LA-5923-MS
Informal Report
C. 1

Special Distribution
Issued: April 1975

Los Alamos Presentation on Laser Fusion

to the

Joint Committee on Atomic Energy

Washington, DC

March 13, 1975

by

Gene H. McCall

For Reference

Not to be taken from this room

DISTRIBUTION MADE WAS
HANDLED BY L-4

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

An Affirmative Action/Equal Opportunity Employer

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

In the interest of prompt distribution, this report was not edited by the Technical Information staff.

LOS ALAMOS PRESENTATION ON LASER FUSION

To the
Joint Committee on Atomic Energy
Washington, DC

March 13, 1975

by
Gene H. McCall

The advantages of fusion energy have been discussed many times and it sometimes appears that fusion research is similar to the search for the holy grail when we speak of unlimited power for the next millions of years.

Allow me to make a simple comparison (Table I) however between fusion fuels and the fossil fuels that we know now. One gallon of gasoline, when burned, produces 128 000 Btu of heat, which is characteristic of fossile fuels. If we extract the naturally occurring deuterium in one gallon of gasoline and burn it to completion in a fusion reaction, we would obtain 9 000 000 Btu in heat. In obtaining this energy, we've done very little to the gasoline and 99.98% of it is still left. This points up the fact that fuel mining for fusion reactors produces no environmental impact. I don't propose that we conserve gasoline so that we can later burn it in fusion reactors, ordinary water would do just as well, but this points out that a gallon of natural water contains more energy than 100 gallons of gasoline.

TABLE I

WHY FUSION?

1 GALLON OF GASOLINE PRODUCES 128 000 BTU WHEN BURNED.

NATURALLY OCCURRING DEUTERIUM IN ONE GALLON OF GASOLINE WOULD PRODUCE 9 000 000 BTU IN FUSION REACTIONS, AND 99.98 PERCENT OF THE GALLON IS LEFT.

FUEL MINING PRODUCES NO ENVIRONMENTAL IMPACT.

When the idea of laser fusion was first conceived, it was believed possible to proceed along a logical line of development to power generation in fusion reactors driven by lasers, and we established the laser fusion program to meet this goal. A major feature of laser fusion research which distinguishes it from many other research programs, however, is a large number of unexpected spinoffs that have occurred in the few years that the program has been in existence. I show these schematically in Fig. 1.

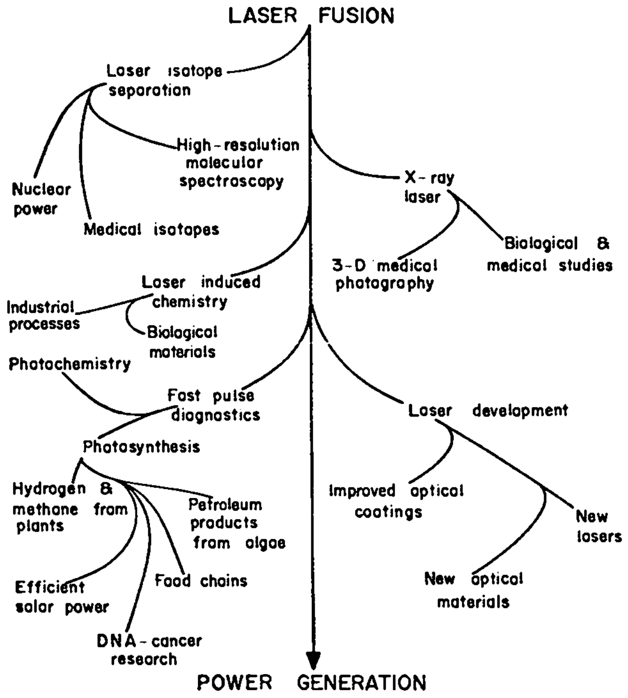


Figure 1

For example, laser isotope separation was devised as a direct result of trying to understand laser chemistry and lasers themselves. Laser isotope separation, as has been pointed out, can have an important impact on nuclear power generation, can result in the separation of medical isotopes, and already has had a major impact on the spectroscopy of molecules. Techniques developed in the isotope separation program have resulted in new descriptions of molecules and more accurate studies of their chemical reactions.

Most of the laser fusion groups in the world are also working on x-ray lasers; x-ray lasers, generally, will initially use lasers of the type constructed for fusion research to drive them. The fabrication of a successful x-ray laser could lead to very high resolution, three-dimensional medical x-ray photography, and could eliminate much of the guesswork in radiography. It will also be extremely important in studying biological and medical problems such as the structure of DNA.

Laser induced chemical reactions have already been generated, and it may be possible to use laser chemistry in industrial processes to produce products that are almost 100% the desired product. This will significantly reduce the cost of processing required to purify industrial materials. It also seems likely that laser induced chemistry can be used to generate materials that previously have been found only in biological specimens.

Another direct outgrowth of the laser fusion is the invention of fast pulse diagnostics, which were originally designed to measure the length of the very short pulses generated for fusion experiments. These pulses may exist only for the amount of time required for light to travel an eighth of an inch. Using the instruments developed for these measurements, much work has been done in photochemistry in an attempt to unravel the processes that occur after the absorption of light. At Los Alamos, work is being carried on in photosynthesis, and for the first time, in both chemical chlorophyll and in living algae, it has been possible to observe the absorption of light by a living cell and the transfer of this energy into the reaction center of the cell. Since photosynthesis is the most efficient use of sunlight known to man, it is possible that studies of this type will result in more efficient use of solar power than is presently envisioned with solar collectors. Also, we know that hydrogen and methane are produced by plants, and through studies of this type we may find how they do it and how it can be done artifically and efficiently. Of course, this type of excitation transfer study is also applicable to excitation along DNA chains, which relates to cancer research. The study of photosynthesis is closely tied to the world's food chains, and because of the world's food shortages these research projects have become much more important. Finally, it is known that some petroleum products are produced from algae; a fact which opens a whole line of fuel production research.

The other branch on my tree is laser development, which, here, is a very short one, but it is completely open-ended. We have already developed greatly improved optical coatings and we have developed optical materials that are much more uniform and much clearer than those produced before. The results of these developments should appear in cameras, microscopes, and other optical instruments within the next few years. The new laser branch is a very short one but, considering the developments that have already come from laser research, the possibilities here are limitless.

At Los Alamos we have always felt that a successful laser fusion program will be a combination of various projects. First, we must develop large lasers that are capable of generating energy in short pulses at power levels large enough to implode fusion targets. Second, experiments on the interaction of high-intensity laser light with matter must be done as the lasers are being developed, and new experimental results must be incorporated into laser designs. Third, advanced research programs, which will eventually produce new lasers capable of operating power plants, must be carried on. We believe we have achieved the near optimum mix of these three catagories at Los Alamos. At each stage of laser development, beginning with low-energy Nd:Glass systems and proceeding to multikilojoule CO_2 systems in the next year or so, we have suspended laser construction to do target experiments to make sure that we understand the interaction physics before proceeding. The highlights of the Los Alamos laser fusion program are shown in Table II. Pellet compression experiments have been done with Nd:Glass

TABLE II

HIGHLIGHTS OF LASL LASER FUSION PROGRAM

- First pellet compression with single-beam Nd: Glass laser, Nov. 1973.
- Compressions of 50-100 with 2-beam 200-Joule Nd: Glass laser in current experiments.
- Pellet fabrication techniques have been perfected for DT-filled microballoons and more complex targets and are in use. Target designs are based on use of extensive computer physics simulation codes.
- Neutrons have been generated in CO_2 laser target experiments, June 1974.
- Two-beam, 2500-Joule, CO_2 laser system in final assembly and checkout phase. Target compression experiments summer 1975.
- Eight-beam, 10 000-Joule, 1-nanosecond CO_2 laser facility is under construction. Completion 1976. High pellet compression and possibly significant TN burn expected.

1/29/75

TABLE III

APPLICATIONS OF LASERS AT LOS ALAMOS

EARLY EXPERIMENTS	GLASS LASERS (100-J, 150-PS) HAVE BEEN USED TO UNDERSTAND HOW LASER LIGHT IS ABSORBED AND HOW PELLETS ARE HEATED AND COMPRESSED
REQUIRED FUSION POWER LEVELS	CO_2 LASERS (200-J, 1-NS) HAVE BEEN USED TO DETERMINE HOW THE WAVELENGTH, OR COLOR, AFFECTS THESE PROCESSES AND HOW TO MODIFY PELLET DESIGN TO COMPENSATE FOR DELITERIOUS EFFECTS. THESE STUDIES ARE IN PROGRESS AND PRELIMINARY WORK IS VERY ENCOURAGING
ECONOMY	NEW LASERS ARE BEING SOUGHT TO IMPROVE THE EFFICIENCY AND COST EFFECTIVENESS FOR ECONOMIC ELECTRIC POWER GENERATION.

lasers and the first indication of compression was achieved in November of '73 with the first data on compression being taken in October of 1973. With our two-beam, 200-J Nd:Glass laser we are currently measuring compressions of 50 to 100 times. We have perfected pellet fabrication techniques for generating deuterium and tritium filled targets and have also built and used more complex targets than the simple glass microballoons which were used in the early experiments. These targets designs are based on the use of extensive computer modeling codes, an approach which has been very successful in the past. Using the CO_2 1-ns, 150-J laser, we have for the first time generated neutrons with a carbon dioxide laser in June of 1974. A two-beam, 2500-J carbon dioxide laser system is now undergoing electrical test at Los Alamos and should be ready for target experiments this summer. Also under construction is an 8-beam, 10 000-J CO_2 laser scheduled for completion in 1976. Using this laser we expect very high pellet compression and, possibly, significant thermonuclear burn.

The laser development program at Los Alamos is primarily devoted to CO_2 lasers. As shown in Table III, we have used glass lasers at 100 J, 150 ps for early experiments to understand the absorption of laser light by matter and to understand how pellets are heated and compressed by laser radiation. To reach the power levels required for significant fusion reactions, we plan to use carbon dioxide lasers. We have used them at the 200-J, 1-ns level to determine how the wavelength, or color, of the light affects the target processes and how pellet designs must be modified to compensate for the deleterious effects of the long wavelength produced by this laser. The studies are still in progress but the preliminary work is very encouraging and we feel that the wavelength problem will not prevent the successful use of CO_2 lasers in fusion research. Neither of these lasers is efficient enough for power production and the search for new lasers is constantly going on.

A comparison of various types of lasers is shown in Table IV. The Nd:Glass laser system has a measured efficiency of about 0.02%, and because of this severe limit on the efficiency it is possible to build lasers with energies only up to about 10 kJ. Even these lasers suffer from problems of damage to the laser system in normal operation and incur a high operating expense. The CO_2 laser has

TABLE IV

LASER	SHORT PULSE MEASURED EFFICIENCY	PRACTICAL ENERGY LIMIT	PROBLEMS
NEODYMIUM-GLASS	.02%	10 kJ	DAMAGE TO LASER, EXPENSE
CARBON DIOXIDE	1.7%	100 kJ	LONG WAVELENGTH, OPTICS
FUTURE CONTENDERS (MORE THAN 5 YEARS AWAY)			
HYDROGEN FLUORIDE	5% (LONG PULSE)	1 000 kJ (ESTIMATE)	MATERIALS, WAVELENGTH
OXYGEN	3 - 5% (LONG PULSE)	50 kJ	ENERGY EXTRACTION, IMPURITIES

been operated at Los Alamos with an efficiency of 1.7% in a 1-ns pulse, and it appears possible to build this laser in energies as large as 100 kJ. It has the disadvantage that the wavelength is very long--10 times as long as the Nd:Glass system--and target design for this laser is difficult but not impossible. It's also more difficult to obtain high-quality optics in the far-infared than it is in the visible or near-infrared.

Let me emphasize that only two lasers exist today which can be built in sizes large enough for significant thermonuclear yield. These are the Nd:Glass system and the CO_2 system. Other lasers that have been discussed as candidates for power reactor lasers or the new generation of fusion lasers are at least five years away and perhaps longer. I do not mean that in five years we will have new lasers in large sizes; I mean that in five years we will know enough of the technology to begin designing such lasers. Two possible contenders for the future, that we feel are attractive, are the hydrogen-fluoride and oxygen lasers. The hydrogen-fluoride system is a chemical laser and obtains its energy from chemical reaction rather than electrical power. This laser has been operated in a joint experiment between Sandia Laboratories and Los Alamos at an efficiency of about 5%. This is conversion of chemical energy from hydrogen and fluorine into laser light, but it was done with the very long pulse. The simplicity of the chemical system, however, is such that it may be possible to build such a laser in 1-MJ sizes. There are some significant problems with materials and handling of the corrosive gases, and also the wavelength is somewhat longer than that of Nd:Glass. The oxygen laser operates in the visible and has been operated with an efficiency of 3 to 5% in a long pulse. It may be possible to build it in sizes as large as 50 kJ but there are problems with energy extraction and it is very sensitive to impurities in the gas mixture.

A comparison of the Los Alamos CO_2 laser systems with those which have been built in other locations is shown in Table V. The relevant parameter for such a laser system is really power, it is not strictly energy, and when I have spoken of energy earlier I have assumed that this energy is delivered in a time short enough to be used in laser fusion research. I quote power in this case because for most of the lasers listed here the pulses are not short enough to be used for laser fusion. In fact, when one speaks of energy, the energy produced by the lights in this hearing room during the time of these hearings will probably exceed the total energy produced by operating the lasers everywhere in the world. Using power as the relevant parameter we can see that AVCO has produced a very large laser which operates at about 2 J/ns. At the Limeil Laboratory, outside Paris, there is an operating CO_2 system at 3 J/ns. In Canada there is a CO_2 laser system at the Defense Research Establishment in Valcartier operating now at 5 J/ns. The Naval Research Laboratory and the Lawrence Livermore Laboratory have systems very similar to one another; the NRL system is now operating at 25 J/ns and the Livermore system at 50. The Los Alamos target laser which has been used for target experiments is currently operating at 250 J/ns. The projected sequence of

TABLE V

High-Power CO_2 Laser Systems

AVCO	2 J/ns
LIMEIL (France)	3 J/ns
DREV (Canada)	5 J/ns
NRL	25 J/ns
LLL	50 J/ns
LASL	250 J/ns

CO_2 laser construction at Los Alamos is shown in Figs. 2, 3, 4, and 5. Figure 2 shows the current target laser, the 250-J laser, which is large on the scale of existing lasers. The window that you see in front is approximately 10 inches in diameter, the white area here, which contains the gas lasing medium, is about 6 feet long and behind it there is another 40 feet of various electrical equipment, laser preamplifiers, oscillators, etc. The next step in the progression is shown in the 2-1/2-kJ CO_2 system currently undergoing electrical checkout in a converted reactor test building at Los Alamos. The driver stage preamplifiers are underneath the floor in a large pit originally used for testing reactors cores. This is a two-beam system, each beam approximately a foot in diameter, and the amplifier stages are 6 feet long. This module forms the basis for the 10-kJ CO_2 system shown in Fig. 4. By arranging four of the 2-1/2-J modules together we will obtain a 10-kJ, 1-ns target irradiation facility which should be operating in 1976. At this point, we have changed the design of the lasers and the next photograph shows an artist's conception of the high-energy gas laser facility, or 100-kJ system. You can see the increase in scale by observing the size of the man shown near the target chamber. Our first target chambers at LASL were approximately 4 inches in diameter--this one is almost 20 feet in diameter and is driven by 6 beams, each of which is 4 feet across. The status of the 100-kJ facility is shown in Table VI. It was authorized in 1975 at 22.6 million, and we are now near the end of the pre-title one design study which should provide us with firm cost estimates on the system. This study will be completed in April, and we should receive an updated cost estimate in May of '75. It appears there will be some cost increases which are the result of escalation only. Changes in design of the laser system and building to make the facility more economical have allowed us to hold the cost very near the original estimate; however, we did not receive the operating funds required to proceed on schedule so the effect of inflation is greater than anticipated. Preliminary laser design is in progress, and we are also operating an experimental program to determine which target designs will be useful for producing significant thermonuclear yield with this system.

TABLE VI

HIGH-ENERGY GAS LASER FACILITY

AUTHORIZED IN FY 75 AT $22.6 MILLION

PRE-TITLE I DESIGN STUDY - COMPLETE APRIL '75

UPDATED COST ESTIMATE - MAY '75
(COST INCREASES ARE RESULT OF ESCALATION ONLY)

PRELIMINARY LASER DESIGN - IN PROGRESS

EXPERIMENTAL PROGRAM TO ESTABLISH TARGET DESIGN - IN PROGRESS

I mentioned earlier that at Los Alamos we have done implosion experiments with glass lasers since October of 1973 and we believe we have measured compressions in targets formed of glass microballoons as early as November of '73. I would like to show you a typical firing sequence for this type of target and some of the results. Shown in Fig. 6 is what we call the Los Alamos ball-and-disc target. It consists of a glass microsphere about the size of the grain of sand, mounted on a plastic disc. The colors you see are a prism effect from a very thin plastic disc which is only a few hundred atomic diameters thick and is used to absorb and transport the energy down to the balloon. This tiny target which is almost invisible to the naked eye is mounted inside the target interaction chamber shown in Fig. 7. Clustered around this chamber in seeming disarray, but actually in careful alignment, are various detectors such as neutron detectors, x-ray detectors, pumping systems to provide the vacuum, alignment telescopes, television systems, etc. Within the darkened chamber (Fig. 8) there is a lens which focuses the two laser beams on the target, which is held in a thin metal foil. There is an x-ray pinhole camera shown here which photographs the x-ray emission from the target to measure the compression. Next (Fig. 9) we see a greatly magnified photograph of an actual experiment. The tiny ball-and-disc target, heated to temperatures of millions of degrees, appears as a white spot in the center of the thin metal target holder. The remainder of the light is produced by material expanding from the target. In the corner of the photograph one can see a shock wave generated by the collision of expanding target material with a diagnostic instrument. The results of such an experiment are shown in Fig. 10. The x-ray pinhole photograph is shown in the upper part of the figure. A weak implosion produces a smoke ring pattern in the photograph which has a diameter equal to the original diameter of the glass shell. A strong implosion produces a bright center when the material from the shell collapses and collides at very high velocity. If one scans these photographs with an instrument which measures the darkness on the film, we obtain curves such as this where the hole in the center is clearly visible at the right and the peak is visible in the photograph at the left. Data of this type have been taken since October 1973.

In summary, we are optimistic about the future of laser fusion, and the possibility of generating large thermonuclear yields from laser pellets. We believe that, within the program, we have a near optimum mixture of target theory and experiments, laser development, and advanced laser research. If the past is an indication of the future, we are optimistic about the possibility of developing economic lasers and about the possibility of new and exciting spinoffs from this program. We believe that the applications of laser fusion and its spinoffs to both civilian and military problems will be significant during the next decade. Laser fusion will not contribute to civilian energy requirements in the next two decades, but it may well be the most important source of energy in the following years.

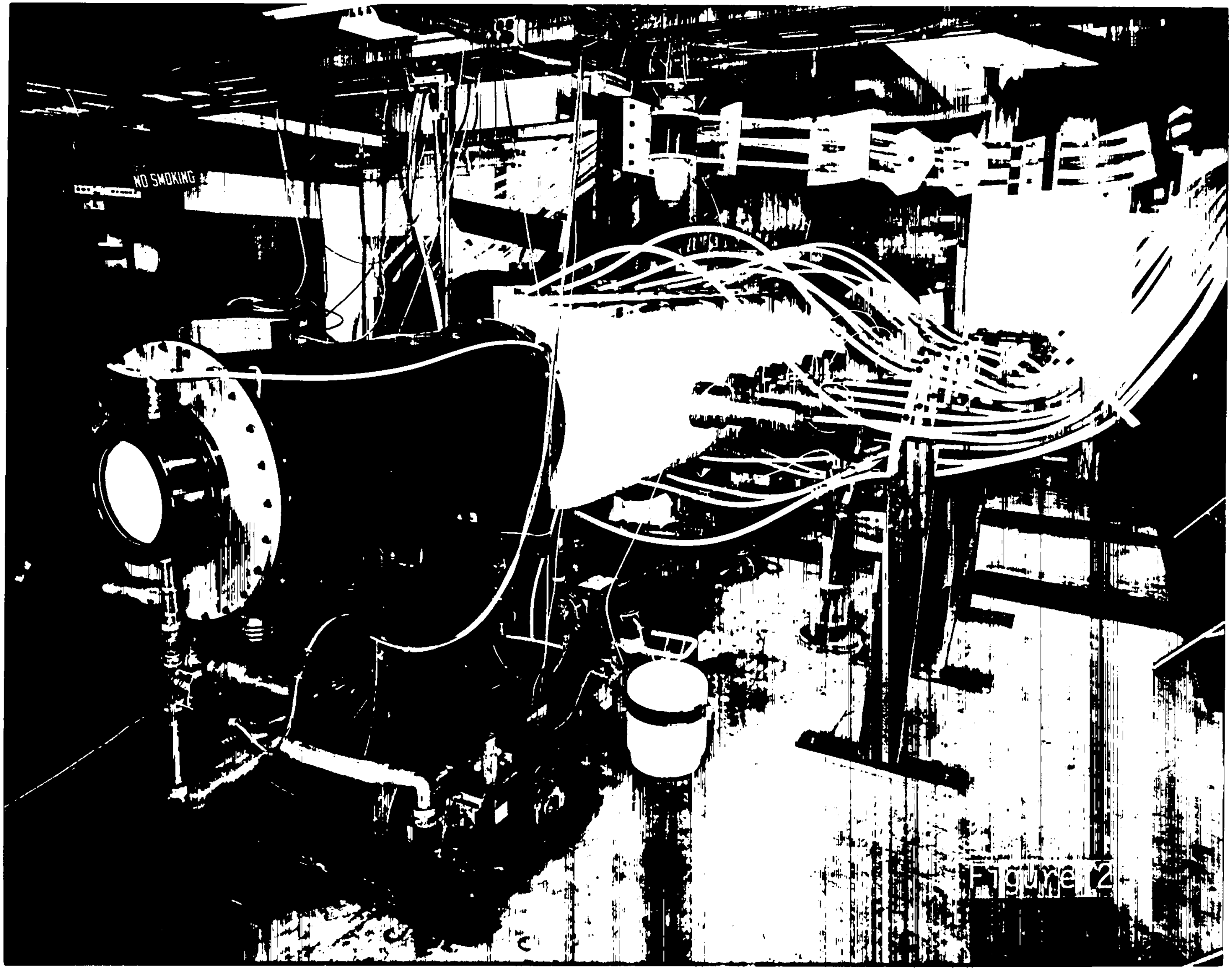
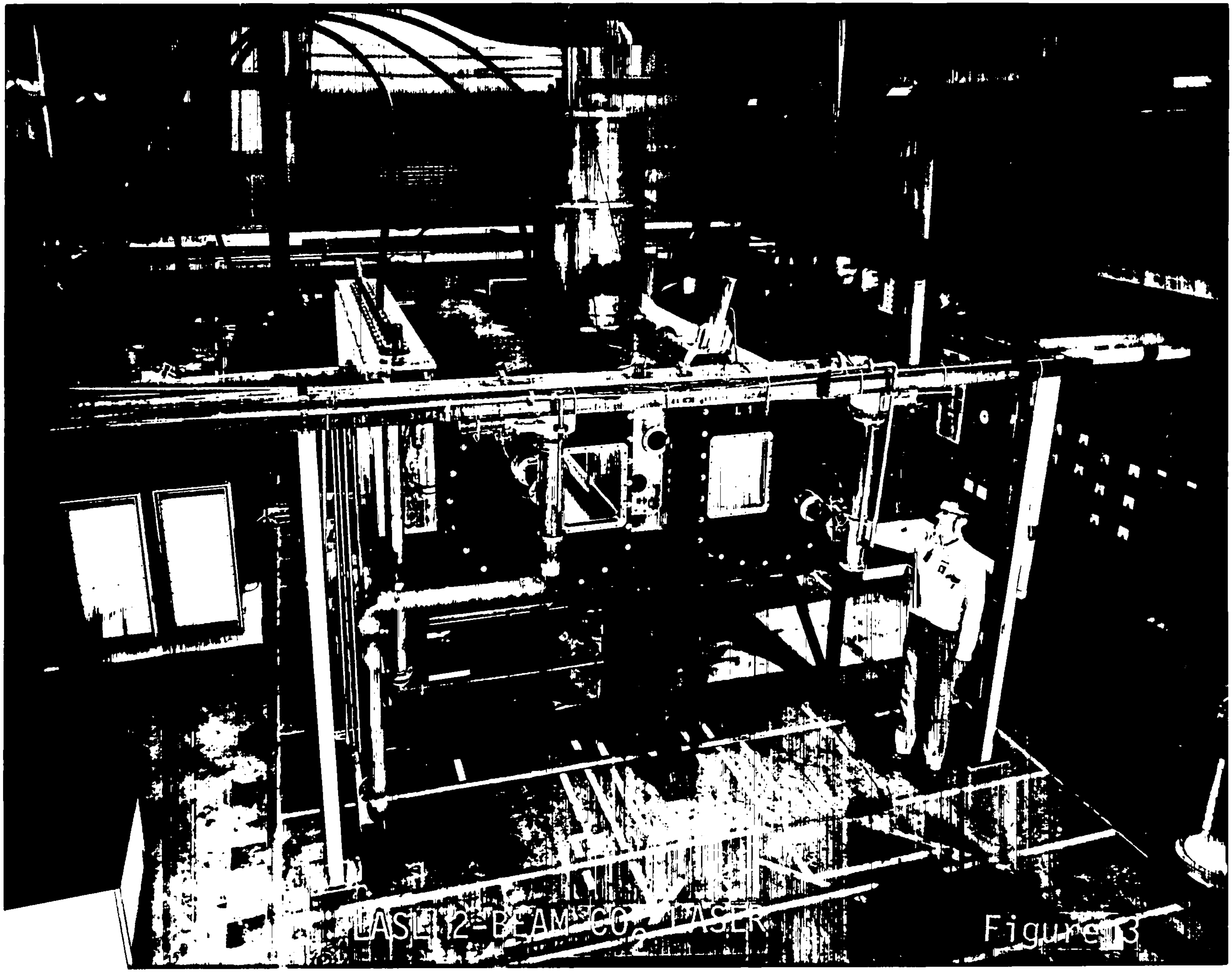


Figure 2

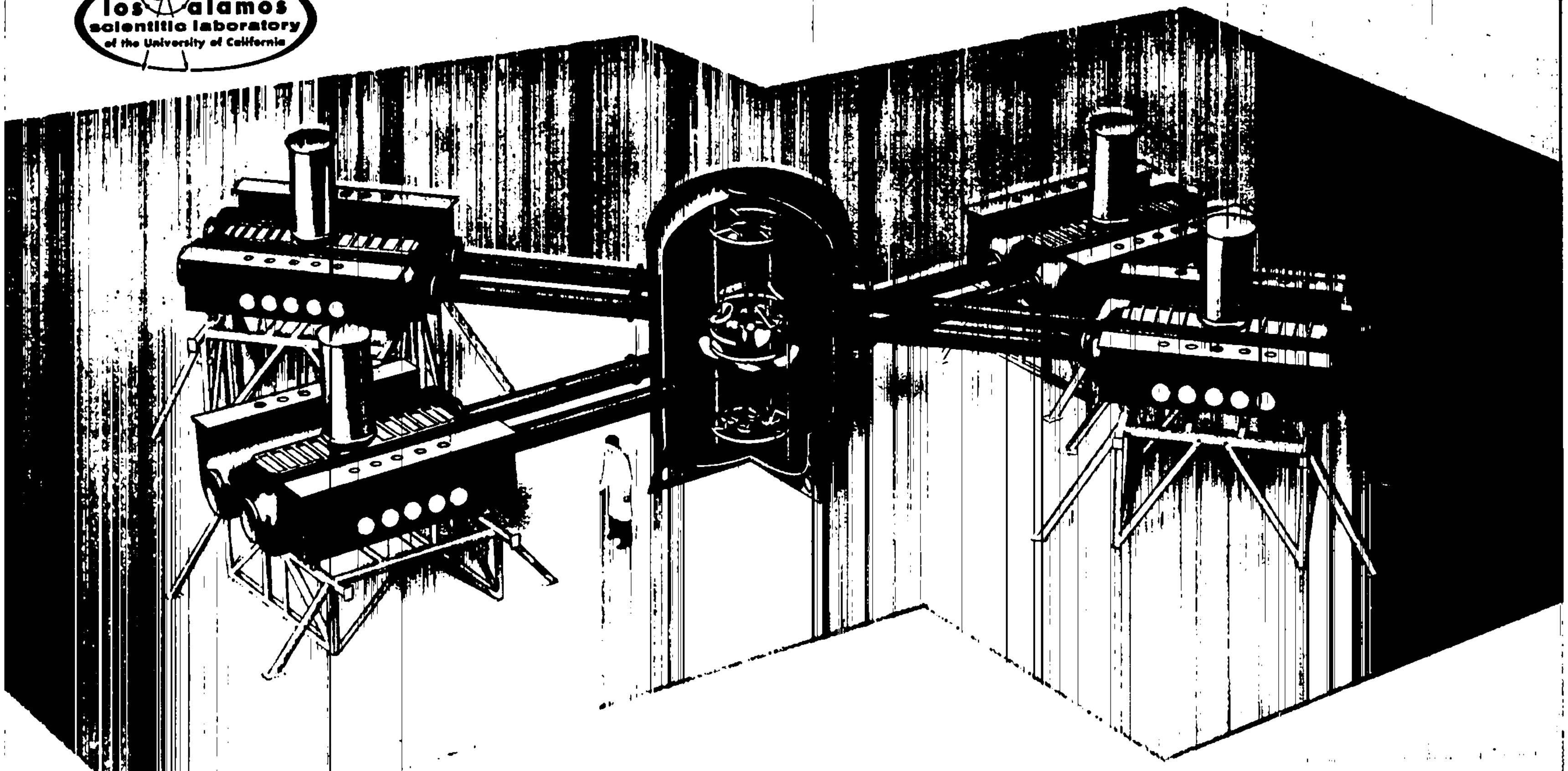


LASL 2-BEAM CO_2 LASER

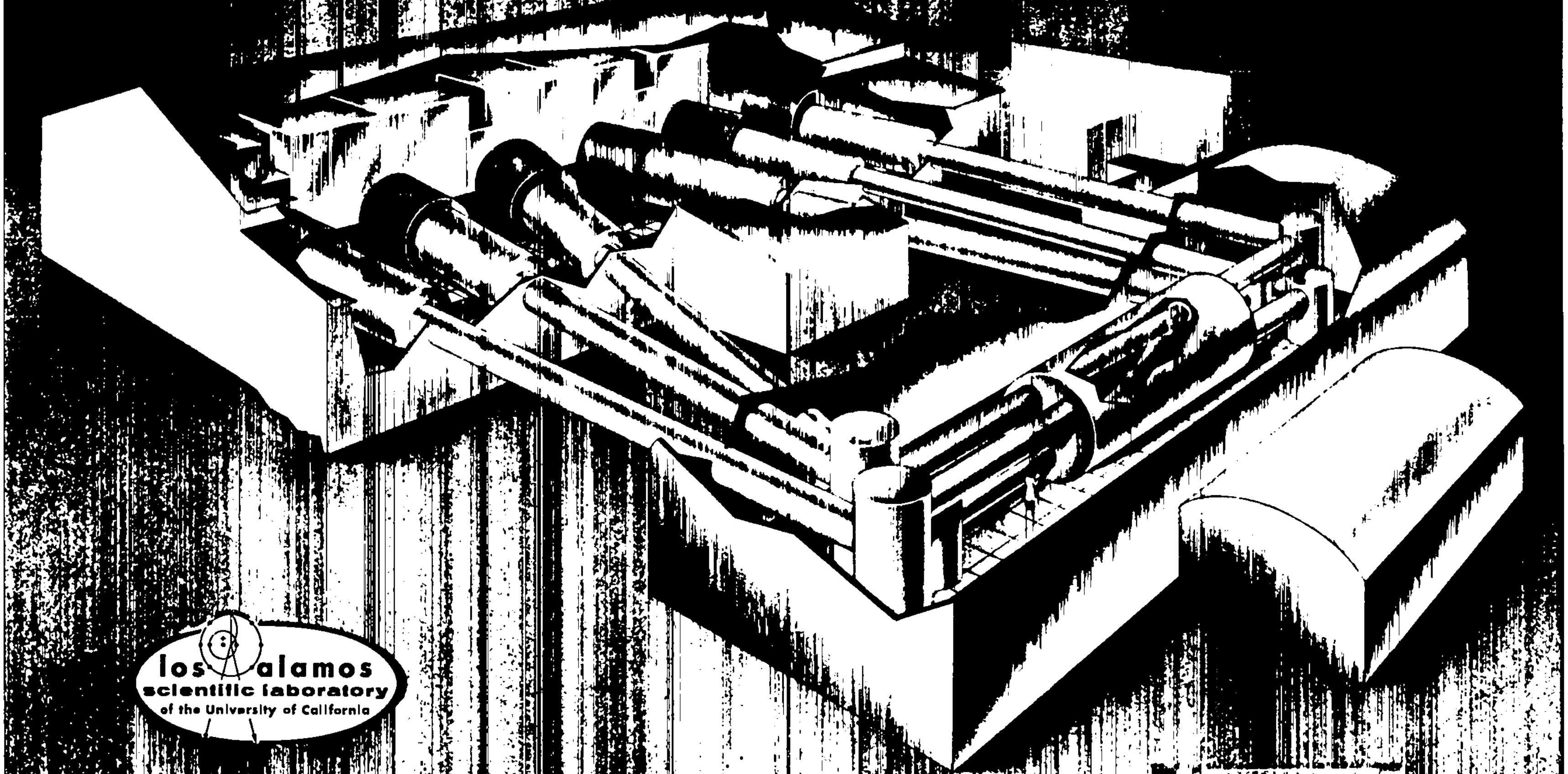
Figure 3

10 kJ 8-BEAM CO_2 LASER & TARGET CHAMBER

los alamos scientific laboratory
of the University of California



High Energy Gas Laser Facility



los alamos
scientific laboratory
of the University of California

Figure 5

Figure 6

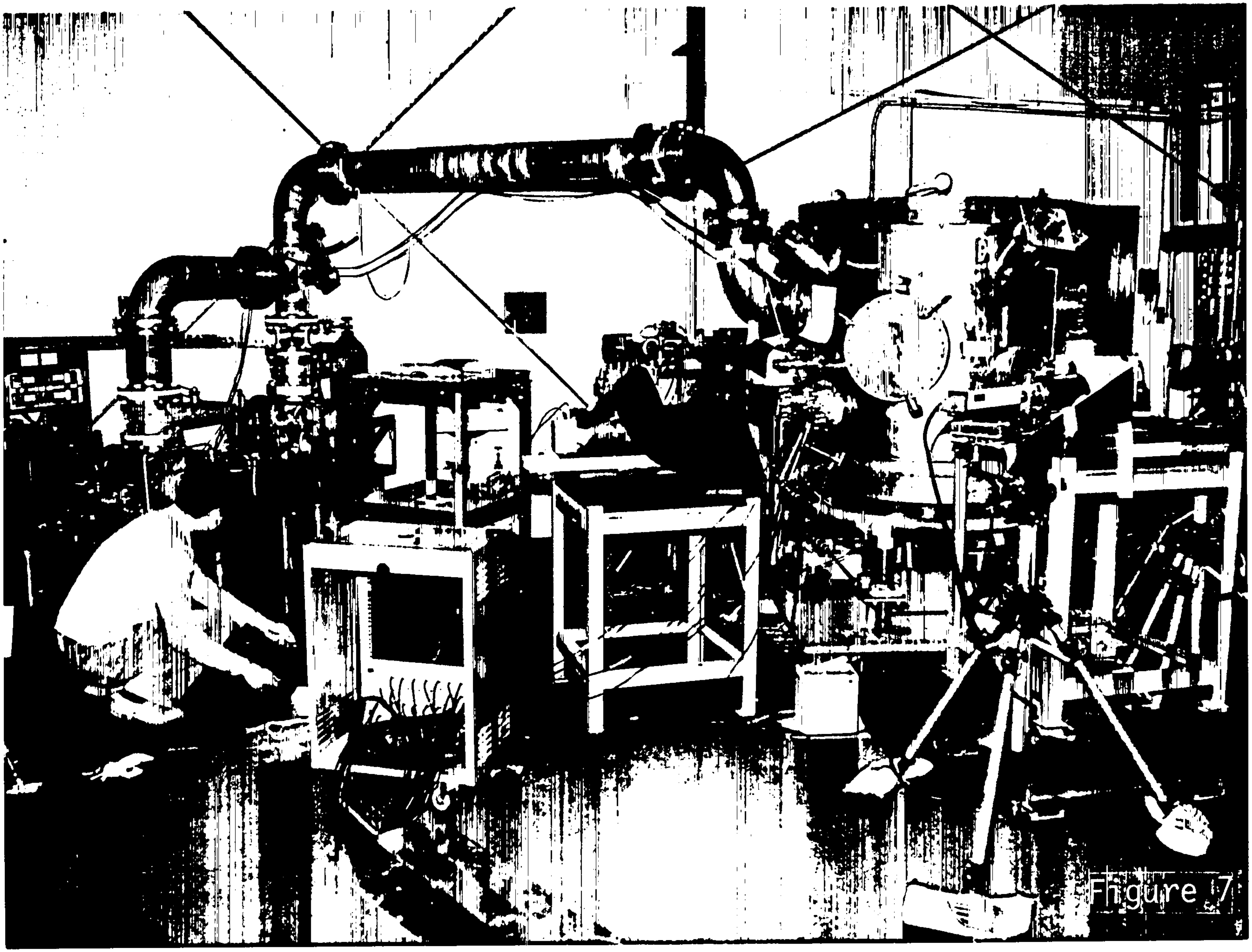
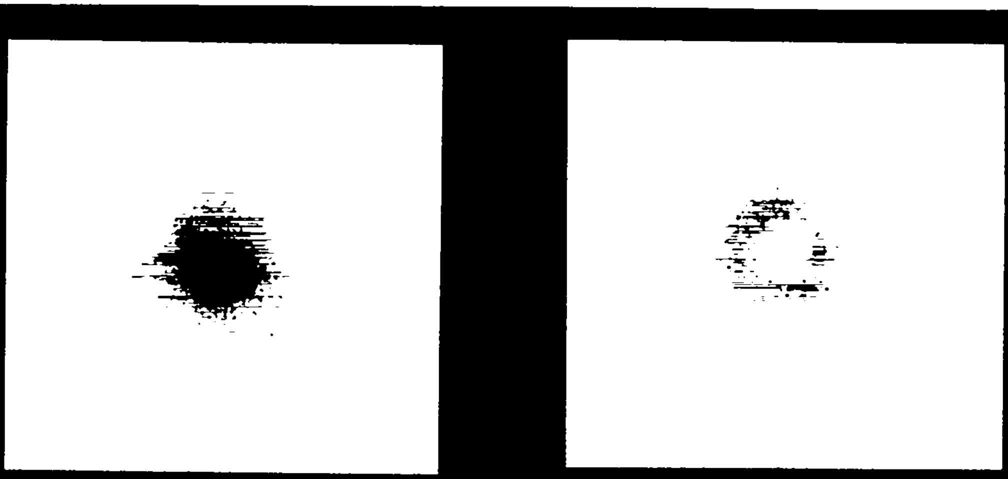


Figure 7

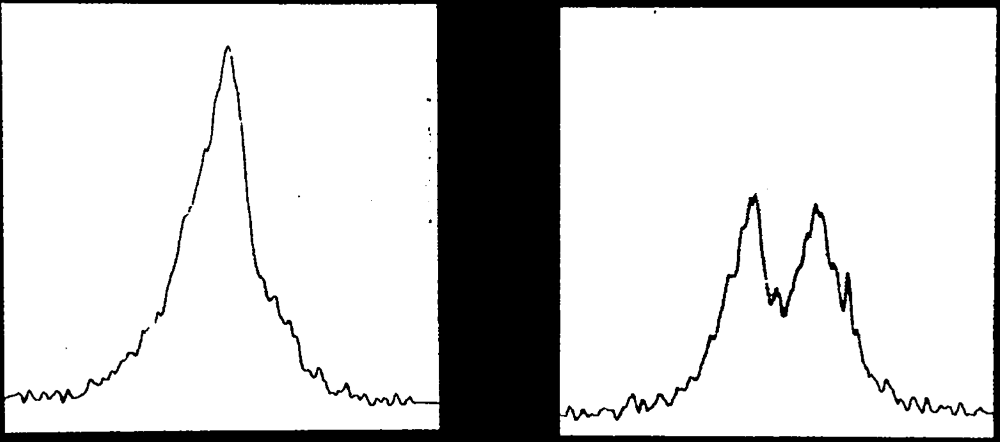
Figure 8

Figure 3



Strong implosion

Weak implosion



X-ray pinhole photograph of laser-driven implosions
Data obtained as early as Oct 1973

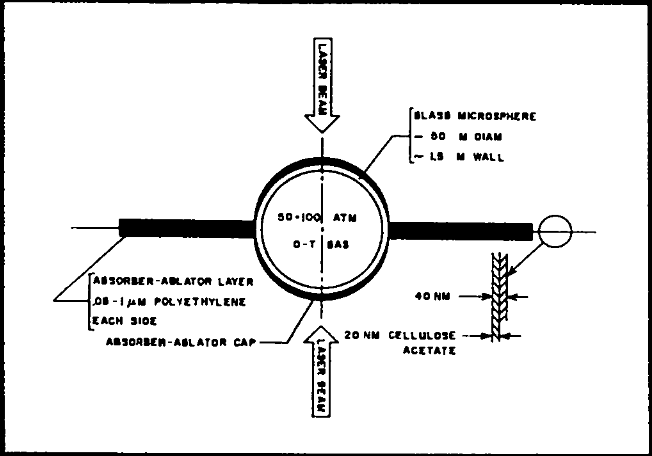


Figure 10