development. Some significant pellet gain appears to be almost certain to be achievable. A failure to reach a gain of 75-fold will still leave other interesting possible applications of laser fusion. . . ."

The major application other than commercial power generation identified in the report is the simulation of nuclear weapons explosions. "The requirements of pellet gain are much less for this application than for commercial power production," the report said. Another possible use, being pushed more strongly by the advocates of laser fusion now that the future of the breeder reactor program looks cloudy, is the generation of fissile fuel from the neutrons produced through laser fusion. This might be done in a hybrid fusion-fission plant. Other schemes would separate laser fusion plants breeding plutonium from the light-water reactors burning plutonium to produce commercial power as well as power to run the laser plant. Most laser fusion researchers say that only a gain of 1 would be needed for the laser breeding schemes to work. The maximum gain achieved in actual experiments, which might be more accurately called a minimum loss, is about 10^{-7} (*Science*, 27 December 1974).

A major unknown factor that will determine how much laser power is needed to reach a certain energy gain is the degree of fuel pellet compression. The report found that 10,000-fold compression of solid hydrogen was probably an upper limit, and that a lesser compression of 1000-fold would require an extremely powerful laser. In between these two values, a compression of 5000 was judged to be the minimum necessary for a practical power plant.

Even at this high degree of compression, a 1000-

ment. You do an experiment once and it's done. If the results were not as you expected it is very difficult to repeat.

"With laser fusion we are getting close to thermonuclear reactions, explosions, for the first time. In the laboratory you can just repeat your experiments at will."

Concern about the effects of nuclear weapons—the vulnerability of military hardware—has centered over the years in the Pentagon's Defense Nuclear Agency, while the task of weapons design and testing was the AEC's responsibility (and now is ERDA's).

Over the years the DNA, in seeking to reduce its reliance on underground explosions, has developed an extraordinary array of machines and techniques for simulating portions of the weapons radiation spectrum, which runs from radio frequencies up to gamma rays of about 14 million electron volts. DNA officials express cautious optimism that laser fusion will represent an important evolutionary advance over existing machines.

One area of prime interest concerns the effects of x-rays and gamma rays on electronics systems in, for instance, missile warheads or communication satellites. To reproduce the physical shock and electric discharge effects of this radiation, the Defense Department has built some 35 huge flash x-ray machines in laboratories across the country that deliver (at short range) bursts of x-rays and gamma rays lasting about as long as a nuclear weapon takes to explode, or one hundred-millionth of a second.

The largest of these machines is named Aurora and is located in the suburbs of Washington, D.C. The Aurora machine fills a concrete building about the size of a small airplane hangar, weighs 7000 tons (most of which consists of electric storage capacitors) and generates a gamma ray pulse of about 0.5 megajoules. Capable of irradiating whole missile stages at once, Aurora's gamma ray blast—which sounds like a muffled cannon—is, at a distance of a few centimeters, roughly equal to that of a 1-megaton antiballistic missile warhead at a range of 3 kilometers.

Neutron effects are of great interest too, and to duplicate them above ground researchers have relied since the 1950's on pulsed nuclear reactors.

Reactors produce no more than about 1 million low-energy neutrons in a single burst, and this is far smaller than the yield of some of the small, "neutron-enhanced" weapons of recent design. (A 1-kiloton explosion for example, can release about 10^{24} neutrons.)

For more intense bursts of neutrons, effects researchers are turning to particle accelerators. At the Los Alamos Meson-Physics Facility (LAMPF), the military side of ERDA is building a special target area for defense work called the Weapons Neutron Research facility. A less well advertised companion to LAMPF's highly publicized biomedical research unit, the WNR will, at \$5.6 million, cost almost twice as much. According to congressional budget documents, the WNR would divert a small portion of the main accelerator beam to

Up the Need for University and Industrial Research

kilojoule laser would be needed to produce the gain needed for a power plant. By comparison, the largest lasers now operating produce about 1 kilojoule, and the \$25 million laser under construction at the Lawrence Livermore Laboratory will produce 10 kilojoules at best. Furthermore, the numbers cited may be overly optimistic because certain plasma effects, which could reduce the energy gain, have not so far been included in the massive computer codes used to describe laser implosions.

In spite of the caveats in the report, James McNally of ERDA says, "I don't find it pessimistic at all. I regard it as very encouraging about the pursuit of the laser fusion research program." In fact, according to several people at ERDA, draft versions of the report included the assessment that laser fusion held more promise than the older approach, magnetically contained fusion.

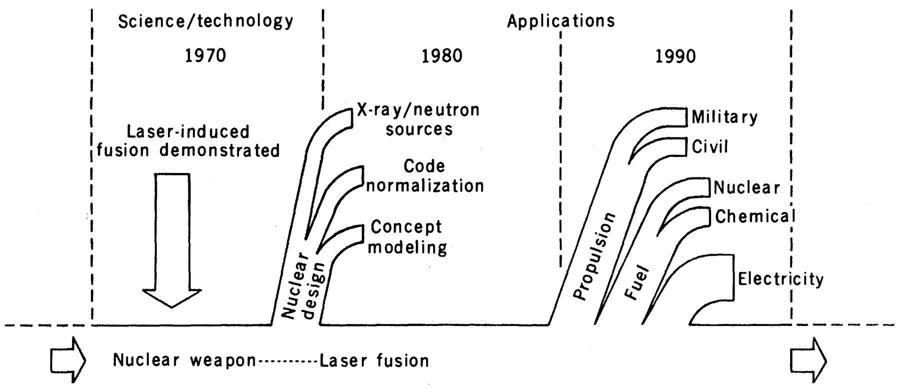
The succinct 15-page report was the work of a four-man panel headed by Lawrence Hafstad, who previously managed reactor development for the Atomic Energy Commission (AEC) in the early 1950's and subsequently managed research and development for General Motors until 1969.

The Hafstad report was commissioned at least partially in response to the problem of KMS Industries, the Ann Arbor, Michigan, company whose progress in laser fusion research, without government funding and without access to government research, was something of an embarrassment to the AEC.

The thrust of the report is that government-sponsored research in laser fusion should be opened up, beyond the narrow base of the two ERDA weapons laboratories, at Livermore and Los Alamos, where it is almost exclusively carried out now. The report found that a larger portion of the R & D resources of the country could be tapped for laser fusion, and that such independent efforts would, through competition, enhance the scientific output and cost effectiveness of the weapons laboratories. It recommended that at least 10 percent of the budget for laser fusion be allocated for projects outside the principal ERDA laboratories, and that proposals for "external" projects should not be solely reviewed by the staff of the weapons laboratories.

Obviously referring to the 24 patent applications filed by KMS Industries which are being contested by the government, the Hafstad report recommended that ERDA should liberalize its administration of patents, saying that "The traditionally restrictive patent policy of the AEC, which may have been adopted for good reasons nearly three decades ago, has long been a serious handicap in getting effective industrial participation in programs intended for civilian use."

The recommendations to open up laser fusion research are now being implemented by ERDA, which recently awarded a limited contract to KMS Industries and is considering longer term proposals from several research establishments, including KMS and the University of Rochester.—W.D.M.



Expected progress in laser fusion applications is charted in a diagram adapted from one prepared by the Energy Research and Development Administration.

generate pulses of up to 4×10^{12} highly energetic neutrons. It would be used for refining computer codes for weapons design, for testing and calibrating instruments used in underground tests, and training defense researchers.

"From its inception," an AEC budget document from 1972 emphasizes, "LAMPF has been recognized as an intense source of neutrons" for military research. A government booklet describing LAMPF says the neutron facility "is seen as a contingency against further limitations or restrictions on underground nuclear testing."

Advantages of Laser Fusion

Laser fusion, if it works, offers several advantages over existing simulators, with only duplicate narrow segments of a bomb's radiation spectrum. A tiny thermonuclear fireball, for example, would have roughly the same radiation profile as a hydrogen bomb, thus allowing researchers to study the complex interaction of x-rays, gamma rays, and neutrons as they impinge simultaneously on electronic systems. There is also the prospect, for the first time, of studying up close in a thermonuclear environment the behavior of thin imploding shells, the radiation transmission properties of plasmas adulterated with different elements, and other esoterica.

And there is also the sheer abundance of controllable radiation to consider. An efficient thermonuclear burn of a sand-grain-sized target could produce a burst of 10^{15} to 10^{19} neutrons, many more than LAMPF will generate.

Though it may be a long time before Aurora is rendered obsolete, weapons program officials expect the x-ray output of laser fusion experiments to be sufficient by 1976–1977 to begin vulnerability testing of "soft" or radiation-sensitive electronics. Modeling of new weapons physics concepts is projected to start sometime between 1979 and 1981.

That laser fusion techniques might represent an improvement over the powerful sources of radiation now available was not immediately apparent to the weapons laboratories. In fact, the idea lay fallow at Livermore and Los Alamos for almost a decade before major funding became available.

The man generally credited with the basic conception is John H. Nuckolls, a Livermore senior physicist. In a conversation last year at Livermore, Nuckolls recalled that he began thinking about ways to create thermonuclear "microexplosions" in 1960, a few months before the first laser was demonstrated. Calculations over the next year indicated that extremely powerful lasers might do the trick, and a small experimental program was begun at Livermore in 1963. At that time, Nuckolls said, "you probably could have convinced no one that it would be useful for weapons simulation."

Laser fusion's potential was largely ignored in the laboratories until 1968, when Soviet and French scientists revealed that they had independently produced neutrons (a sign of fusion reactions) from deuterium targets irradiated by pulsed lasers. These successes, combined with new calculations showing that significant fusion might be achieved with less powerful lasers than originally thought, suddenly transformed a small, mostly theoretical program into one of the fastest blossoming, most competitive research efforts in the national laboratories. Funding jumped from $2 million in 1970 to $25 million in 1973 and will reach $68 million in fiscal 1976. Long-range plans call for spending about $520 million for laser fusion between now and 1980.

Not until November 1971, however, did the Atomic Energy Commission see fit to part the curtain of secrecy that had surrounded laser fusion for a decade. By then, many in the laboratories—Nuckolls among them—were more enthusiastic about using it to generate electricity or produce plutonium from uranium than they were about what now seemed to be the technology's more prosaic military applications.

With the wraps off, the news appeal of laser fusion—a marriage of the two most readily romanticized technologies of the mid-20th century—was instantaneous and strong. Most reports, however, gave only a passing nod to military applications or neglected to mention them at all. A long article on laser fusion in the May 1974 issue of *Fortune*, for example, said that "through various surmises and leaks," the reason for secrecy in the program "was narrowed down to a military project to develop a 'clean,' more compact hydrogen bomb."

Defense officials have in fact suggested that a laser trigger might be devised for a weapon, but this is regarded as far less practical than weapons simulation and perhaps even more difficult to build than a commercial power plant.

The emphasis on civilian applications reflects in part the interests of laser fusion researchers, as well as, perhaps, the White House Office of Management and Budget's practice of counting the entire laser fusion program as part of the Administration's "clean energy" program (though usually with a small-type footnote acknowledging that unspecified military applications might exist).

Several weapons authorities who were interviewed over the past year have emphasized that there are limits to the degree of realism achievable with laser fusion simulation. Its radiation pulse will be briefer than a bomb explosion, and the vast difference in scale makes it seem unlikely that a new bomb design could be fully simulated without a great deal of computer work.

Nevertheless, says a leading physicist on the weapons side of ERDA, "Laser fusion will give us the best simulator we have." In the event of a nuclear test ban, "it would help keep the laboratories stimulated and active in something they believe is important for the country."—ROBERT GILLETTE