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Session }

LASER RESEARCH AND APPLICATIONS

Prepared at the Request of

Hon. Howard W. Cannon, *Chairman*

COMMITTEE ON COMMERCE,
SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

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LETTER OF TRANSMITTAL

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, D.C.

DEAR COLLEAGUE: Rule XXV, of the Standing Rules of the Senate, assigns to the Committee on Commerce, Science, and Transportation, jurisdiction over science, engineering, and technology research and development and policy. Inasmuch as the Committee does not have legislative jurisdiction over many of the departments and agencies in which science, engineering, and technology research and development are carried out and in which policies related thereto are formed, the Committee must carry out its responsibility under its oversight jurisdiction. The rule specifically states that the Committee shall study and review, on a comprehensive basis, all matters relating to science and technology.

Under this mandate, the Subcommittee on Science, Technology, and Space, chaired by the Senator from Illinois (Mr. Stevenson), late last year and early this year scheduled a number of hearings on laser technology—development and applications. These hearings were held at the initiative of the Senator from Alabama (Mr. Heflin) and were chaired by him, except for the field hearing in Albuquerque, N. Mex., chaired by the Senator from New Mexico (Mr. Schmitt). These hearings provide very valuable information about an enormously useful technology that came into being only 20 years ago. Many think it will revolutionize the fields of weaponry, energy, and chemistry.

Although this report, submitted by the Senator from Alabama, has been neither approved nor disapproved by the Committee, I believe you will find it an interesting and useful document on the rapidly developing field of laser technology and its applications.

With best wishes, I am,

Sincerely,

HOWARD W. CANNON, *Chairman.*

LETTER OF SUBMITTAL

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, D.C., September 9, 1980.

Hon. HOWARD W. CANNON,
Chairman, Committee on Commerce, Science, and Transportation,
U.S. Senate, Washington, D.C.

DEAR MR. CHAIRMAN: It is a privilege to submit to you this report on the laser hearings held in December 1979, and January 1980, by the Subcommittee on Science, Technology, and Space, which I chaired, through the courtesy of the subcommittee chairman, the Senator from Illinois, Mr. Stevenson.

During the hearings the subcommittee heard testimony from a broad spectrum of Government, industry, and academic witnesses on laser technology and applications, but the emphasis centered on high energy lasers. This report provides a summary of the hearings, makes findings, conclusions, and recommendations. In summary, lasers are one of the most important technologies to emerge in the latter part of this century. By the turn of the century, I expect lasers will have brought about great changes in the fields of chemistry, weaponry, and energy. It is a technology which the committee will want to continue to oversight closely.

The Federal Government is the principal sponsor of laser research for high energy applications, including military weapons, future energy production, and civilian space applications. Annual Federal funding for laser R. & D. exceeds $400 million. The programs reside primarily in the Departments of Defense and Energy; NASA funds about $6 million annually in laser research and applications. While progress to date has been impressive, there is, in my opinion, urgent need to improve the coordination of Federal laser R. & D. activities. At a future date I expect to make recommendations that will lead to improved coordination of laser research, technology, and applications in the executive branch.

I want to take this opportunity to thank the subcommittee chairman, Mr. Stevenson, for agreeing to these hearings and allowing me to chair them; to thank you, Mr. Chairman, and the ranking member, Mr. Packwood, for agreeing to the very useful field hearings; to thank the Senator from New Mexico, Mr. Schmitt, for chairing the Albuquerque hearings; and to thank the committee staff, Mr. James J. Gehrig, professional staff member, who oversaw the hearings and kept them moving smoothly, Mr. Wallace Kirkpatrick, who handled many of the details of the hearings and prepared the first draft of this report, Mr. Gerald Kovach and Mr. William Gibb of the minority staff, and Ms. Suzelle Smith of my personal staff who helped coordinate all of these activities.

Sincerely yours,

HOWELL HEFLIN, *U.S. Senator.*

LIST OF ACRONYMS

ABM—Antiballistic missile.
AIS—Advanced isotope separation.
ASAT—Antisatellite.
DARPA—Defense Advanced Research Projects Agency.
DOD—Department of Defense.
DOE—Department of Energy.
FDA—Food and Drug Administration.
HEW—Health, Education, and Welfare.
ICF—Inertial confinement fusion.
LANSL—Los Alamos National Scientific Laboratory (sometimes just LASL).
Laser—Light amplification by stimulated emission of radiation.
LIDAR—Light detection and ranging.
LLNL—Lawrence Livermore National Laboratory (sometimes just LLL).
NASA—National Aeronautics and Space Administration.
NATO—North Atlantic Treaty Organization.
NOVA—Name of high energy glass laser at LLNL.
OSD—Office of the Secretary of Defense.
OUSDRE—Office of the Under Secretary of Defense, Research and Engineering.
SHIVA—Prototype of NOVA laser.
TOW—Tube launched-optically tracked-wire guided (acronym for Army antitank missile).
UV—Ultraviolet.
WSMR—White Sands Missile Range.

PREFACE

The acronym "Laser" means "Light Amplification by Stimulated Emission of Radiation." The difference between laser light and light from normal sources in everyday use is as follows: normal light sources utilize random atomic processes in which each atom or molecule emits energy with little regard to the behavior of those atoms (or molecules) surrounding it. Conversely, lasers unify the atoms to emit their latent energy "in step" or "with high coherence." This is usually accomplished by a sort of "domino principle" in which an energy transition in the first atom stimulates transitions in many other atoms. The result is a cascading amplification of electromagnetic energy at a precise wavelength which can be made unidirectional by the use of very high precision mirrors. By using the correct lasant material between two mirrors and exciting it in the proper manner, a beam of radiation can be made to escape that has higher purity and greater intensity than any other radiation known to man.

The laser has three unique characteristics which set it apart from other sources of energy, and lead to every one of its many applications. In their simplest terms, these are:

- Pure color (frequency or wavelength)
- High brightness (intensify)
- Narrow beamwidth

The laser's pure color allows the production of a pencil-like beam of light which can travel for long distances without spreading very much. This is useful for long-distance communications, especially in space, and for many industrial applications such as surveying and distance measurement. One of the early experiments was the sending of a laser light beam to the Moon. In 1968, one of the unmanned Surveyor spacecraft on the surface of the Moon turned its TV camera to look back at Earth, where it easily picked up two argon laser light beams, one from California and one from Arizona. Subsequently, lasers have been used, along with reflectors left on the Moon by the astronauts, to learn more about the complex motions of the Moon and to measure precisely its distance from Earth.

The high brightness of the laser allows extreme concentration of the power of the laser. This characteristic is being used today in laser welding and cutting and in laser surgery. In principle, very high-power lasers offer great potential as military weapons.

In the early years, the laser seemed to be a solution in search of a problem—it seemed that everything the laser could do could be done better or more easily by some other device. Successful laser applications must use to advantage one or more of the three unique properties. Lasers now have become practical and affordable so that there are literally dozens of important applications some of which simply cannot be done by any other means. Selected examples of these applications are

discussed in this report; the hearing record elaborates on these and other applications.

Many approaches have been tried in the past 20 years to accomplish the generation of laser radiation, ranging from excitation of a small ruby rod in 1960 to very large, high power devices presently available. New classes of devices continue to be investigated to achieve higher power levels and other desirable characteristics such as frequency variability. Current research and development is directed to sharply improving performance and upgrading existing devices. Various classes or types of lasers are described in the record of the hearings.

Discussion of lasers usually is characterized by technical jargon which makes it difficult for the nontechnical person to understand the essential features of the technology and applications. This report omits as much of the technical jargon as possible. However, two fundamentally different concepts commonly used in generating and measuring power output levels are worthy of note. "Continuous" power output connotates a steady and sustained power level for seconds, minutes, hours, or weeks. The laser device is simply turned on and "runs" for extended periods. Conversely "pulsed" lasers run only at intervals, which may be very short, for only a small fraction of a second, typically measured in millionths of a second (microseconds) or billionths of a second (nanoseconds) but can do so at extremely high power, referred to as "instantaneous" power output. The SHIVA laser at Lawrence Livermore National Laboratory, for example, produces in one short duration pulse the equivalent amount of electrical power being produced in the entire United States at a given time—25 to 30 terawatts (25 to 30 trillion watts). It, therefore, is important to distinguish the mode of operation when considering the power output levels required for various applications.

The energy delivered by a laser is an important quality to consider in many applications; and is the product of the power delivered times the duration of operation. Hence, the huge peak power of the SHIVA laser delivers relatively modest amounts of total energy because of the short pulse duration and the relatively long time between pulses. A laser running continuously at 10 megawatts will deliver very large amounts of total energy in few seconds.

Laser devices are characterized as low-power or high-power depending upon the amount of power they emit in the beam, commonly referred to as a power output level. The DOD guide is a typical standard: low-power devices emit less than 20 kilowatt of power. Illustrative uses of low-power devices include scanners at retail stores, light shows, measuring and surveying instruments, designators for smart bombs, laser gyroscopes of guidance and navigation, etc. High-power devices emit more than 20 kilowatts of power (although this definition is not universal); they are used for industrial processes such as welding, heat treatment, metal cutting, power-beaming, directed energy weapons, and fusion. Current state of the art for high-power lasers extends beyond the 200 kilowatt level where DOD classification prevents open discussion. Some of the DOD applications, such as directed energy weapons, potentially require power output levels ranging from megawatts to gigawatts in short pulses. Thermonuclear fusion require

terawatt outputs. Interlocking two or more laser devices is possible to achieve the higher output power levels. Laser "weapons" are referred to as high-energy—rather than high-power—devices, because the total amount of energy deposited on the "target" is the paramount requirement.

Laser "systems," particularly high-power ones, generally include three classes of difficult technology: the laser device, the mirrors to focus the energy, and precise pointing and tracking to hold the beam on the desired target. The mirrors must be highly polished to reflect virtually all of the laser energy; excessive absorption of the energy produces heat and destroys the mirrors. The pointing and tracking accuracy is extremely demanding. Directed energy weapons, for example, require accuracy comparable to pointing a spotlight from Washington, D.C., on to a 2-foot target over Los Angeles. Correction for atmospheric effects on the beam is required through the use of adaptive optics with dynamic focus capability.

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EXECUTIVE SUMMARY

Invention of the laser device ranks among the most important discoveries of this century, potentially rivaling in the 21st century the significance of the atom bomb and discovery of integrated circuits. Development of directed energy weapons—the principal application of which is defense against offensive nuclear weapons—might move the superpowers into a postnuclear era and offers the potential to effect a dramatic shift in strategic military posture. Development of fusion energy, for which laser technology offers promise rivaling magnetic confinement, will provide an inexhaustible supply of electricity without the adverse externalities associated with conventional nuclear and coal power generation. Laser-fiber optics wideband communications technology is destined to provide home and office "communications centers"; uses will include voice, video, data and facsimile information retrieval, and recreation patterns of work, education, entertainment, travel, banking, shopping, and other interactive activities will change. Laser technology seems certain to revolutionize chemistry, facilitating chemical compositions and decompositions which heretofore have been either prohibitively expensive or impossible. The technology shows considerable promise in potential civilian space applications, such as remote sensing of the Earth and its environment, power transmission, and space vehicle propulsion.

Summary of the Hearings

COMMERCE

The laser market will reach $1 billion in 1980; about 58 percent of the sales will be to the Federal Government with the remaining 42 percent representing the commercial market. Two-thirds of the market will be for hardware and one-third for research and development. The 1980 market projections represent sales of 100,000 lasers, increasing the world total to more than 400,000 and the United States total to 330,000.

The laser market is dominated by small business firms. There are 46 manufacturers of laser devices and 257 firms which manufacture products containing lasers. There are 34 foreign manufacturers of laser products. Foreign competition is increasing. The present trend is the foreign purchase of U.S. manufactured laser devices which are embedded in laser products, some of which are exported to the United States.

The small business firms typically create and market new devices in 2 to 3 years, about half the time required by larger firms. The small and fragmented market and the comparatively low return on investment, typically 4–5 percent, generally have not attracted the larger firms.

Commercial applications of laser systems include communications and information handling; surveying, measuring and alinement; surveillance; industrial processes such as metal treatment and cutting; medical and surgical; entertainment; and checkout scanners at retail outlets.

CIVILIAN SPACE APPLICATIONS

The National Aeronautics and Space Administration (NASA) has a distinguished record of impressive technology development and applications, but important opportunities to develop and apply laser technology to provide improved space system capabilities to enhance our understanding of the Earth and its resources and environment for the benefit of mankind need to be exploited more fully. The NASA testimony described an interesting menu of current and potential research and applications, but the budget allocation of $6 million is more indicative of the NASA support for laser technology development and applications. NASA's limited efforts on laser technology could be substantiated by numerous examples. In the interest of brievity, only two examples will be cited.

The unique characteristics of lasers permit precise, global, and near realtime measurements of Earth motion and crust movement around fault lines from which earthquakes eminate. These data are important to earthquake prediction research; but NASA has not yet used satellite-based laser measurements to collect this important data. Laser propulsion of space vehicles appear extremely promising, but NASA has not funded adequately such technology.

The aggressive pursuit of laser research—analagous to the basic aeronautical research program for aviation—would be fully justified; exploitation of the technology developed by Department of Defense (DOD), Department of Energy (DOE), and industry should be the minimum acceptable NASA role.

DEPARTMENT OF ENERGY

Energy is a defense as well as a civilian issue. The DOE is pursuing, under its military applications program, laser research and applications programs focused toward two major objectives: inertial confinement fusion and advanced isotope separation.

Fusion

The two principal approaches to achieving fusion are magnetic confinement and inertial confinement (ICF). Only the laser program is discussed in this report. Two laser programs support ICF; one program focuses on achieving fusion, the other on the laser beam/fuel pellet interaction phenomena.

The inertial confinement fusion program offers potential near-term military applications and is also a long-term energy option based on virtually inexhaustible fuel—the heavier isotopes of hydrogen called deuterium and tritium. Conceptually, very small fuel pellets are irradiated by laser beams to cause compression and heating of the fuel so that large amounts of energy are released by nuclear fusion. The large energy yields thus obtained could be used to study the physics of

nuclear explosions. In the longer term, energy reactors based on efficient, rapidly pulsed laser beams imploding hydrogen fuel pellets could generate electricity. The current state of technology requires more energy to induce fusion than is produced when fusion is achieved, but theoretical predictions indicate acceptable efficiencies as the technology progresses. "Scientific breakeven," the point at which the energy output from fusion equals the energy required to induce fusion, appears to be achievable by the mid-to late 1980's. The NOVA program, which sought "scientific breakeven" performance, was authorized by the Congress in fiscal year 1979; construction was begun with completion scheduled in 1983, but funding to continue the program was "delayed" by the Carter administration in the January 1980 budget submission. Future plans for continuation of the NOVA program and a revised schedule for completion, are under review; the future of the program is uncertain.

Advanced isotope separation

The objective of the advanced isotope separation (AIS) program is to develop a new low-cost technology to provide an economical means to recover uranium-235 from the residues (tails) generated by the current gaseous diffusion and planned gas centrifuge uranium enrichment plants. Two laser methods and a plasma separation technique are under study for isotope separation. One of the three processes will be selected for engineering scaleup to a Development Module at the end of fiscal year 1981; pilot plant and the first production facility would follow in sequential development-phases.

Only the two laser approaches to isotope separation, molecular and atomic vapor, are discussed in this report. Two types of lasers are being investigated for each process. Should a laser process be selected for the Development Module, the laser issues to be resolved at that time would be lifetime demonstration, reliability, and total system cost. Laser uranium enrichment by isotope separation could be available in the early 1990's. There are options for earlier availability, but the options would require increased upfront funding.

NATIONAL DEFENSE

Low-power laser program (less than 20 KW power output)

The laser was invented as a laboratory device in 1960. The first military laser rangefinder was demonstrated in 1962; the first operational rangefinder was fielded in 1969. The Thanh-Hoa Bridge in Vietnam was completely destroyed in 1972 via a laser-designated bomb, after repeated attempts with ordinary bombs failed to eliminate the bridge at a cost of over 100 aircraft damaged or lost.

The unique properties of the laser have been exploited to provide the modern military force with combat capabilities which existed only in thought just a few years ago. Current and proposed laser devices will revolutionize the way battles are fought. Current military applications include: Fire control and weapons guidance; laser surveillance radar: information transfer and communications training aids; remote line of sight meteorology; chemical, biological agent, and exhaust detection; data processing and holography; materials processing; and optical countermeasures.

According to DOD testimony, the low-power laser development has been the single most successful DOD investment in the last decade. U.S. military fighting capability has been increased an order of magnitude by low energy laser systems.

Laser applications on the horizon will draw heavily from improved understanding of materials through laser spectroscopy, creation of new material properties by rapid melt-cooldown processes, and use of isotope separation for the production of ultra-pure materials (e.g., high resistivity silicon). Applications taking advantage of nonlinear optical processes also appear highly promising.

High-energy laser program (power output greater than 20 KW)

High-energy lasers offer the potential for directed energy weapons in which hostile targets are disabled or "killed" by the energy in the laser beam. The beam can be "pulsed" or "continuous" and travels at the speed of light. Such systems require three stressing technology components: Very high power laser devices; precision mirrors/optics; and precise pointing and tracking. The weapons systems also would require sophisticated fire control technology for battle management.

As a frame of reference, DOD expenditures to date for high-energy research and applications exceed $1.4 billion; at least an additional $.5 to $1 billion may be required before directed energy weapons are shown to be technologically feasible for the most difficult application: defense against intercontinental-range ballistic missiles. Each of the three military departments and the Defense Advanced Projects Agency (DARPA) conduct high-energy laser research and application programs. Fiscal year 1980 funding is: Air Force $101.2 million, Navy, $40.8 million, Army $20.5 million, and DARPA $48.3 million, for a total DOD budget of $210.8 million.

FINDINGS AND RECOMMENDATIONS

The most significant findings and recommendations relate to the need for improved coordination of the federally sponsored high-energy laser activities, and improvements in the DOD high-energy laser program.

In contrast to low-power laser systems which are operational in the three services, the high-energy laser technology is in an embryonic state. Current research focuses on laboratory developments and technology experiments.

While the testimony of most witnesses supports the view that the potential of laser devices in the next two decades is staggering, it should be acknowledged that there is a diversity of opinion in the scientific community (and among senior managers in DOD) about the achievability and significance of high-energy laser systems—and whether the greatest potential lies with ground-based or space-based systems.

The potential of high-energy laser technology to alter the strategic balance between the United States and the Soviet Union presently is unique. Decisions by the Government on the development of high-energy laser technology and weapons systems will make a dramatic difference in the emerging tactical and strategic balance. The revolution-

ary nature, dramatic potential military impact, and embryonic state of the technology require "special" management attention in the DOD.

Current DOD strategy for the development of high-energy lasers is one of moderately paced technology development and excludes weapon system development. This strategy is based, in part, on a conclusion that it is premature for high-energy laser weapon system development programs. There is a feeling that the Soviets are moving prematurely into such weapons development. However, little evidence was found to support such an important conclusion. According to the testimony, the Soviets are outspending the United States by 3 to 5 times in the field of high-energy lasers and may have begun the development of operational weapons systems.

Current experimental laser devices and associated technology appear to be approaching levels of maturity to support some potential near-term applications, such as antisensor systems, and appear to be scalable to support other potential applications such as antisatellite and low-altitude air defense for ships and ground-based targets. Much additional research and experimentation must be done to support the most difficult applications, such as defense against tactical, submarine-launched, and intercontinental-range ballistic missiles.

The DOD high-energy laser budget is spread among four separate organizations: DARPA, the Air Force, Navy, and the Army. While there is coordination among the programs, each program is directed toward technology objectives of primary or unique interest to the sponsoring organization. The individual funding levels do not permit the accumulation of the critical mass funding necessary to undertake weapon system development. There is a compelling need to revise the DOD high-energy laser research and development planning and funding to achieve a balance between technology development and weapon system development. Achievement of this objective could be enhanced by the Secretary of Defense designating an office in the Office of the Deputy Under Secretary for Research and Engineering to manage and direct the overall DOD high-energy laser program.

The Federal Government is the principal sponsor of high-energy laser research in most areas, including military weapons, future energy production, and civilian space applications. Annual Federal funding for laser R&D exceeds $400 million with the programs residing primarily in the Departments of Defense and Energy; NASA funds about $6 million annually. While progress to date has been made, there is a need to improve coordination of the overall Federal laser R&D activities.

There is a need to improve the coordination of the high-power laser programs among the various departments and agencies of the Federal Government. Improved coordination would increase the effectiveness of the separate departmental and agency laser programs, thus increasing efficiency and effectiveness of the overall Federal effort. It is recommended that institutional mechanisms be established to improve coordination. Various means to improve coordination of Federal laser R&D are being assessed; and recommendations will be made in the near future to achieve that result.

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INTRODUCTION

The Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation held 4 days of oversight hearings on the status of laser research and applications. With the concurrence of the Chairman, Senator Howell Heflin chaired hearings in Washington, D.C., on December 12 and 14, 1979, and a field hearing in Huntsville, Ala., on January 8, 1980. Senator Harrison Schmitt chaired a field hearing in Albuquerque, N. Mex., on January 12, 1980.

The hearings were held in both open and closed sessions; the closed hearings dealt with national security matters.

The field hearings provided the opportunity to hear firsthand reports from the scientists and senior managers in the organizations conducting laser research and applications, and to visit the laboratories and test ranges where the research and testing are conducted.

The purpose of these hearings was to provide a broad overview of this highly diverse and rapidly developing technology. Oversight hearings were important and timely for several reasons. First, laser technology offers unusually high potential for national security, future energy production, and civilian space applications. Second, the Federal Government is the principal sponsor of laser research and technology applications; Federal funding for research and applications since invention of the first lasing device in 1960 exceeds $2.46 billion; sustained or even higher Federal funding levels are predictable in the future. Third, the Federal funding is spread among various departments and agencies of the Federal Government. The principal programs exist in DOD, DOE, and NASA; small additional amounts are contained in the budgets of other organizations. There is some synergism among the departmental research and applications programs, but there is no formal coordination and integration mechanism at the Federal level. Program formulation and budget allocation are decentralized and focus on narrowly defined "mission" responsibilities. Fourth, there are unusually strong and highly diverse views within the scientific community (and within the Federal Government) about the potential of high-energy lasers, the time when potential applications could be achieved, the areas which should be emphasized, and appropriate Federal funding levels. The greatest diversity of opinion relates to the potential military applications.

The focus of the hearings was on laser research and technology applications. The subcommittee sought a "benchmark" on laser research and technology, the extent to which the technology currently is "in use" in industry and government, an understanding of the most promising potential applications, the research and technology development

necessary to achieve future applications, whether additional Federal funding is necessary, and if so, at what level.

Witnesses represented a cross section of Federal organizations, industry, nonprofit, and academic institutions actively engaged in laser work. The witnesses also represented the spectrum from creative and visionary thinkers to the developers of military and commercial hardware. The complete witness list is printed in the appendix.

The invention of the laser in 1960 represented a significant breakthrough which was widely hailed throughout the world. Laser technology includes the inherent advantage of transmission at the speed of light, concentration of energy in a highly focused, low cross-section beam, and purity of color which were heretofore possible only in the visions of science fiction writers. Applications of low-power lasers are already known to the general public. These include such diverse items as checkout code readers in retail stores, surveying and measuring instruments, fiber optics communication systems, surgical devices, and target designators for defense. Lasers represent a billion dollar annual market in the United States.

While the technology has found an impressive range of important applications to date, current research offers potential opportunities which we have only begun to grasp. Military applications of high-energy laser weapons may include the potential for disabling or instantaneous "kill" of hostile targets such as satellites, tactical and strategic aircraft, and ballistic missiles. The military implications of such technology are profound and have the potential to effect a dramatic shift in the national security posture of the superpowers. There also are compelling opportunities to use laser technology in important peaceful applications, including:

1. Remote sensing from space to monitor the Earth's atmosphere, oceans, and land masses to improve our abilities to predict and modify weather and predict earthquakes, find scarce mineral resources and measure pollution;
2. Terresterial wideband communications which will revolutionize the industry and produce dramatic impacts on society;
3. Space-based communications with very high data rates over interplanetary distances;
4. Photochemistry;
5. Power beaming of electrical power from convenient powerplant locations to remote users; energy transmission could include space to space, space to ground, and ground to space;
6. Space vehicle and conventional jet aircraft propulsion; and
7. Isotope separation and thermonuclear fusion to improve generation of electrical power.

All of these applications appear to be feasible; no physical principles have been identified which would prevent the applications. But it should be emphasized that considerable research and development is necessary to underpin technical and economic feasibility.

SUMMARY OF HEARINGS

The testimony presented an overview of laser technology, a survey of current and potential industrial, civilian space and military applications, a summary of ongoing research and future research opportunities, and identification of a variety of potential future applications, some of which will be technologically feasible within a year or 2 and others which may not be technologically feasible before the 21st century.

This summary is organized under the headings of Health and Safety, Commerce, Civilian Space (NASA), Energy, and National Defense. However, the synergistic characteristics of laser technology should be borne in mind. Department of Energy laser research, for example, focuses on military nuclear weapons-related issues, but also contributes to important civilian energy applications and the general technology base; numerous applications evolve from that base.

Health and Safety

Laser beams contain high concentrations of radiated energy, which offer a variety of potential health and safety hazards to human subjects. Commercial and industrial laser systems are regulated under the Radiation Control for Health and Safety Act of 1968. The provisions of the act give the Secretary of the Department of Health and Human Services (DHHS) the authority to establish and carry out an electronic product radiation control program, including the establishment and enforcement of performance standards for electronic products.

Laser devices and systems are covered by regulations issued by the Bureau of Radiological Health, Food and Drug Administration (FDA) of DHHS which is responsible for carrying out the mandate of the act. Discussions between committee staff and FDA regulatory personnel and between staff and representatives of Government and industry revealed general satisfaction with current standards and procedures.

Commerce

Testimony indicated that the laser market will grow to $1 billion in sales in 1980; about 58 percent of the sales will be to the Federal Government with the remaining 42 percent representing the commercial market. Of the $1 billion in sales, two-thirds, $654 million, will be for hardware; the remaining $348 million will be for research and development. The spread between hardware and R. & D. will widen in the future.

The 1980 market projections represent sales of 100,000 lasers, increasing the world total to more than 400,000 and the U.S. total to 330,000. The United States currently dominates the international market, but foreign competition is increasing. A developing international

trend is the purchase of U.S. manufactured lasers by foreign firms which build them into commercial products, some of which are then exported back to the United States.

The laser market is dominated by small business firms. No laser company has broken into Fortune magazine's list of the 1,000 largest corporations, except for the Hughes Aircraft Co. Hughes is a major manufacturer of lasers, but the laser sales constitute only a small fraction of the company's total sales. The pacesetters in laser manufacturing are younger, smaller companies, faster to react to technological developments and needs, and willing to accept sales levels that are too low to attract the larger corporations. The industry realizes about a 4-percent return on investment; the rate of return is expected to increase to 5 percent in 1980. These smaller companies create and produce reliable laser products in 2 to 3 years—about half the time required for larger companies to produce and market new products.

The commercial applications of laser systems has a well-established trend; future applications are expected to continue to increase at a steady rate. Growth will occur in two ways. First, utilization of laser systems will expand in areas of present applications such as checkout scanners at retail outlets; measuring and alinement systems in surveying and construction; industrial processes such as welding, metal cutting, and heat treatment; and medical care. Second, new technology will provide more "flexible" systems and new applications in fields which have not yet been penetrated. Laser applications to photochemistry, for example, currently is undergoing extensive laboratory experimentation and is expected to move rapidly to the commercial market. Indeed, lasers offer the potential to "revolutionize" photochemistry by making possible new chemical processes which heretofore have been either impossible or prohibitively expensive. Laser technology permits the chemical separation of small and discrete elements of matter, or conversely the "mixing" of such small amounts of matter, to form an almost endless flow of new chemical compounds and products. This application of laser technology is expected to have a profound impact on markets and society.

The communications market also is worthy of explicit note. This market structure is characterized by "in-house" R. & D. and sales, and data on the market is generally not included in the industry data summarized above.

Laser/fiber optics communications systems, hereinafter referred to as "fiber optics" systems, have begun to enter the commercial market as "standard" systems. The rate of adoption will be governed primarily by growth in market demand, but current projections envision substantial domestic and international markets by the end of the decade.

High performance digital system transmission rates have been demonstrated in commercial service systems, carrying a full range of voice, data, and video traffic. There were no service interruptions attributable to lightwave components and standard system error requirements were met. A standard commercial fiber optics system was used for both voice circuits and television service during the Winter Olympic games at Lake Placid, N.Y., in 1980.

The increased capacity and efficiency of fiber optics wide bandwidth communications system offer affordable business and residential

"communications centers;" uses will include voice, video, data, and facsimile for communications, entertainment, information retrieval, education, games, shopping, and other interactive services. Adoption of fiber optics technology for terrestrial wide-band width telecommunications will have a profound impact on society, the economy, and industry. Business and home optical fiber communications "centers" are expected to produce significant changes in basic societal patterns and life style: shopping, acquisition and use of information, banking, work patterns, travel, and entertainment, to mention only a few examples.

There is the potential for a significant fiber optics export market for the United States. Applications are expected to emerge overseas at a rate closely parallel to that in the United States. Projections of the total optical communications market in Europe, Japan, and Canada approach $1 billion by the end of this decade. If the United States maintains its technology edge in this competitive arena, there will undoubtedly be attractive opportunities for export of optical communication systems, fiber cable, and components such as laser devices, detectors, and terminals.

Civilian Space

The National Aeronautics and Space Administration uses and is studying the application of some advanced laser technology in its programs. For fiscal year 1980 total funding is about $6 million and about 60 inhouse research personnel at 6 NASA centers are engaged in research and development. The funds include support of studies at 14 universities throughout the country. Two major laser technology thrusts are pursued by NASA. Information technology, generally involving relatively low average power devices, seeks improved capabilities in ranging, remote sensing, communications, and data handling. In energy technology, which is concerned with high average power devices, the objective is to establish basic feasibility of concepts and devices for the generation of continuous high-power laser beams in space and for the conversion of laser light energy into electrical or propulsion energy at a receiver.

INFORMATION TECHNOLOGY

Laser systems can be used in passive and active modes for the remote sensing of characteristics of the Earth and other planets. In one passive mode, a sensitive laser receiver detects sunlight that is not absorbed by chemical species of interest, thus identifying its presence or absence. This technique is called absorption spectroscopy. In this case, small solid-state lasers operating in the micrometer wave range are used in a receiver to enable detection of this incoming radiation with very high sensitivity. Quantities of gases in a few parts per billion level have been detected by this method. NASA's current program includes the development of a laser system with a 1982 scheduled aircraft flight test. This has direct applicability to pollution monitoring.

In another passive technique, a new generation of submillimeter wave lasers is being investigated for use in receivers capable of detecting and measuring chemicals which are identified by the radiation they emit naturally. This new technology is independent of the space-

craft's position relative to the Sun. It will thus permit broader coverage of the Earth's atmosphere. This new measurement capability is expected to have a major impact on the atmospheric sciences, meteorology, and climatology.

An active laser ranging system permits precise measurements over great distances. A laser ranger transmits a short pulse of very intense radiation and measures the round-trip transit time of this pulse between the transmitter and a reflector target. Motivation for developing a very accurate laser ranging instrument was supplied by the geodynamics community for the detection and measurement of the motion of the Earth's crust to 1–3 centimeter per year accuracy and the utilization of this data in the development of predictive models for earthquakes. Laser ranging systems are uniquely suited to the measurement of these small crustal motions, and when operated from a space platform, can provide near real-time global data on seismically active regions. Such a system has application for studying the dynamic changes in the polar ice caps and their relationship to atmospheric processes. It is also being considered for highly accurate high spatial resolution terrain profiling and could possibly be used to predict geodynamic activity in the vicinity of nuclear powerplants. The laser ranging system can also provide high spatial resolution altimetry data to calibrate and complement microwave system data. NASA plans to flight test a laser ranging system on both aircraft and the Space Shuttle in the 1982–83 time period.

In another active mode called Light Intensification, Detection, and Ranging (LIDAR), small areas of a surface or atmosphere can be illuminated by the laser and the resulting reflected radiation can be detected on an aircraft or spacecraft receiver. This is particularly suitable for 24-hour per day monitoring, and where planets receive inadequate solar flux, for illuminating surfaces or exciting atmospheric species. A tunable carbon dioxide laser transmitter has been developed and is being miniaturized and made flight ready. The laser receiver has been demonstrated in the laboratory. Flight experiments are planned in the 1985–86 time frame.

Present lasers that emit in the visible and infrared parts of the spectum have widespread use. New uses could be evolved if lasers in the ultraviolet (UV) spectral range were available. NASA is developing a series of UV gas lasers that will have applications in laser spectroscopy for planetary atmospheres. These will provide the capability to better penetrate those atmospheres and selectively excite chemicals of interest. (Ultraviolet lasers also are being investigated by the DOE for isotope separation.)

Semiconductor lasers that operate at room temperature are being developed as optical sources for extremely high data rate information transfer and processing in aeronautical, space, and ground-based data systems. These devices are small in size and weight, highly efficient, stable, and capable of being modulated for use in fiber optics data transfer systems. Such systems provide high information capacity with freedom from electromagnetic interference. The semiconductor materials are derived from compounds such as aluminum gallium

arsenide. Work is continuing toward integrated electronic and optical data transfer systems for use in the late 1980's.

ENERGY TECHNOLOGY

High-power lasers offer attractive concepts for transmitting ("power beaming") energy over long distances in space. Potential applications require conversion of the energy transmitted via laser beam into electricity, propellant, heat or other useful forms of energy at the receiving end of the laser beam.

The NASA program encompasses beam generation, receiver conversion, propulsion, and related fundamental research and technology. Operation of lasers in space requires highly efficient power sources which have the potential of continuous operation over long periods. Two promising laser concepts, nuclear and solar pumping, are currently being investigated. In the nuclear pumped device, thermal neutrons generated in a reactor are absorbed by a fissionable material, providing fission fragments which excite the lasing medium and cause it to radiate. The nuclear pumped device has shown considerable progress over the past several years; an output power of about 400 watts was experimentally demonstrated in 1979. Although, the fundamental feasibility of nuclear-powered lasers has been demonstrated, much remains to be done to achieve the power levels and efficiencies required for "operational" use.

In the solar pumped device, a concentrator focuses the incident solar flux onto a lasing medium which absorbs the broadband energy and reradiates a laser beam. The solar-pumped device has distinct advantages including the small system size to transmit energy over long distances in space. Studies of this concept are in progress and experimental hardware is being assembled to investigate the feasibility of producing laser beams by this technique.

Power conversion at the receiver can be accomplished electrically (photovoltaic, thermophotovoltaic, plasmas, optical diodes), mechanically (heat engines) or chemically (photochemical storable H^2 and O^2). Photoelectrolysis offers the potential of 50-percent efficiency in the conversion of the laser light directly to electricity, or in the production of storable H^2 or O^2 which could later be recombined in a fuel cell or propulsion engine. Laboratory demonstrations have shown conversion efficiencies of 25 percent. Other aspects of this program include work on laser heated engines and optical diodes.

Several interesting receiver concepts which convert the laser light energy into propulsion energy have been studied. Driving aircraft engines from a space-based laser is one such concept. Another concept converts electrical energy to thrust in an ion or plasma space engine. Other potential applications include laser-powered orbital transfer vehicles—to move satellites from the low Earth orbit of the space shuttle into higher orbits—and direct launch of payloads from Earth to orbit. Recent studies indicate that such concepts may be far superior to conventional propulsion systems.

In other work, NASA is attempting to advance the use of lasers in diagnostic measurements, and welding of solar cell assembles, and to annealing solar cells that have been degraded by exposure to par-

ticulate radiation in space. Recent work suggests that onorbit annealing with laser radiation may be possible.

Energy

Energy is a defense as well as a civilian issue in DOE. There are strong synergisms between civilian energy technologies and defense technologies in many areas, as exemplified by nuclear weapons and nuclear electrical energy. The DOE is responsible for both nuclear weapons research and production for the DOD and for nuclear electrical power generation technology to help meet civilian energy needs. Laser technology extends this mutuality of interest. However, the only high-power laser technology being developed by DOE currently is directed primarily toward defense nuclear program requirements. However, laser energy technology has potentially a wide variety of civilian energy applications.

Laser technology can hasten the development of our short-term energy options in fossil fuels, improve processing of fuel supplies for "conventional" nuclear powerplants, and may be the key to thermonuclear fusion and beaming of solar power. The technology also appears to offer potential for nuclear waste disposal which is receiving little attention and funding in DOE.

Two witnesses described concepts of "beaming" electrical power by laser beam. Concepts included beaming power, perhaps generated by using offpeak powerplant hours, to space and back to Earth to meet peak power demands in other geographical areas, thus reducing the requirement for generating capacity (capital investment) to meet peak demand; power beaming of energy from Earth to space, or space to space, to meet space vehicle electrical power needs, or alternatively as a form of space vehicle propulsion; and beaming energy from space to Earth to take advantage of solar collection outside the atmosphere to meet terrestrial needs.

The theoretical basis for conversion of electricity into laser energy, transmission of the energy via laser beam, and reconversion of laser energy into electricity has been established.

The major variables include efficiency of the laser devices in energy conversion (exciting the lasing medium), propagating the laser beam through the atmosphere and space, and reconversion of the laser energy into electricity or other usable form. The frequency at which the laser operates, atmospheric conditions, and altitude of the laser device also are important variables in beam propagation. Only limited empirical data have been collected to confirm theoretical predictions; witnesses discussed a need for expanded experimental programs.

The two principal laser applications currently being funded by DOE are ICF and isotope separation. Both laser programs are carried out primarily in the DOE National Weapons Laboratories, Los Alamos National Scientific Laboratory (LANSL) and Lawrence Livermore National Laboratory (LLNL).

INERTIAL CONFINEMENT FUSION

Several technological approaches to achieve fusion are being pursued in parallel. Fusion technology using lasers is in an embryonic state. The pursuit of parallel approaches is considered prudent and

should be continued until the technology matures sufficiently to permit an informed choice, considering all relevant factors such as efficiency, cost, environmental factors, safety, risks, et cetera. Two experimental laser programs in Inertial Confinement Fusion (IFC) are underway in DOE. (There is also a particle beam ICF program not discussed here.)

The ICF program has the dual goal of supporting near-term military applications and developing the long-term energy option of nuclear fusion. Very small fuel pellets of the heavier isotopes of hydrogen—deuterium and tritium—are irradiated by laser beams to cause compression and heating of the fuel so that large amounts of energy are released by nuclear fusion. Fusion reactors using high-power, rapidly pulsed laser beam drivers might be built to generate electricity, to produce nuclear fission fuels (e.g., enriched uranium or thorium), for use in light water reactors, or to produce a chemical fuel such as hydrogen.

The SHIVA neodymium laser at the LLNL, in operation since late in 1977, is the world's most powerful laser, capable of irradiating targets with 25 to 30 trillion watts (terawatts) for brief instants. The "instantaneous" power of this system exceeds the instantaneous power generated in the United States. This is accomplished by storing in capacitors energy which is then switched into the laser system in extremely short pulses, on the order of tens to hundreds of billionths of a second.

However, still more powerful, efficient, and economical laser systems are required to produce fusion. Scientific "breakeven," the point at which the energy produced equals the energy used to drive the fusion reactor by the laser, may be achievable in the mid to late 1980's and is the highest priority near term objective that will allow validation of the ICF process.

A technical extension of the SHIVA system, called NOVA, was under construction and scheduled to be completed in 1983. Experiments on NOVA were expected to reach the threshold of ignition and eventually to achieve scientific "breakeven." The development of damage-resistant coatings and more powerful amplifiers than those on SHIVA could permit NOVA to deliver 7–10 times the energy of SHIVA. However, the fiscal year 1981 funding for the NOVA program was deferred by the Office of Management and Budget (OMB). Consequently, the future of the NOVA program—and the time frame for demonstrating scientific "breakeven"—is uncertain.

DOE also has an ICF program (Helios) at the Los Alamos National Scientific Laboratory which uses a carbon dioxide laser. The beam energy of Helios is comparable to SHIVA but it operates at a longer wavelength, producing different target coupling (interaction) phenomena. A comprehensive understanding of the beam/target coupling physics is fundamental to the fusion program. A new laser facility, ANTARES, is now under construction at LANSL, with scheduled operation in 1983, which will provide yet a better understanding of the laser beam/target interaction phenomena.

An aggressive effort is underway to identify efficient gas lasers that are capable of being scaled to the high power required to achieve laser-induced fusion. In the near term, such a driver, in single-pulse operation, supports the program's military goals.

ICF is one of the most demanding of the high energy laser applications in several respects. Energy on the order of a megajoule will be required to drive ICF reactors for net energy production. ICF targets are barely visible to the naked eye; hence they require very precise focusing of the laser beam. Efficient absorption of the laser energy into the target fuel requires that the laser light be emitted in an extremely narrow bandwidth, and short wavelength, perhaps as low as 0.5 or 0.25 micrometers.

The most valuable potential civilian application of ICF is the production of electricity through conversion of the target's released energy in a reactor vessel to drive a generator. Sufficiently high energy gain in the fusion process would offset the low electrical efficiency of the laser as well as the loss experienced in the conversion of heat to electricity.

In summary, the inertial confinement fusion program has developed large single-pulse solid-state and gas lasers which appear capable of being scaled to the energy and power requirements needed for demonstrating the scientific feasibility of laser-induced fusion. A broad base exists for developing repetitively pulsed, efficient lasers to meet the requirements of an Engineering Test Facility, which the DOE projects to be in operation in the 1990's.

ADVANCED ISOTOPE SEPARATION

The objective of the AIS program is to develop a new, low-cost technology to provide economical recovery of uranium-235 from the residues (tails) generated by the current gaseous diffusion and planned gas centrifuge uranium enrichment plants. Two laser methods and a plasma separation technique are under study for isotope separation. One of the three processes will be selected for engineering scaleup to a Development Module at the end of fiscal year 1981; pilot plant and the first production facility would follow in sequential development phases.

Only the two laser approaches to isotope separation, molecular and atomic vapor, are discussed in this report. Two laser candidates are being investigated for each approach. Should a laser process be selected for the Development Module, the laser issues to be resolved at that time would be overall efficiency, lifetime demonstration, reliability. and laser system cost. The lasers required for uranium enrichment in production plants would be available in the early 1990's to satisfy DOE requirements. Options for earlier availability- -with increased up-front funding—are discussed in subsequent sections.

In the moleculer process, being developed at LANSL, uranium hexafluoride, U^{235} fluoride, is selectively energized and disassociated by the use of a carbon dioxide infrared laser with a very precise frequency.[1] The infrared laser provides the specificity that isolates and energizes U^{235} fluoride molecules for separation from the remaining uranium-238 isotope.[2]

The infrared laser energy must therefore be specifically tuned to the precise frequency (wavelength) so as to be absorbed only by the desired

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[1] A characteristic of most lasers is that the frequency at which they radiate depends exclusively upon the lasant medium.

[2] Natural uranium is composed of 0.7 percent U^{235} and 99.3 percent U^{238}. Light water reactors operate typically with a fuel mixture that is enriched to 3.2 percent with U^{235}.

isotope. The LANSL approach uses the well-developed carbon dioxide infrared laser and a wavelength shifter which converts photons from the laser to photons that are tuned to be absorbed by the U^{235} fluoride molecule.

A typical infrared laser is envisioned to operate at 1,000 pulses per second at 2 kilowatts average power. A preprototype laser nominally meeting these requirements will be operational at LANSL in 1981. Further engineering is required, however, to be able to produce an infrared system that operates for 1,000 hours at an efficiency of at least 1 percent.

Krypton fluoride lasers which operate in the ultraviolet portion of the spectrum also are suitable for the atomic vapor isotope separation process. The power requirements are estimated to be similar to those for the infrared lasers. A preprototype krypton fluoride laser is being fabricated at 1 kilowatt (half power scale-down) power level and is also scheduled for operation in 1981.

The atomic vapor process, being developed at LLNL, takes advantage of the small isotopic differences in the electronic spectra of uranium atoms. The process requires the controlled vaporization of uranium atoms followed by excitation of U^{235} using tunable lasers. The excited uranium atoms can then be physically removed from the uranium vapor by electromagnetic methods. Collection of the uranium can take place as a liquid condensate (continuous drain) or as a solid (batch process).

The testbed laser system at LLNL currently uses 6,000 pulse per second copper vapor lasers to pump dye lasers for photoexcitation of uranium. Dye lasers have the special property of being able to convert laser light to a new frequency that is exactly tuned to the absorption frequency of the useful uranium isotope. The tunable laser can selectively excite only uranium-235, thus providing the desired separation between U^{235} and U^{238}. Because uranium atoms absorb light more readily than the UF6 molecule, the laser energy requirements for the atomic vapor process are much less, typically one-tenth less, than those of the molecular process. This advantage is partially offset by the need to rigidly control the spectral features of the laser beam and the requirement to use several beams simultaneously to sequentially pump the uranium atom to ionization.

Both rare gas halide and copper vapor lasers are sufficiently advanced to satisfy the atomic vapor program laser requirements. LLNL is currently assembling a larger testbed for laser enrichment demonstrations in 1981 that integrates 40 copper vapor lasers.

Because engineering lifetime and reliability issues are a concern in copper vapor laser technology, LLNL is also pursuing rare gas halide lasers as an alternative pump source for the dye laser. The rare gas halide lasers, such as those at Los Alamos discussed above, are less advanced but offer many advantages, principally system simplicity. Because they operate efficiently at higher output powers, 5 to 10 times fewer devices would be required in large scale production demonstrations.

National Defense

As noted in the introduction, laser systems are characterized as high-power and low-power. The DOD identifies lasers with power out-

put greater than 20 kilowatts as high-energy lasers; program responsibilities follow this definition within the Office of the Secretary of Defense.

LOW-POWER LASER PROGRAM

The laser was invented as a laboratory device in 1960. The first military laser rangefinder was demonstrated in 1962; the first operational rangefinder was fielded in 1969. In 1972, in Operation Linebacker in Vietnam, the Thanh-Hoa Bridge was completely destroyed via a laser-designated bomb, after repeated attempts with ordinary bombs failed to eliminate the bridge at a cost of over 100 aircraft damaged or lost.

The unique properties of the laser have been exploited to provide modern military forces with combat capabilities which existed only in science fiction just a few years ago. The current and proposed applications of laser devices to military problems will revolutionize the way battles are fought. Military applications include:

- Fire control and weapons guidance
- Laser surveillance radar
- Information transfer and communications (short to moderate range line of sight terrestrial; fiber optics to replace cables; and long-range space communications)
- Training aids
- Remote line of sight meteorology
- Chemical; biological agent; and exhaust detection
- Data processing and holography
- Laser material preparation
- Optical countermeasures

New laser applications on the horizon include improved understanding of materials through laser spectroscopy, creation of new material properties by rapid melt-cooldown processes, and use of isotope separation for the production of ultra-pure materials (e.g., high resistivity silicon). Systems applications taking advantage of non-linear optical processes also appear highly promising.

Several classes of lasers are currently in use. The classes represent the lasant material used. Each class possesses unique advantages and disadvantages for various applications. The state of technological development varies widely.

According to DOD testimony, low-power laser development has been the single most successful DOD investment in the last decade. While the low-power laser research and development investment has been modest, it has provided 15 designation and ranging systems, of which 9 are operational, production is pending on 1 system, and 5 systems are in engineering development. Of the 15 systems, 8 are Army, 4 are Air Force, and 3 are Navy systems.

U.S. fighting capability has been increased substantially by the use of low-power lasers. The great successes of systems currently available has created demands for new and improved capabilities. Development is progressing but the fielding of new military systems using low-power laser capabilities is constrained by funding availability.

Although achievements to date are impressive, the potential of low-power laser technology has barely been tapped; revoluntionary developments in the application of lasers to military systems can be expected in the future.

HIGH-ENERGY LASER PROGRAM

The objective of the DOD high-power laser program is to determine the feasibility of developing high energy laser weapon systems capable of effectively engaging and destroying selected targets. The DOD is engaged in technology development programs which will culminate in a series of technology feasibility demonstrations. If these demonstrations are successful, the DOD will decide in the mid 1980's whether to build the prototype systems. Even if the technology developments are successful and the laser is proven to be a useful weapon, it will not appear in the field before the 1990's under current program and funding projections. Opportunities to accelerate the program are discussed in the findings and conclusions sections.

Features and applications

High-energy laser directed energy weapons systems offer several unique and attractive features and a varity of potential applications. Laser beams travel at the speed of light, 186,300 miles per second. The lethal flux (the amount of energy put on the target), therefore, arrives at the target almost instantaneously, reducing or eliminating the requirement to "lead" the target. It takes less than 6 millionths of a second for laser light to travel 1 mile, and in that time an airplane traveling at twice the speed of sound would travel only a little more than one-eighth inch. The speed and precision of a laser weapon would permit it to selectively disable or destroy single enemy targets in the midst of a host of friendly vehicles.

For each "shot" of the laser, relatively small amounts of fuel are used to generate the beam. There is, therefore, the potential for storing a large number of shots in each laser system. Finally, since the beam is directed by mirrors the laser weapon has the potential to move rapidly from target to target over a wide field of view. Consequently, a laser weapon could handle a large number of targets even if the targets are coming from all directions.

To achieve an effective weapon system, development efforts must address those characteristics of high-energy laser weapons which tend to limit the capabilities of such weapons. For example, a successful laser weapon engagement occurs when the beam burns through the target surface and destroys the warhead or other vital component (such as an electronic package, guidance system, fuel line, optical components or windshields so that transparancy is lost). While the energy is delivered near instantaneously, the laser must dwell for a short time on the target to destroy it. Jitter of the focused spot on the target smears the energy in the beam over a larger effective spot size, increasing the time required to destroy the target. Thus, the beam control subsystem must hold the beam steady on the target aimpoint.

Fire control for laser weapons will have to be especially capable. A laser must be pointed with great accuracy, which in turn requires the fire control subsystem to be especially accurate in telling the beam control subsystem where to point. In addition, to realize the firepower potential of a laser weapon, the fire control must be quick to recognize that the target being engaged has been damaged sufficiently so that the laser weapon can then move to the next target.

A final example of a characteristic which tends to limit laser capabilities is the effect the atmosphere has on the laser beam. The atmosphere absorbs some of the energy being propagated, causes the

beam to "bloom" or defocus, and adds jitter to the beam. The severity of the atmospheric effects varies among the various laser frequencies and under different atmospheric conditions (e.g., rain, smoke, haze, wind, and density).

Interactions between the high-power beam and the atmosphere effectively increase the spot size of the beam on the target, lowering the intensity of the beam and increasing the amount of time the beam must be held on the target. Of course, in bad weather or in the presence of clouds or aerosols such as smoke, more of the energy in the laser beam is absorbed, effectively limiting the range of the laser weapon. Space-based systems would not encounter the atmospheric effects since they would operate in the vacuum of space. Space-based systems would face other problems associated with deployment of systems in space, such as size, weight, lifetime and reliability.

There are many potential applications for which high-energy weapons systems appear attractive including the defense of satellites, aircraft, ships, and groundbased targets against guided projectiles, hostile aircraft, and missile threats. There also is a wide variation in the performance requirements of high-energy laser systems, depending on the "mission" they are performing. Current U.S. technology could support the least difficult high-energy weapon system requirements, such as antisensor systems, and the technology probably could be scaled to provide weapons systems capable of other potential applications such as disabling hostile satellites. Conversely, defense against intercontinental-range ballistic missiles is extremely stressing and further technology development is necessary to provide for such systems.

In summary, the high-energy laser weapons designer can envision a weapon in a high-density threat environment that methodically moves from target to target giving all-azimuth coverage; focuses the beam on the most threatening target; holds the beam on the selected aimpoint despite the target's distance, speed, and maneuver; burns through the target skin and ignites the fuel or destroys the warhead or other vital component. Then, with instructions from its sophisticated fire control system, the weapon switches the beam to the next target providing the greatest threat and so continues through tens or hundreds of successful engagements before the fuel is expended.

Test results to date

In the course of development efforts to date, laser weapon testbeds (using technology developed in the DOD high-energy laser program) have scored "firsts" for the United States in engaging moving targets. The first such success was in 1973 when the Air Force used a high-energy gas-dynamic laser of moderate power and an on-gimbal telescope to shoot down a winged drone on the Sandia Optical Range at Kirtland AFB, N. Mex. In 1976, the Army, using a high-energy electric laser of modest power successfully destroyed winged and helicopter drones at Redstone Arsenal, Ala. The most recent tests were in March 1978 when the Navy, using a chemical-laser of moderate power developed by the DARPA and a Navy pointer/tracker, successfully engaged and destroyed, in flight, TOW anti-tank missiles launched by Army technicians at San Juan Capistrano, Calif.

The major objectives of these experiments have been to obtain experience and insight into the problems of integrating a laser of mod-

erately high power with a pointing and tracking device, and maintaining the laser beam on the selected aimpoint. The successful destruction of moving targets provided dramatic proof of the successful attainment of these technology goals.

Current and planned program

The DARPA and the military services are proceeding with a number of technology demonstration programs to provide the technological foundation for prototype weapons systems development programs which could be initiated in the late 1980's.

The DARPA high-energy laser program is concentrated in three technical areas: laser devices, optics/mirrors, and pointing and tracking. The pointing and tracking experiment will be conducted in space; the other technology demonstration programs will be ground-tested. While encompassing the three critical technology areas of laser weapons, these efforts are not "integrated" and therefore will not provide a complete understanding of the total system.

The testbed for the Air Force is the Airborne Laser Laboratory, a highly instrumented NKC–135 aircraft. The Air Force is investigating the integration and operation of a high-energy laser system in a dynamic airborne environment, and the propagation of the laser beam from an airborne vehicle to an airborne target. Potential applications could include aircraft defense against hostile aircraft, air-to-air and ground-to-air missiles, and disablement or destruction of hostile satellites.

The Army is in an early phase of examining the feasibility of laser weapon concepts for defense against weapons which use optical sensors and against aircraft, and other air defense scenarios typical of the Army battlefield. A modestly funded technology development program is under way which could provide the technological foundation for defense against guided munitions, low altitude defense against tactical aircraft (helicopters and fixed wing), and high altitude, high performance aircraft. Conspicuously absent is the evaluation of a laser system capable of destroying tactical ballistic missiles such as the Soviet SS–20 which poses a serious threat to NATO forces.

The Navy is developing plans for a test series in the 1980's at the DOD High Energy Laser National Test Range being built at the White Sands Missile Range (WSMR), N. Mex. The principal application of interest to the Navy will be ship defense aginst guided munitions, aircraft, and missiles.

Army and Air Force tests are also planned at WSMR laser test facilities.

Program funding

The cumulative DOD funding for high-energy lasers through fiscal year 1980 exceeds $1.4 billion. Another $0.5 to $1 billion may be required before an adequate technology base is developed to support the most difficult high-energy laser system applications. The fiscal year 1980 budget is $210.8 million,[3] distributed as follows: Defense Advanced Research Projects Agency, $48.3 million; Air Force, $101.2 million; Navy, $40.8 million; and Army, $20.5 million. The program is

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[3] The fiscal year 1980 high-energy laser budget was reduced $15 million by the Secretary of Defense in March 1980. The fiscal year 1981 high-energy laser program budget submission of $233 million was reduced $40 million by the Secretary of Defense in March 1980; Air Force and Navy programs were reduced by $20 million each.

coordinated by the Directed Energy Technology Office, Office of the Under Secretary of Defense, Research and Engineering (OUSDRE). The cost of the development of laser directed energy weapons will be high. For example, one witness described a system concept for destroying hostile satellites, aircraft, and submarine launched and intercontinental range ballistic missiles and expressed the view that such a system could be developed and deployed in 3 to 5 years at a cost of $10 billion. This represents the most optimistic assessment of system availability and cost of high energy lasers as directed energy weapons. Other witnesses were highly encouraging about the military potential of high-energy lasers, but were less optimistic about the ability to develop and deploy such systems within this decade and the expected total cost of such ABM systems. A major point of contention is whether considerable progress can occur as a result of certain "breakthrough" technologies now emerging. New technologies, such as the free electron laser, appear to offer great potential to avoid many of the difficulties and pitfalls that have slowed the progress of lasers toward operational systems.

COMMENTS ON THE SOVIET HIGH-ENERGY LASER PROGRAM

The Soviet Union appears to be concentrating substantial resources on high-power laser technology—3 to 5 times the amount of U.S. expenditures. However, the status of Soviet technology development in high-energy lasers, and the extent to which the program focuses on research versus weapons development, is uncertain. The Soviets may have begun the development of specific weapon systems. The United States, on the other hand, has decided to retain a technology focus for its high-energy laser program for the next 5 years. DOD witnesses expressed the view that U.S. scientists understand the technical issues basic to translating high-power laser technology into weapon systems, that the U.S. decision is correct, and that the Soviets may be moving prematurely to weapon systems. The DOD is continually reviewing the U.S. program and watching Soviet progress with great interest as the potential clearly exists for a dramatic "surprise" by significant Soviet developments in high-power laser weapons. This is especially troublesome because of the impact such a "surprise" could have on the strategic and tactical military balance between the superpowers.

FINDINGS

Importance of the Technology

The laser ranks high among the important technological discoveries of this century, potentially ranking in significance with nuclear fission and integrated circuits. The use of low-power laser systems already has produced a large improvement in military capability. Further improvements can be expected. High-energy laser systems may completely revolutionize military strategy, doctrine, and tactics and thus effect a dramatic shift in the military balance of the superpowers. Further laser systems have the potential to revolutionize energy production, space vehicle propulsion, communications, and photo chemistry. These civilian applications will produce dramatic changes in society.

Role of Government-Sponsored Research

Government-sponsored research has played an essential role in laser research and experimental programs. Government-sponsored basic research in the United States since World War II, particularly in the universities, laid the scientific foundation that later contributed to the discovery and development of the laser. Noteworthy research included work on magnetic resonance, microwave spectroscopy, frequency standards, electronics for radio astronomy, the ammonia beam maser, and optical properties of semiconductors. Industrially funded laser applied research and technology applications programs increased as Government-sponsored programs yielded promising results. Industrial research also benefited indirectly from Federal funding. For example, almost all the industry funded engineers and scientists in quantum electronics and related fields who pioneered the development of optical communications technology benefited from training or experience in Government-sponsored research.

The Federal investment to date in this research and technology has yielded extremely important returns; similar returns can be expected from future Federal investments in laser research and applications.

Progress and Potential

Considerable progress has been made in laser research and applications since the experimental demonstration of the first laser device in 1960. Early research and experimental programs focused on low-power lasers. It, therefore, is not surprising that low-power devices have paced the military and commercial utilization of lasers.

High-energy lasers of modest power levels have entered the industrial market in the last few years. Extremely high-power devices, representing energy levels in the lower end of the regime of directed energy weapons and fusion, have been demonstrated, but only in the

laboratory. It is now possible to move forward with weapons system development programs for the least difficult missions. The more difficult missions must await development of higher energy lasers and the closely associated optics and pointing and tracking technology.

There is a strong correlation between program focus and funding levels and achievement of operational use of these devices. Current Federal programs and projected funding profiles will not lead to directed energy weapons, for a decade or more, but availability could be accelerated with increased funding.

The impressive and steady array of achievements in low-power lasers intensified the visionary thinking about the potential of high-energy lasers and the pursuit of theoretical and laboratory research to make the high-energy devices a reality. High-energy laser technology is multidisciplinary and enormously complex. Progress has been made through stronger interactions of theoretical research and laboratory experiments. Perfection of lasing devices is as much an art as a science. Laboratory experimentation of laser devices has been the essential route to progress and has been time consuming. For example, the SHIVA laser at the Lawrence Livermore Laboratory, the highest peak-power laser operating in the world today, is a "research tool" in the fusion research program directed to understanding the beam-material interaction by coupling theoretical work with empirical data. Construction of the SHIVA system took 5 years at a cost of $25 million.

While Federal expenditures have been considerable and technological progress to date has been impressive, considerable additional research must be conducted to provide the technological foundation for many important applications. Total Federal funding to date exceeds $1.4 billion, an additional $0.5 to $1 billion technology investment may be required. However, the potential beneficial effects of laser technology to national security, energy, the civil space program, industry and society justify the investment and pursuit of the technology at an unrelenting pace.

Federal Program Structure

The laser research and technology programs of the Federal Government reside in the respective departments and agencies, primarily the DOD, DOE, and to some extent NASA. There is some interaction among the Federal programs. Some witnesses advocated centralization of the department and agency programs into a single Federal organization— such as the former AEC—and substantial increases in funding to accelerate the rate of progress and to improve institutional coordination.

Coordination among the Federal departments and agencies is rather weak, and much of the coordination stems from professional relationships among the senior managers and researchers, rather than institutional relationships. The Federal program structure stresses achievement of differentiated departmental, rather than national, missions and goals. Increased synergism among the programs should be sought in the context of "opportunity at little or no cost." Opportunities to exploit synergism at increased departmental costs usually are passed up.

The current Federal program structure is working, but could be improved by better institutional coordination.

The coordination issue programs has been raised previously with the DOD by the House Armed Services Committee. The DOD responded by establishing a Directed Energy Technology Office (high-energy lasers and particle beams) in the Office of the Under Secretary for Research and Engineering, but assigned responsibility for only a portion of the high-energy laser program to that office. Much of the decisionmaking authority for the defense programs including program content and budget allocation continues to be divided among the Deputy Under Secretary, Research and Engineering for Strategic Systems, DARPA and the military services.

The current DOD organization for the high-energy laser program is not achieving the most effective concentration of the available funds to produce military weapon systems at the earliest possible time.

An amendment to the fiscal year 1981 defense procurement authorization bill was introduced in the Senate to provide authorization and direction for a major national program to develop and deploy, in 3 to 5 years at a cost of about $10 billion, a space-based high-energy laser antiballistic missile (ABM) system.[4] While the amendment was defeated by a vote of 50–39, it reflects a growing concern about the lack of a national commitment to the rapid development of high-energy weapons systems. Yet the Deputy Under Secretary, Research and Engineering for Strategic Systems, who has institutional responsibility for the U.S. ABM program, has directed that the U.S. ABM program substantially divest itself of modest amounts of funds budgeted for "seed money" and conceptual system studies.

The DARPA program is totally independent of other DOD programs and autonomous in program formulation and budget allocation.

The Director, Directed Energy Technology Office, has normal control over the military service programs, but the determination of program content and budget allocation is strongly biased in favor of the services. He limited authority to enforce coordination and integration. The Director's authority to influence programs and budgets stems substantially from personal characteristics such as scientific expertise, charisma, and "jaw boning," not from institutional authority. The institutional arrangement and delegation of authority have a profound impact on the budget, program content, and priorities; it, therefore, needs critical analysis.

No DOD Strategy for Weaponization of High-Energy Lasers

The DOD strategy for the development of high-energy laser technology consciously excludes development of high-energy laser directed energy weapons; a strategy is needed which balances technology and weapons systems development, especially weapons for the least difficult applications. The strategy should specify long-term weapons systems objectives which would provide the framework for planning balanced and integrated technology development and experimental

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[4] Two things should be pointed out here:
(1) It is not possible to develop and deploy a space based laser ABM missile system within 5 years.
(2) The U.S. has ratified the Treaty on the Limitation of Antiballistic Missile Systems which entered into force Oct. 3, 1972.

programs. DARPA and the military departments pursue the technology development under the broader context of their respective missions. This poses difficulties in achieving a balanced, integrated DOD program.

High-energy laser weapon systems concepts, frequently ill-defined, must compete in trade-off studies with "conventional" systems: effectiveness, cost, risk, etc. Because directed energy weapons are so new and fundamentally different from conventional systems, the appropriate means of assessing system effectiveness, cost, and risk, in comparisons against conventional systems, are not well understood. This process drives program objectives toward fragmentary and near-term accomplishments, rather than long-term system capabilities.

This tends to exert downward pressures on the high-energy laser technology budgets. The need is for a well-defined DOD strategy for high-power laser technology and weapons system development. The budget should be "fenced" and controlled by a high-level DOD official. DARPA and the Services could continue to carry out the programs when approved. Desired organizational and program characteristics are discussed in the recommendations section.

DOD Funding Is Inadequate

The funding for the DOD high-energy laser program has been "stretched" to cover the maximum number of scaled-down research projects and field experiments, leaving only small amounts for highly innovative research work. Experimental programs are in the early stages of hardware development in DARPA, and to a lesser extent, in the three military services. Often, research funds are reallocated to solve experimental program problems, thereby "drying up" the research funds. The current DOD program focuses on technology demonstration at a modest pace and level of risk. Decisions regarding weapons system development are in the distant future.

Current DOD budget allocations for higher-energy laser programs are not sufficient to achieve operational directed energy weapons at the earliest time. But, it is possible to significantly accelerate the achievement of directed energy weapons systems. There also is a need to develop new and promising laser devices such as the free electron laser.

Diversity of Scientific Opinion

There exists within the "scientific community" (and among the senior officials within OSD) a great diversity of professional opinion about the potential of high-power systems for various applications, when (if ever) they will become feasible, and how "affordable" such systems will be in cost. The greatest diversity and intensity of opinion relates to military applications. However, according to the testimony, progress to date has been "convincing" and no insurmountable physical principles have been identified which preclude future developments. Another decade or more of intensive research may be required to establish the technical feasibility of achieving the most difficult applications. To accomplish this increased Federal funding is unequivocal.

Notwithstanding the findings set forth above, the diversity and the intensity of professional opinions among nationally prominent scientists regarding the potential and technical and economic feasibility of high-energy lasers in various applications is unsettling. Urgent needs of strategic military and domestic energy requirements, to which high-energy laser technology may make extremely important contributions, require the Congress to play an active leadership role in charting the Nation's course in the development and utilization of high-energy laser technology.

Civilian Space Applications

NASA has a distinguished record of impressive technology development and applications, but important opportunities to develop and apply laser technology to provide benefits for mankind need to be exploited more fully. The NASA testimony described an interesting menu of current and potential research and applications, but the budget allocation of only $6 million is more indicative of NASA support for laser technology development and applications. NASA's limited efforts on laser technology could be substantiated by numerous examples. Only two will be cited.

The unique characteristics of lasers permit precise, global, and near realtime measurements of Earth motion and crust movement around fault lines from which earthquake eminate. These data are important to earthquake prediction research; but NASA has not yet used satellite-based laser measurements to collect this important data. Various approaches to laser space vehicle propulsion appear promising, but NASA has not adequately funded such technology.

The aggressive pursuit of laser research—analogous to the basic aeronautical research program for aviation—would be desirable; exploitation of the technology developed by DOD, DOE, and industry is the minimum acceptable NASA role.

RECOMMENDATIONS

The United States should aggressively pursue a more comprehensive and balanced program of laser research and applications. Funding should be increased.

An institutional mechanism should be established to coordinate the Federal programs and funding in high-power laser research and technology developments.

The NASA should fully exploit laser technology, both low power and high power, to provide improved space system capabilities. Illustrative potential applications include: Remote sensing of Earth to enhance our understanding of the Earth and its resources and environment for the benefit of mankind; to improve our understanding of earthquake phenomena and the ability to reliably predict earthquakes; improved weather prediction and modification capabilities; laser space vehicle propulsion; and laser power beaming.

The laser fusion and isotope separation programs in the DOE should be at a higher funding level. Multiple approaches to fusion and isotope separation should be continued until solid technological foundations are developed to permit an informed selection of the preferred approach for each technology.

Fusion and isotope separation could potentially fulfill important military needs and provide important future energy sources which should not be sacrificed for near-term budgetary goals; competing technology approaches should not be eliminated prematurely based solely on budgetary considerations. Today's budget choices must reflect balanced consideration of near-term "fixes" and long-term "solutions" to meet the Nation's energy needs.

The potential contribution of laser technology to nuclear waste disposal should be fully examined. Appropriate laser research and applications programs should be initiated.

The potential effects of high-energy laser systems on the strategic military balance of the superpowers is enormous. A sharp distinction, therefore, must be drawn between this new and potentially "revolutionary" technology and evolutionary advances in conventional technology.

It is recognized that military capability rests on operational systems in the hands of the troops; technology does not win military conflicts. These factors logically exert pressures to buy improved existing systems, but the future strategic posture of the Nation hangs in the balance. High-energy laser technology development and weaponization programs could tip the balance in our favor. Special attention by the administration and the Congress is needed to insure that the high-energy laser technology development strategy, programs, and institutional responsibilities are structured and funded to lead directly to weapon systems in an orderly and timely way.

The Secretary of Defense and the Secretaries of the military departments, in concert with their scientific and technical staffs, should develop a DOD strategy for high-energy laser technology development and the deployment of high-energy laser weapons systems. While organizational prerogatives of the administration and the Secretary of Defense must be respected, the characteristics set forth below should be considered in developing a high-energy laser program strategy and organization.

- Focus on development of high-energy laser weapons systems at the earliest practicable date. The program should include a balanced approach to the development of potential near-term applications, such as anti-sensor and anti-satellite systems, and intermediate system capabilities, such as low-altitude air defense and ship defense; technology development should extend to longer-term systems, such as anti-ballistic missile system capabilities against intermediate and intercontinental range ballistic missiles.
- Adequate investment in advanced research on laser devices, optics, and pointing and tracking. Investment in new research and technology should not be sacrificed to support technology demonstration experiments.
- A well integrated single DOD high-energy laser program, *rather* than separate programs in the DARPA and the military departments. One organization, reporting directly to the Deputy Under Secretary for Research and Engineering, should have responsibility (and budget control) for the entire DOD high-energy laser program. DARPA and one or more of the military services could be assigned responsibility to execute clearly defined portions of the integrated DOD programs. This characteristic relates solely to program and budget; it does not suggest changes in assigned roles and missions of the services and DARPA.
- Institutional responsibility for the high-energy laser program in the DUSDRE must include unambiguous assignment of responsibility and authority to one office or individual to integrate and control the overall DOD high-energy laser program and budget, including program and budget changes.
- Allocation of a "fenced" high-energy laser budget in the Office of the Deputy Under Secretary of Defense for Research and Engineering. "Fencing" the budget at the OSD level is necessary to achieve program integration, balance, and continuity.
- High-energy laser systems responsibilities should follow existing roles and mission of the military services as they progress through the various development and operational phases, but the characteristic of DUSDRE control and "fenced" budgets should be preserved until operational systems status is assured.

As an interim solution, it is recommended that the funding increases shown in the following table for the fiscal years 1981, 1982, and 1983 budgets be adopted to accelerate technology development. Future year budget allocations should be sufficient to sustain an accelerated and fully integrated DOD program, including adequate funding for research on new laser devices and the associated optics and pointing and tracking technology.

DOD HIGH-ENERGY TECHNOLOGY FISCAL SUMMARY

[In millions of dollars]

[As of July, 1980]

Service: Program element [1]	Fiscal year— 1978 and prior	1979	1980	1981	1982	1983
Army:						
63314A	153.9	17.3	19.0			
62307A			1.5	20.4	22.5	30.6
				[2] (30.0)	[2] (58.0)	[2] (39.0)
				[3] (25.0)	[3] (70.0)	[3] (60.0)
Navy:						
63754N	250.1	33.8	40.8			
62735N				31.8	57.0	76.2
				(18.0)	(18.0)	(18.0)
Air Force:						
63605F	449.5	90.7	89.8	58.3	97.9	117.8
62601F		10.6	11.4	13.1	14.5	16.2
				(15.0)	(15.0)	(15.0)
DARPA	231.4	30.8	48.3	69.3	84.2	89.5
				(30.0)	(91.0)	(99.0)
Total	1,084.9	183.2	[4] 210.8	[5] 192.9	276.1	330.3

[1] Program element numbers relate to the fiscal year 1981 budget.
[2] Recommended budget increase to accelerate demonstration of initial weapons systems capabilities.
[3] Recommended additional budget increase to accelerate demonstration of more capable air defense systems. The budget increases may be mutually exclusive.
[4] The fiscal year 1980 high-ebergy laser budget was reduced $15,000,000 by the Secretary of Defense; $10,000,000 in Air Force, and $5,000,000 in Navy budgets.
[5] The fiscal year 1981 high-energy laser budget submission was reduced $40,000,000 by the Secretary of Defense; $20,000,000 each in the Air Force and Navy bubgets.

Note: Recommended increases are shown in parentheses.

APPENDIX

SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

WITNESS LIST

Wednesday, December 12, 1979, Washington, D.C.

Dr. John Rather, Principal Staff Scientist, Civil Systems Division, BDM Corporation, McLean, Va.
Mr. Howard Rausch, Editor *Laser Focus*, Newton, Mass.
Dr. Abraham Hertzberg, Professor, Department of Aerospace and Astronautics, University of Washington, Seattle, Wash.
Dr. Joseph A. Giordmaine, Director, Solid State Electronics Research Laboratory, Bell Telephone Laboratories, Murray Hill, N.J.
Dr. Gregory H. Canavan, Director, Inertial Confinement and Fusion, Department of Energy

Friday, December 14, 1979, Washington, D.C.

Dr. J. Richard Airey, Director, Directed Energy Technology, Office of the Under Secretary of Defense Research and Engineering, Department of Defense [1]
Dr. Douglas H. Tanimoto, Assistant Director, Strategic Technology Office, Defense Advanced Research Projects Agency, Department of Defense [1]
Dr. George Gamota, Assistant for Research, Office of the Under Secretary of Defense Research and Engineering, Department of Defense [1]
Dr. Gregory H. Canavan, Director, Inertial Confinement and Fusion, Department of Energy
Dr. George F. Smith, Vice President, Hughes Aircraft Company and Director, Hughes Research Laboratories, Culver City, Calif.
Dr. Edward Gerry, President, W. J. Schafer Associates, Inc., Arlington, Va.

Tuesday, January 8, 1980, Huntsville, Ala.

Dr. Walter B. Olstad, Deputy Associate Administrator, National Aeronautics and Space Administration
Dr. Tony Pirri, Physical Sciences, Inc., Woburn, Mass.
Dr. William B. McKnight, Physics Department, University of Alabama, Huntsville, Ala.
Dr. John Williams, Physics Department, Auburn University, Auburn, Ala.

Tuesday, January 8, 1980, Redstone Arsenal, Ala.[1]

Mr. James D. Carlson, Director, Ballistic Missile Defense Advanced Technology Center, Huntsville, Ala.
Col. Wood R. De Leuil, Director, Directed Energy Directorate, U.S. Army Missile Command, Redstone Arsenal, Ala.
Mr. Willis P. Oliver, U.S. Army Missile Intelligence Agency, Redstone Arsenal, Ala.
Dr. John Rather, Principal Staff Scientist, BDM Corporation, McLean, Va.

Saturday, January 12, 1980, Albuquerque, N. Mex.

Dr. Keith Boyer, Los Alamos Scientific Laboratories
Dr. Reed Jenson, Los Alamos Scientic Laboratories
Dr. Roger Perkins, Los Alamos Scientific Laboratories
Dr. Hans Mark, Secretary of the Air Force
Dr. William Leahmann, Los Alamos Scientific Laboratories
Colonel John Rich, Air Force Weapons Laboratory
Dr. Gerold Yonas, Sandia Laboratories
Mr. James Gerard, Dr. Richard Begley, BDM Corporation

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[1] Testimony received in closed session.