The Laser Programs

by Keith Boyer

The laser programs of Los Alamos had their inception in 1968 when I was directing the test activities of the Nuclear Rocket Propulsion program (Project Rover) in Nevada. At that point decisions were being made that would shift much of the program's test activities over to Aerojet and Westinghouse, and it was an appropriate time to explore new activities.

The main concept of the Rover nuclear rocket was to generate a high-temperature exhaust stream for propulsion by passing a gas, such as hydrogen, through the hot core of a nuclear reactor. However, I thought that a system based on fusion rather than fission might provide an extremely high-temperature exhaust stream for efficient propulsion. One possibility was the "Orion" concept in which a series of thermonuclear explosions "pushes" the spacecraft by ablating a replaceable layer of material, such as water, off a pusher plate. This process could produce high thrust and a very high efficiency system.

But what would ignite the thermonuclear explosions? Because of my interest in lasers, I was aware of the development of a high-energy carbon dioxide (CO_2) gas-dynamic laser system by the Air Force Weapons Laboratory. Our calculations indicated that if the energy then predicted for this laser could be released in a short enough time (about a nanosecond) and focused uniformly onto a small pellet of thermonuclear fuel, an efficient fusion process might be achieved.

Another feature that made the gas-dynamic laser attractive to our program was the manner in which the laser's population inversion was generated. The CO_2 gas was pumped to higher energy states by heating the gas, then the inversion was formed with rapid cooling through an expansion nozzle. Our early systems could use the Rover reactor as the heat source for driving this laser at high energies. Thus, the investigation of laser fusion seemed appropriate. The Space Nuclear Propulsion Office in Washington agreed, and a modest effort was started that year at the Nevada Rover test site. Of course we recognized that fusion as a commercial energy source was the most important application and one that would surely precede any propulsion application, but we had found our first sponsor.

Design studies soon revealed difficulties in achieving the desired short, high-energy pulses at the low CO_2 pressures necessary in the gas-dynamic laser system, so other pumping mechanisms for the laser were considered, including optical, electrical, and chemical energy sources. Also, more information was needed about the effective absorption efficiency of the laser energy by appropriate targets, about the physics of the interaction process, and about energy transport and utilization in initiating fusion.

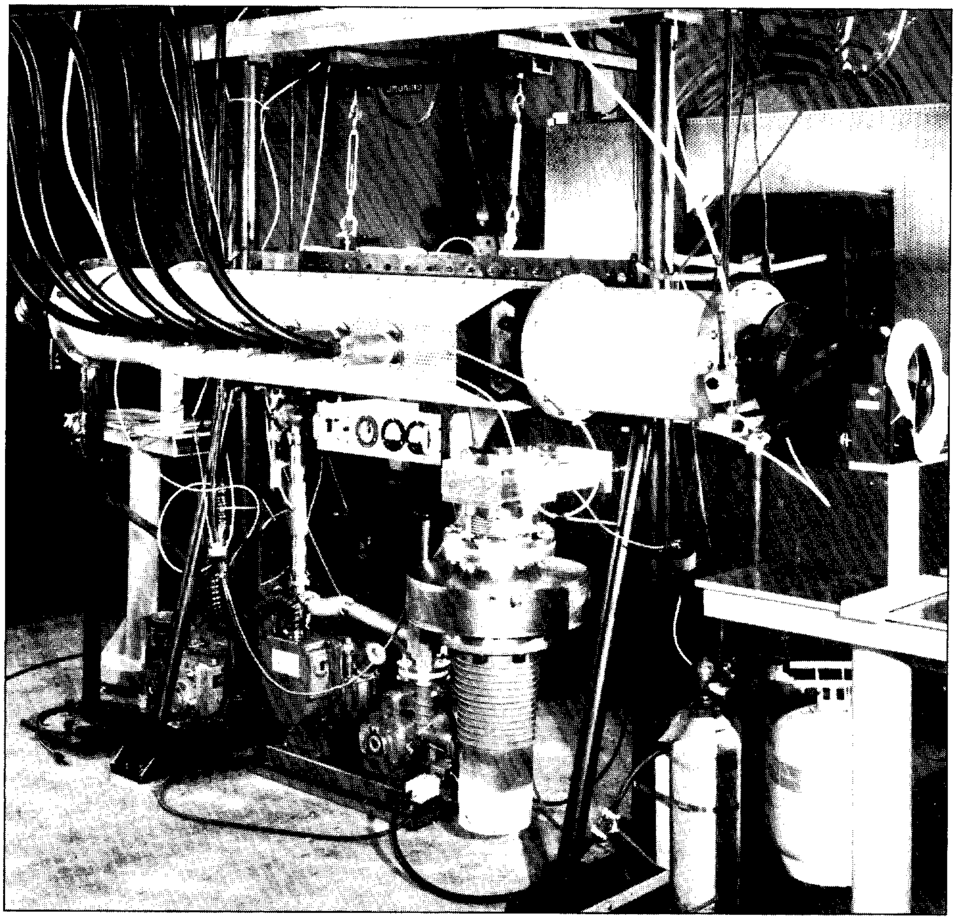
Raymond Pollock, a weapon designer, agreed to collaborate on this study and was able to derive the scaling laws and calculate the requirements to achieve thermonuclear burning of small pellets of fuel by assuming ideal interaction physics of the laser light with the target.

In early 1969 Bill Ogle, then the Weapons Testing Division Leader, agreed to authorize a small experimental exploratory effort. This activity included about ten staff members and initiated a three-pronged experimental effort: development of a one-joule, picosecond glass laser for the light-target interaction studies, investigation of electrical-discharge-pumped CO_2 lasers that could be scaled to high energy, and development of chemical lasers. Although chemical lasers would serve as backup for the undeveloped $C0_2$ laser, we intended to pursue both laser development and laser applications, and we recognized the potential of chemical lasers for studying photochemistry. For the CO_2 laser one of the early innovations, in which Charles Fenstermacher played a key role, was an electron-beam-controlled discharge capable of pumping large volumes of high-pressure CO_2 gas.

A year later we had established estimates of key parameters for laser fusion, such as laser energy, pulse width, and preliminary pellet design. We were able to outline a program designed to determine the feasibility of laser fusion, including several different laser options. About this time we became aware of other programs in various parts of the world, including those at Livermore, Sandia, the University of Rochester, the Lebedev Institute in the Soviet Union, and the Osaka University in Japan, but all of these were based on glass lasers. Moreover, apparently only the Los Alamos and Livermore programs initially considered a target design that used laser energy to compress the fuel strongly as well as to heat it, a technique that reduced the laser energy required by many orders of magnitude. This situation changed soon as the various programs, including a new one at KMS Fusion (a commercial venture), discovered the necessity of compression.

Harold Agnew, recognizing the importance of developing new and promising activities at Los Alamos, asked me in January 1971 to set up an expanded laser program. This program was run out of the Director's Office in order to enlist Laboratory-wide support. Our effort soon had a wide base of activities, including a theoretical group organized by Richard Morse in the Theoretical Divison; an interaction physics and target group under Gene McCall, who played a key role in the Laser Fusion program; a $C0_2$ laser development group under Fenstermacher; a glass laser group under Dennis Gill; and a chemical laser group directed by Reed Jensen. A series of seminars was established to review the existing state of laser technology and interaction physics and to explore new applications such as laser photochemistry.

By early 1972 the program had achieved sufficient size and complexity so that a new Laser Division was established. Two new groups were added, one on laser applications and one on target fabrication. At this time the first large $C0_2$ laser chain was being built and plans were in progress for a series of $C0_2$



One of the amplifiers used in the early '70s in a $C0_2$ laser chain that generated a l-nanosecond, 0.5-kilojoule pulse.

laser systems of increasing size, including a two-beam, 2-kilojoule laser later called Gemini; a six-beam, 10-kilojoule laser now operating under the name of Helios; and a 100-kilojoule system whose configuration was being debated and which evolved into the present Antares system.

The early interaction data was obtained using a 50-joule, picosecond glass laser, Meanwhile, work proceeded on development of a larger 500-joule, glass laser system. Frequency-conversion crystals were also planned to be used with this laser to give green light and ultraviolet light, although at lower energies. These latter frequencies were needed to explore fully the question of the most efficient wavelength for the laser fusion process, a question that has not yet been resolved. The chemical laser work proceeded with the development of hydrogen fluoride lasers, which promised to provide the highest energy output of any laser system.

A coordinating committee was established in Washington to provide guidance for the laser fusion programs in the United States with representation from the Division of Military Applications of the AEC, the Magnetic Fusion program, and the heads of the various AEC Laboratory laser programs. The Los Alamos budget approximately doubled each year through the early '70s,

Our plan to pursue a broadbased laser technology program included a small project in the Chemical Laser Group to investigate the use of laser energy to separate uranium isotopes. This particular activity captured the interest of Paul Robinson, who had transferred from the Rover Reactor Division, together with a number of other staff, as the Rover program decreased in size. Paul had earlier been active in the gas-dynamic laser effort in Nevada and now, together with Reed Jensen, played a major role in the isotope separation project. The separation was based on the photolytic dissociation of uranium hexafluoride vapor cooled by a supersonic expansion to permit isotopic selectivity using a combination of infrared and ultraviolet laser photons, This activity continued to grow until it was split off from the Laser Division as the Applied Photochemistry Division with Paul as Division Leader. This division also became involved in both high-repetition-rate, high-power laser development and in broad aspects of laser photochemistry. Projects included high-resolution laser spectroscopy, photochemical processing, laser sound generators for potential military uses, and chemical and biological warfare agent detectors. Although a recent Washington decision terminated the Los Alamos molecular uranium isotope separation process in favor of the Livermore atomic vapor process, the molecular process was close to engineering demonstration and was judged by many of us to be the superior process. In spite of the uranium decision a growing Los Alamos program on the separation of plutonium isotopes is doing well.

The laser fusion programs are still vigorous, but many problems have developed, and the final utility of laser fusion for energy production remains uncertain. Inflation and budget stretchouts reduced the design energy of the Antares $C0_2$ laser, which has just begun its checkout phase, from 100 to 40 kilojoules, The estimates of laser energy needed for a useful thermonuclear yield have risen from a few hundred kilojoules to a few megajoules. The longer wavelengths of both CO_2 and glass lasers produced undesirably large hot-electron components in the absorption process. The resulting self-generated magnetic fields are believed to reduce the lateral heat conduction that was originally counted on to symmetrize the implosion of the fuel pellet. Shorter wavelengths appear to be more satisfactory, and work is proceeding on ultraviolet excimer lasers, such as krypton fluoride, but the optics problems for these wavelengths are severe. Glass lasers can be frequency shifted to the third harmonic with good efficiencies, although the basic efficiency of the glass laser itself is too low to provide the driver for a laser fusion reactor. However, this technique is being pursued at other laboratories.

The Los Alamos program is now emphasizing investigation of physics problems of interest to the weapons programs, Because this effort appears to be increasingly productive, program funding and support is expected to continue. In spite of the apparent difficulties associated with the long wavelength of the $C0_2$ laser, it may be possible to find clever target designs that permit the many advantages of this laser to be used for successful initiation of the fusion process. Other laser activities, such as the Free Electron Laser program, are now expanding both the Laboratory's interest in and its commitment to laser technology. ■