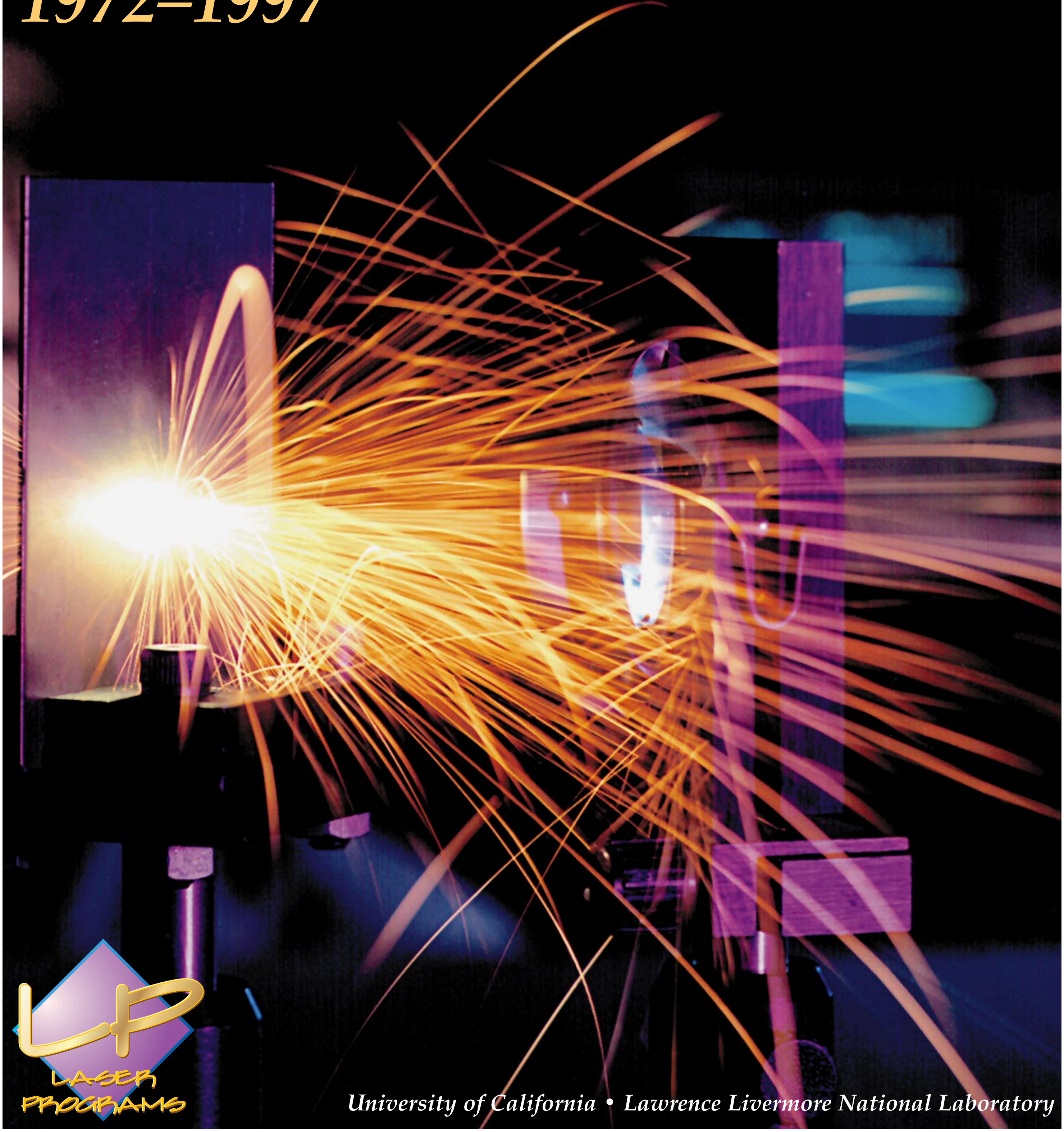
Laser Programs

The First 25 Years…

1972–1997



LASER PROGRAMS

University of California • Lawrence Livermore National Laboratory

About the cover ...

A laser machining workstation is coupled to the AVLIS laser system as part of the Lasers and Advanced Manufacturing Processes program linking unique high-irradiance lasers with Lab expertise in materials and processing science.

The back cover features photos of neodymium glass slabs that are used in solid-state lasers such as Nova; a device used to inject copper laser light into optical fibers for the AVLIS separation process; vials of dyes used in the AVLIS dye lasers; and a diode-pumped laser like those used in the NIF, spin-off applications, and potentially in a laser driver for inertial fusion energy.

Produced by Laser Programs Document Services

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Welcome to Laser Programs. I am pleased that you can share in the excitement of 25 years of history since we began as a small program of 125 people to our current status as a world premier laser and applied science research team of over 1700 members. It is fitting that this program, which was founded on the dream of developing inertial confinement fusion technology, should celebrate this anniversary the same year that the ground is broken for the National Ignition Facility (NIF). Also at the same time, we are feeling the excitement of moving forward the Atomic Vapor Laser Isotope Separation (AVLIS) technology toward private sector use and developing many alternate scientific applications and technologies derived from our core programs. It is through the hard work of many dedicated scientists, engineers, technicians, and administrative team members that we have been able to accomplish the remarkable internationally recognized achievements highlighted here. I hope this brochure will help you enjoy the opportunity to share in the celebration and pride of our scientific accomplishments; state-of-the-art facilities; and diligent, dedicated people that together make our Laser Programs and Lawrence Livermore National Laboratory the best in the world. Thank you for sharing in our good times, good work, and good friends.

E. Michael Campbell

E. Michael Campbell
Associate Director
Laser Programs

Laser Programs Associate Directors

In 1971, in response to encouragement from James R. Schlesinger (the head of the Atomic Energy Commission), Laboratory Director Mike May asked Associate Director Carl Haussmann to pull together the fragmented laser efforts at the Lab into a program with focus and direction.

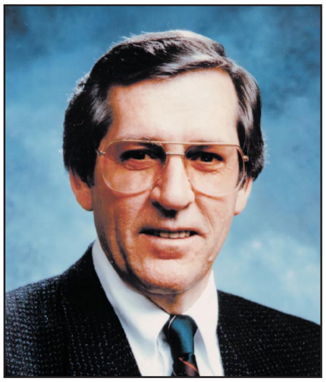
A. Carl Haussmann
1972-1975

Carl Haussmann became the first Associate Director of the Laboratory's newly founded Laser Program. A graduate of the U.S. Military Academy with a B.S. in Military Art and Engineering in 1946, he also earned a masters degree in physics from Pennsylvania State University in 1951. Haussmann merged expertise from outside the Laboratory with various internal capabilities to form a consolidated team. He focused the program's efforts toward laser fusion and its potential utility, laser science, thermonuclear explosion physics, diagnostic and code development, effects simulators, and civil power.

John L. Emmett
1975–1989

John Emmett, who was working at the Naval Research Laboratory in Washington, D. C., and had a Ph.D. from Stanford University, was asked to join the Lab's new Laser Division in July 1972. During his tenure as Associate Director, a series of successively more powerful lasers—including Argus, Shiva, Novette, and Nova—and most of the program's research facilities and office buildings were built. When he left the Lab in 1989, the Laser Programs had grown from 125 employees and a yearly budget of $7 million to a world-renowned team of 1700 people and an annual budget of $275 million—remarkable growth in less than two decades.

James I. Davis
1989–1994

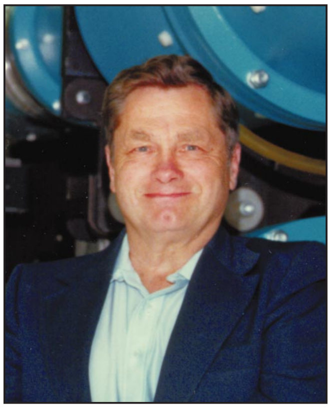


Jim Davis joined the Laboratory in 1974 from Hughes Aerospace. He earned his baccalaureate in physics from the California Institute of Technology in 1962 and his doctorate in physics from UCLA in 1969. Davis was the leader of the AVLIS Program for almost a decade, taking it from a small research activity up through large-scale uranium separation demonstrations. During Jim's tenure, the AVLIS Program was transferred to the United States Enrichment Corporation for commercial power-plant fuel production, and he was instrumental in negotiating the early Key Decisions for the National Ignition Facility.

E. Michael Campbell
1994–Present

Appointed Associate Director of the Laser Programs in February 1994, Campbell joined the Laboratory in 1977 after receiving his masters and Ph.D. in applied physics from Princeton University. Before 1994, he spent his entire career in the laser fusion program beginning as a staff physicist and rising to be Program Leader for Inertial Confinement Fusion. Campbell has led pioneering research in the use of lasers and ion particle beams to produce high-energy-density matter for scientific research and for controlled thermonuclear fusion.

The First 25 Years...



Associate Director Carl Haussmann combined three small, independent laboratory laser fusion projects and recruited the most knowledgeable people in the country's laser community to form the Laser program in 1972.

In 1972, the Lawrence Livermore National Laboratory (LLNL) created the Laser program to explore the possibilities of achieving energy gain through inertial confinement fusion (ICF). In 1975, the Lab's first ICF laser, called Janus, was built with two beams and 50 to 100 pounds of laser glass. That same year, the one-beam Cyclops laser was developed. The two-beam Argus was built just one year later. The 20-beam Shiva became operational in 1977, delivering 10 kilojoules of energy in a billionth of a second. In 1983, the Novette laser came on line creating the first soft-x-ray laser. The Nova laser was produced in 1984, 10 times more powerful than Shiva.

Six large fusion lasers were engineered and built in 10 years. The next 10 years in ICF were devoted to studying and demonstrating the physics required for fusion ignition and gain. Nova became the first laser to be extensively employed by the nuclear weapons program and helped establish the Stockpile Stewardship and Management Program (SSMP). And now, construction of the National Ignition Facility (NIF), with 192 laser beams and 200 tons of optics, has begun in 1997.

Deputy Associate Director Bill Krupke has served in this capacity for the last three Associate Directors for Lasers. Bill has recorded the longest tenure in the Laser Programs.

In 1973, the Uranium Atomic Vapor Laser Isotope Separation (U-AVLIS) Program was established to separate uranium-235, needed for fission reactors, from uranium-238, found in naturally occurring uranium. In 1974, a milligram quantity of enriched uranium was produced for the first time with the AVLIS process. In 1980, large-scale enriched uranium separation was achieved with the REGULIS separator. In 1984, the MARS Facility processed sufficient enriched uranium to project industrial-scale implementation of this technology. These successful U-AVLIS demonstrations led the Department of Energy (DOE) to select the U-AVLIS process over other enrichment technologies for continued development of power-plant fuel. In 1992, the United States Enrichment Corporation (USEC) was formed as a government corporation to provide enrichment services for the power industry. USEC chose U-AVLIS as its future enrichment technology and is proceeding with U-AVLIS demonstration and deployment.

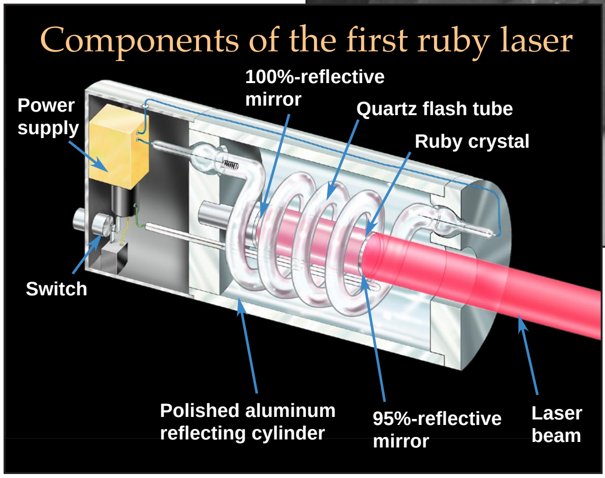
Based on technologies from the ICF and AVLIS projects, spin-off programs have developed new technologies for long-term storage and disposal of nuclear materials, advanced laser-based manufacturing, short-wavelength projection lithography for mass production of integrated circuits, radar devices for sensing objects behind solid barriers, remote sensing, and numerous Department of Defense applications that involve directed energy.

What has sustained this relentless drive of LLNL's Laser Programs for experimentation, achievement, and results?

Looking back over 25 years, it is clear that it was the initial foresight that envisioned reaching multimegajoule energy output, fusion ignition, and isotope separation using lasers through scaled steps; it was the disciplined engineering that created the laser tools to carry out the experiments; it was the unique blend of physicists, engineers, chemists, computer scientists, technicians, and administrative staff who worked as integrated teams; and it was the leadership who recognized that the tasks would be multidecades long and who never lost sight of their goals.

Early ICF Laser Research

Lab researchers began exploring uses for the laser soon after its invention in 1960. Early ideas included laser-induced fusion and a laser interferometer, a device used for precision measurements. The photo shows an early exploration of the laser's use in communications.


Components of the first ruby laser

Laser light is "monochromatic and coherent," which means that all of a laser's light rays are a single frequency (for visible lasers, the same color), in phase, and nearly parallel, resulting in a very bright, long, narrow light beam. In contrast, incoherent "white" light has many frequencies and diffuses in all directions, similar to the light from a flashlight. Laser stands for "light amplification by stimulated emission of radiation."

Shortly after the laser was invented in 1960, Lab scientists Stirling Colgate, Ray Kidder, and John Nuckolls, among others, made computer calculations with weapons design codes to study the possibility of using powerful, short-duration laser pulses to compress and ignite a small quantity of deuterium–tritium fuel. These calculations revealed that laser heating alone of the fusion fuel would not be enough to generate net energy, even with lasers as large as one million joules (1 megajoule). To achieve energy gain—that is, more fusion energy released than energy required to initiate the fusion reaction—the laser would also have to compress the fuel to about 1000 times its liquid density (200g/cm^3). In 1962, the Lab started a small laser fusion project in the Physics Department, with Ray Kidder as the project leader, to explore this possibility.

In the early 1970s, a new generation of computer calculations by John Nuckolls, Lowell Wood, George Zimmerman, and Ron Thiessen showed that interesting laser fusion experiments could be done with lasers as small as 10 kilojoules and that target gains of 100 could be achieved with a megajoule-sized laser. By this time, there was widespread interest in laser fusion, both at the Lab and elsewhere, and, in 1972, the Inertial Confinement Fusion (ICF) Program was formed.

A Series of ICF Lasers

In 1975 the first laser, Janus, demonstrated thermonuclear burn of deuterium-tritium.

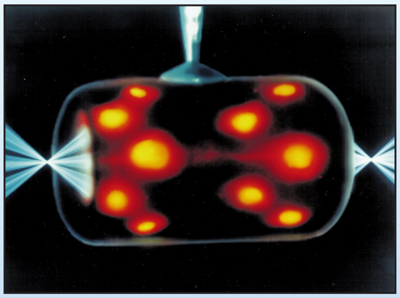
The one-beam Cyclops was also built in 1975.

Over the last two decades, the ICF Program has built and operated a series of laser systems, each five to ten times more powerful than its predecessor. Each system was a tool to expand the researchers' scientific understanding, and each has taken them a step closer to achieving fusion ignition and energy gain. Along the way, a community computer code for laser fusion called LASNEX was developed, which has proven to be the "work horse" of U.S. fusion predictions.

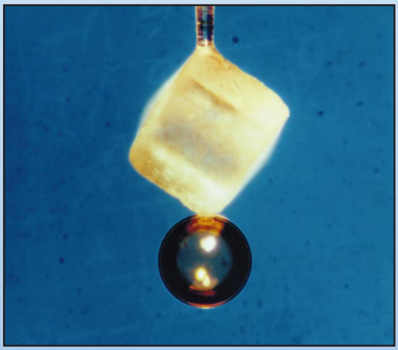
The two-beam Janus laser, completed in 1975, was used to demonstrate laser compression and thermonuclear burn of deuterium–tritium. The same year, the one-beam Cyclops laser became operational. With it, important target experiments were performed, and optical designs for the future Shiva laser system were tested. A year later, the two-beam Argus laser increased knowledge about laser–target interactions and helped the ICF Program develop technologies needed for the next generation of laser fusion systems.

In November 1977, the 20-beam Shiva laser was completed. About the size of a football field and the world's most powerful laser at that time, it delivered more than 10 kilojoules of energy in less than a billionth of a second in its first full-power firing. In June 1979, Shiva compressed

Inertial Confinement Fusion



Nova indirect-drive hohlraum target.



Nova direct-drive capsule with a grain of salt for scale.

Nuclear fusion is the energy source for our sun and the stars. In a fusion reaction, the nuclei of two lightweight atoms collide, forming a heavier atom and releasing energy. The amount of energy released is immense. For equal amounts of fuel mass, the energy from fusion is about a million times greater than that released from a chemical reaction, such as the burning of fossil fuels.

For fusion to occur, several conditions must be met. The nuclei of the fusion fuel—deuterium and tritium—must travel toward each other fast enough to overcome the electrostatic forces that naturally repel them from each other. Thus, the fuel's temperature must be roughly 100 million degrees Celsius, and enough fuel must be held together long enough for the nuclei to collide and fuse.

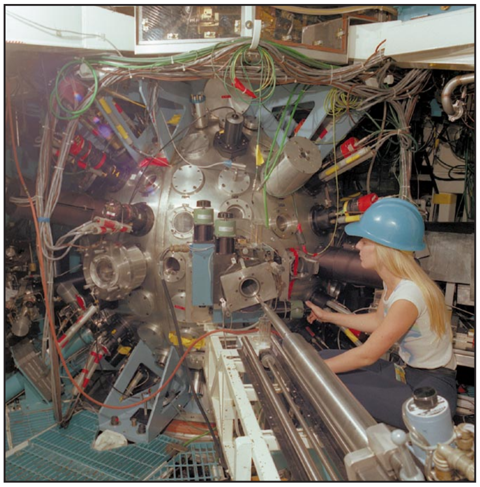
The inertial confinement fusion approach relies on the inertia (that is, the tendency of matter to resist changes in its state of motion) of the fuel to maintain a highly compressed state long enough for it to react and produce energy. In our solid-state laser systems, a small pulse of infrared laser light is amplified again and again through many laser stages until it reaches high power. The infrared light is then converted to ultraviolet light and focused onto the fusion target. Within an indirect-drive target, the light is converted yet again to x rays as it interacts with a small cylindrical container (hohlraum) that surrounds the tiny spherical capsule containing the deuterium–tritium fusion fuel. X rays heat the outer surface of the capsule, for an instant, to about a million degrees. The outer surface vaporizes and escapes outward, driving the inner part of the capsule and the deuterium–tritium fuel in on itself—that is, it implodes—and the fuel is compressed and heated to star-like fusion conditions of tens of millions of degrees. Another promising approach (direct-drive) to ignition and high gain directly illuminates the fusion capsule with a properly conditioned laser.

fusion fuel to a density 50 to 100 times greater than its liquid density.

Novette, which came on line in January 1983, was a test bed for the Nova laser design and served as an interim target experiment facility between Shiva and Nova. It was the first large laser (multikilojoule) designed and engineered to generate not only infrared beams but also green and ultraviolet light. In July 1984, Novette was used to create the first soft-x-ray laser in the laboratory.

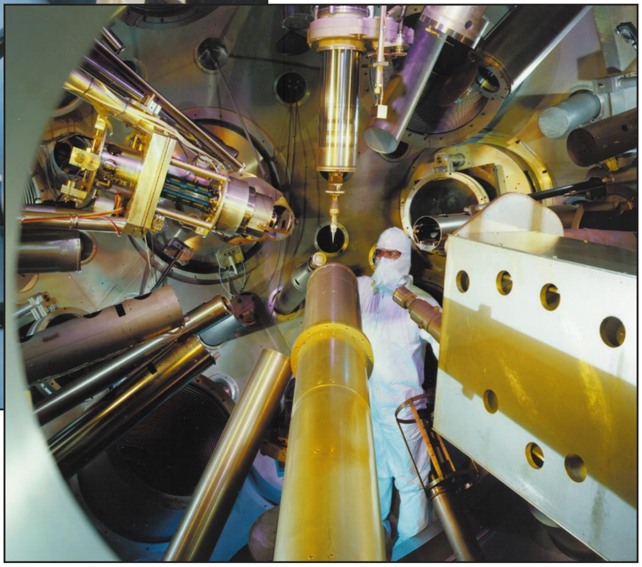
Nova became operational in December 1984. Ten times more powerful than Shiva, it was the world's most powerful laser at that time. Its ten beams produce laser pulses that can deliver up to 100 trillion watts of infrared laser power for a billionth of a second. For that brief instant, its power is 200 times the combined power that can be produced by all the electrical generating plants in the U.S. In January 1986, Nova produced the largest laser fusion yield, with a record 11 trillion fusion neutrons. In August 1987, Nova compressed a fusion fuel pellet to about 1/30th its original diameter, very close to that needed for high gain. In April 1989, it exceeded its maximum performance specifications by generating more than 120 kilojoules of laser energy at its infrared wavelength in a 2.5-nanosecond pulse. In May 1996, a record-setting laser shot produced pulses of more than 1300 trillion watts, or 1.3 petawatts of peak power, more than 1300 times the entire electrical generating capacity of the United States. The laser pulse lasted less than one-half a trillionth of a second, more than a thousand times shorter than that typically produced by the Nova laser.

With each new laser system, LLNL also developed increasingly sophisticated diagnostic instruments to measure and observe what was happening with the laser beam, in the target, in the interaction between the laser light and the plasma, and in the fusion process.



The 20-beam Shiva, completed in 1977, provided more power, better control over conditions, higher temperature, and greater fuel compression than previous lasers.

Nova, ten times more powerful than Shiva, was built in 1984. Nova experiments explore fusion and high-energy-density physics questions.



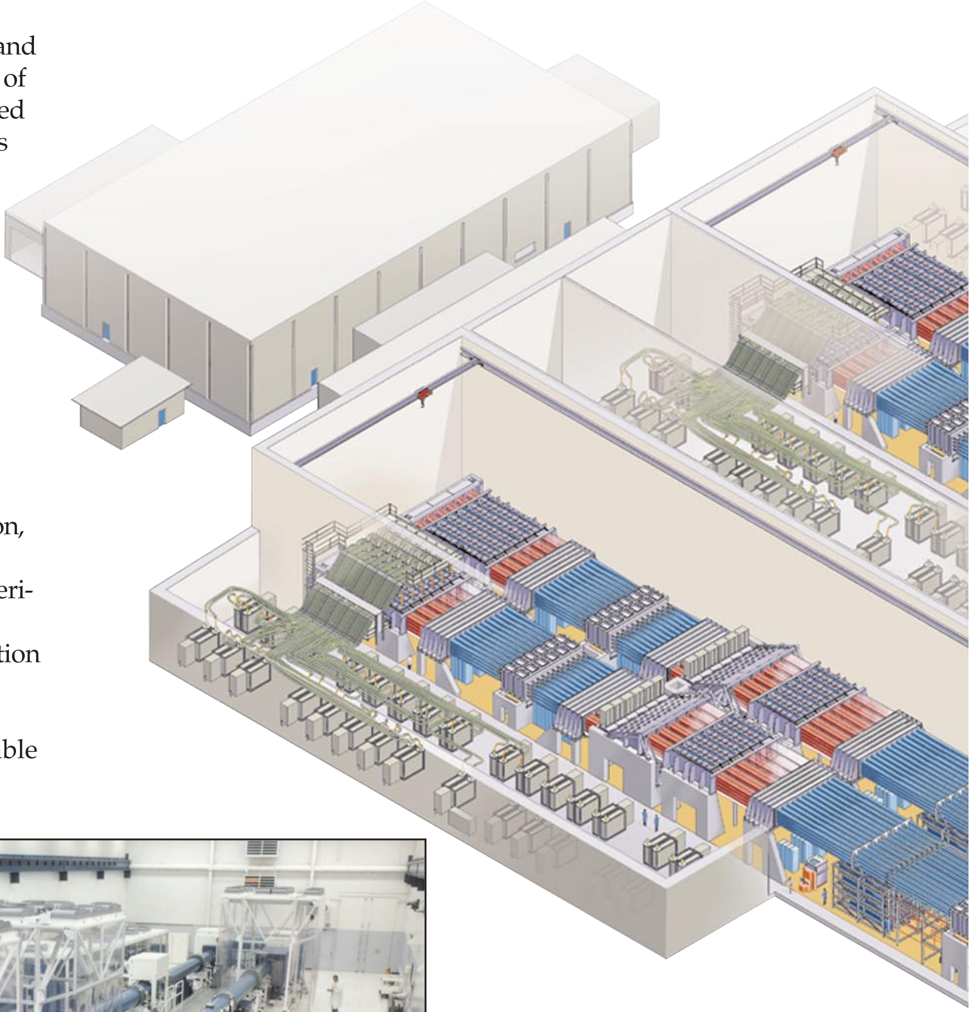
Inside the 5-meter-diameter Nova target chamber, the ten laser beams focus on a tiny target suspended in the center of the chamber.

National Ignition Facility (NIF)

It took over ten years to develop a laser capable of performing the physics experiments needed to effectively study inertial confinement fusion. It then took another ten years of experiments to determine the design of the next-stage laser needed to produce fusion ignition. Today, construction of that laser has begun.

The National Ignition Facility (NIF) will be a U.S. Department of Energy national center to study inertial confinement fusion and high-energy-density science in the absence of nuclear weapons testing. Its construction, led by LLNL, is a partnership with Los Alamos National Laboratory, Sandia National Laboratories, the University of Rochester, and numerous industries. The NIF will be a vital element of the DOE's Stockpile Stewardship and Management Program and will be used by scientists from a multitude of different institutions and disciplines to support research advancements in national security, energy, basic science, and economic development.

The NIF's total project cost is $1.2 billion, approximately 75% of which will go to U.S. industrial partners for equipment and materials or design and construction services. Engineering design began in 1996, construction started in 1997, system start-up of one bundle of eight beams is planned for late 2001, and all 192 beamlines will be available at the end of 2003.



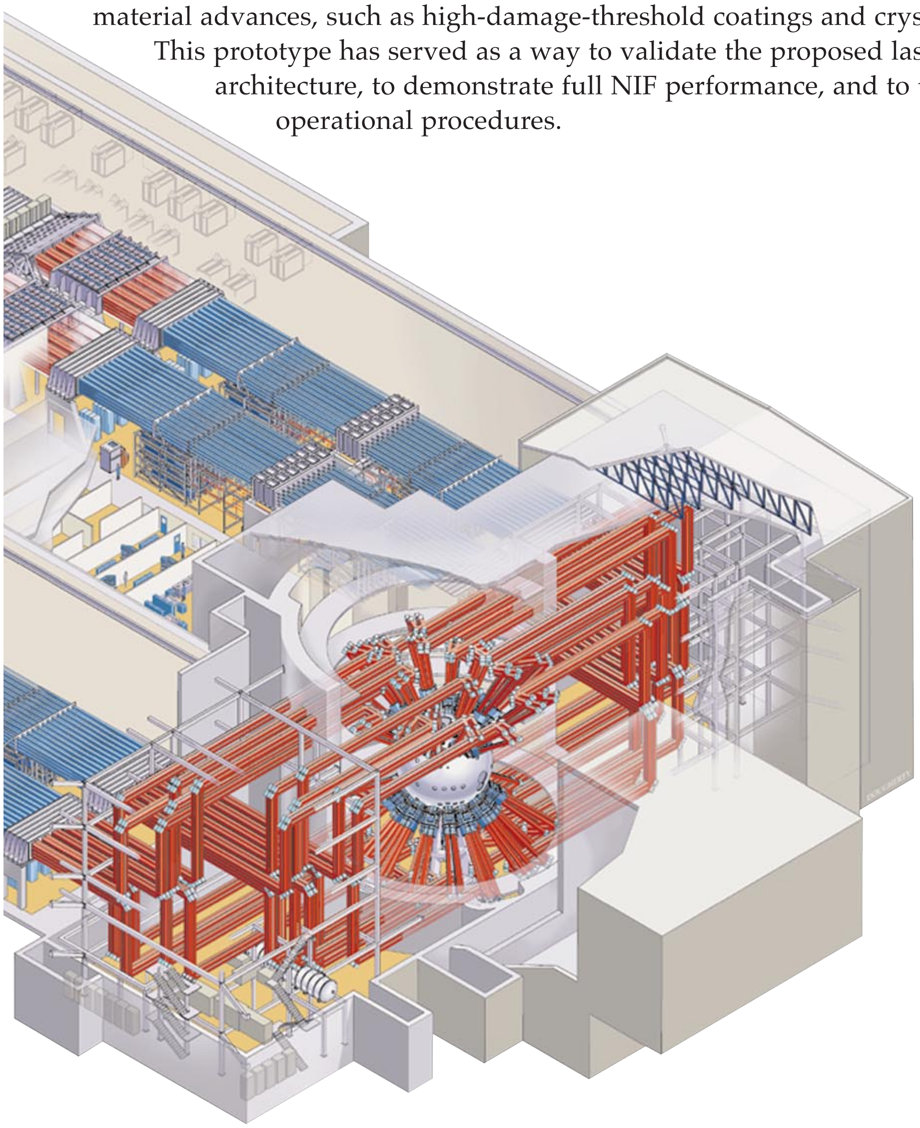
The Beamlet laser, a scientific prototype of one of the NIF's 192 beamlines, has been operating at LLNL since 1994.

The NIF will feature four main elements: a laser system and optical components, an area for the targets, an environmentally controlled building housing the laser system and target area, and an integrated computer control system.

The NIF's laser system, the heart of the new facility, features 192 high-power laser beams. Together, the laser beams will produce 1.8 million joules (approximately 500 trillion watts of power for 3 billionths of a second) of laser energy in the near-ultraviolet spectral region; this is a significant step beyond the Nova laser, currently the world's largest, which produces 45 thousand joules (45 trillion watts for 1 billionth of a second).

The light from the NIF's beams will be tightly focused onto a tiny target located inside a 10-meter-diameter spherical chamber equipped with the most advanced diagnostic equipment. The target will be filled with cryogenic fusion fuel. The laser light will compress (to pressures greater than 100 billion times that of earth's atmosphere) and heat the fuel to produce fusion reactions yielding up to 10 times the laser energy delivered to the target.

A full-scale prototype of one NIF beamline, called Beamlet, has been operational since 1994. It incorporates recent technology breakthroughs and material advances, such as high-damage-threshold coatings and crystals. This prototype has served as a way to validate the proposed laser architecture, to demonstrate full NIF performance, and to test operational procedures.



Inertial Fusion Energy

The National Ignition Facility will be used to prove that small inertial fusion targets can produce substantially more fusion energy than the laser beam (the driver) uses to heat the targets to the temperatures needed for the deuterium and tritium fuel nuclei to fuse together and release energy (ignition and energy gain). These ignition and energy gain experiments will take place once every few hours on the NIF, each shot producing the energy equivalent to burning a few pounds of coal.

However, to make an inertial fusion power plant in the future create the amount of electricity produced by typical power plants today, it will require new drivers capable of igniting targets in rapid succession (five to ten targets per second) and new target chambers with large coolant flows to remove the fusion heat. The leading candidate driver for such high pulse rates would use beams of heavy ions (such as lead ions), which are produced in a high-current pulsed accelerator and are focused onto the target with magnetic lenses. LLNL is doing experiments on a ring-shaped heavy-ion accelerator called a recirculating induction accelerator. LLNL is also developing new types of solid-state lasers, called diode-pumped solid-state lasers, as a potential alternative driver for power plants. Instead of using flashlamps as in the NIF, powerful arrays of small solid-state laser diodes are used to optically pump experimental lasers of the type developed at LLNL to ten pulses per second.

Uranium-AVLIS

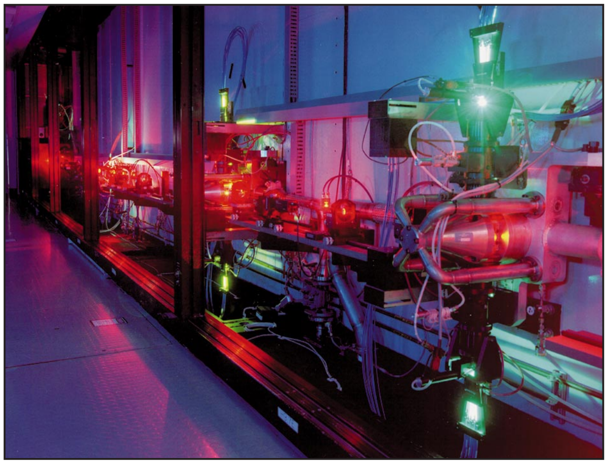
The Uranium Atomic Vapor Laser Isotope Separation (U-AVLIS) Program began in 1973 to help maintain the U.S. market share of supplying the world's enrichment services. The program was developed to produce uranium enriched in the uranium-235 isotope, which is needed to fuel fission reactors. The goal of this program today is to provide the world's lowest-cost uranium-enrichment method for commercial power-plant fuel.

Of the many different types of lasers, including solid-state, copper vapor, diode, and liquid dye, the U-AVLIS process uses copper vapor and liquid dye lasers as well as solid-state lasers to effect the separation process.

Copper vapor lasers produce green and yellow light from a mixture of copper vapor and neon. They are excellent sources of short, high-intensity laser pulses at very high pulse-repetition rates. Arrays of copper vapor lasers, scaled to high-average-power levels, are used for the U-AVLIS process as pump sources for tunable dye lasers. In addition, solid-state lasers are used to excite the low-power process lasers where the precise wavelengths that match uranium-235 are generated.

A copper vapor laser amplifier is undergoing testing in an LLNL facility.

Dye lasers use liquid organic dyes. Dye lasers can produce a broad and almost continuous range of colors, most of them in the visible part of the spectrum. An optical system is built into the laser to select certain colors, or to "tune" from one color to another. Energy to excite the dye must be supplied by another light source, in our case, copper vapor lasers. Dye lasers are particularly well suited for applications in which a precise color is required. Thus, they are an integral part of the U-AVLIS process.



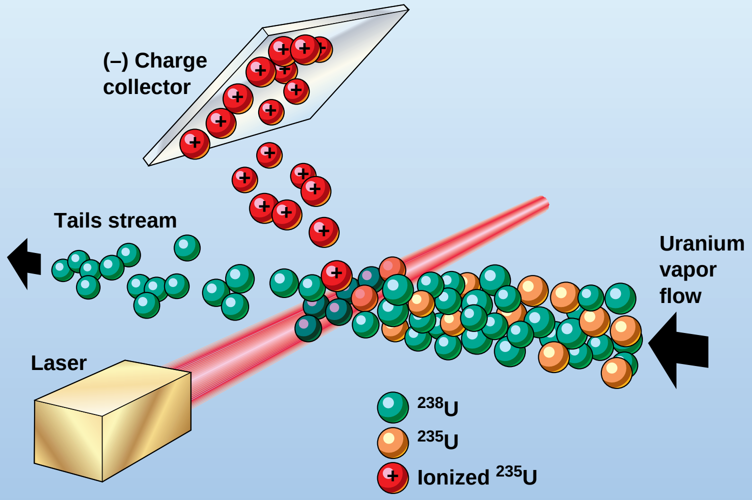
The dye laser corridor shown here displays the vivid red-orange color of the light used to separate uranium isotopes. Green copper laser light is delivered by optical fibers.

Advantages of U-AVLIS

U-AVLIS is a very compact and efficient process. Separation can be done in a single pass through an AVLIS separator, a great improvement over the hundreds of passes required in other processes. U-AVLIS is also energy efficient, using 1/20th the electrical power required by a gaseous diffusion plant. Large savings come from conserving electrical energy. Replacing existing U.S. gaseous diffusion enrichment plants with U-AVLIS would conserve electricity and provide a low-cost enrichment technology.

U-AVLIS also has the potential to mitigate adverse environmental, safety, and health impacts. The process can use uranium oxide, which is less hazardous, produces less low-level nuclear waste, and is less expensive than the uranium hexafluoride currently used by diffusion plants. In addition, computer control, robotics, and remote handling greatly reduce concerns about personnel health and safety. The high efficiency of the separation process, the demonstrated performance and durability of system components, and the environmental, safety, and health advantages combine to make U-AVLIS superior to other uranium enrichment processes.

AVLIS Process

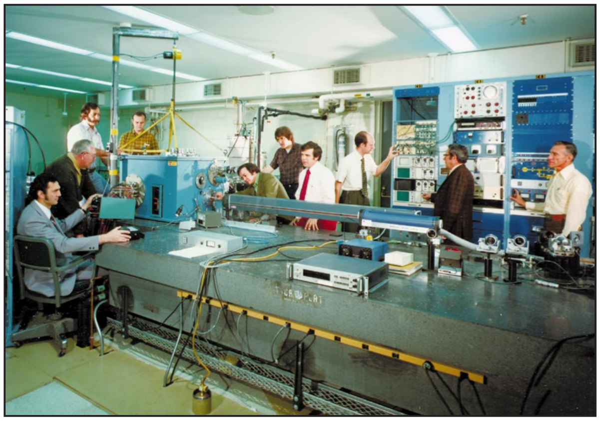


Isotopes of every element have unique spectroscopic “signatures” defined by the colors of light absorbed by their atoms. By precisely tuning lasers to the color signature of a specific isotope, those atoms can be selectively photoionized and then electrically separated. The AVLIS process can, in principle, be used to separate isotopes of most elements.

The separation process uses finely tuned, high-power lasers to tag the fissile isotope of uranium-235 by removing one of its electrons. A positive uranium-235 ion results. The product stream is formed by collecting these ions as well as a portion of the feed material on charged plates. Uranium depleted in uranium-235 forms the tails stream. This process takes place in a vacuum chamber in which the uranium is vaporized and exposed to the lasers. Both streams are removed as small nuggets of solid uranium metal. Further chemical processing and fabrication yield finished fuel for use in nuclear power reactors.

First U-AVLIS enrichment demonstration (1974)

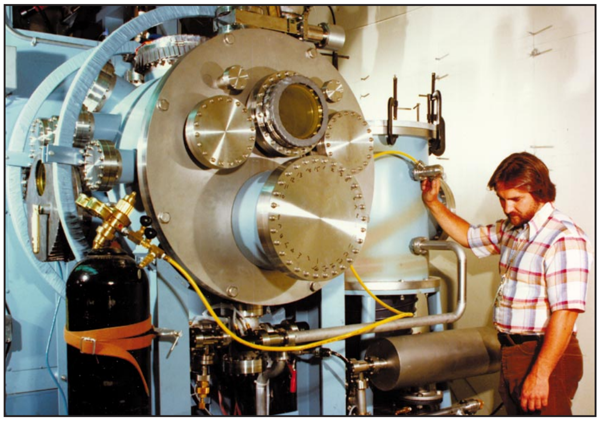
Using a refractory metal oven to produce vaporized uranium, the Morehouse experiment produced milligram quantities of enriched uranium, verifying the physics of the AVLIS process for the first time at LLNL. A combination of lasers, resonance optical radiation, and electrostatic ion collection were used. This was the starting point for the LLNL-developed process. Subsequent increases in the scale of efficiency over the next several years were needed to show commercial promise.



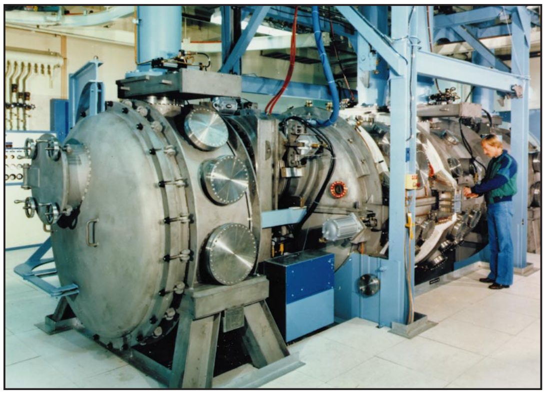
The Morehouse experiment produced milligram quantities of enriched uranium for the first time.

Large-scale enrichment (1980)

A few years after the proof-of-principle experiments at microscopic scale, a larger, gram-scale experiment using electron beams to vaporize uranium and more powerful lasers successfully separated several grams of enriched uranium at an enrichment of a few percent. This was achieved with the REGULIS separator. Based on an electron beam evaporation process, this unit was the next step in reaching practical production levels.



The REGULIS separator successfully separated several grams of enriched uranium.



The MARS Facility is coupled to process lasers in an adjacent facility.

Component research and development (1978–1984)

Continued scale-up of the lasers and separators culminated in experiments in uranium and plutonium at practical-use scale. At the MARS Facility, where fractions of metric tons of uranium were processed, the assays and product masses developed were high enough that economic projections of industrial-scale implementation of this technology became realistic. At the same time, the lasers were scaled to near-plant operating parameters. These components are key to economic production of high-power laser light needed to operate a commercial plant.

This uranium enrichment plant design equals the capacity of existing gaseous diffusion plants.

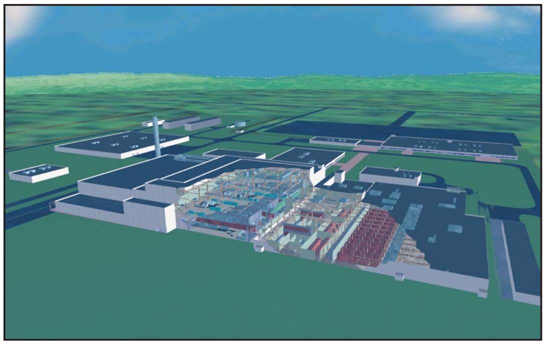
DOE selects U-AVLIS over other contending enrichment technologies (1982–1985)

After many internal and external reviews, the Department of Energy (DOE) decided in favor of U-AVLIS over other enrichment technologies (including gaseous diffusion and the gas centrifuge) for continued development of an advanced commercial enrichment process to provide low-enriched uranium to power reactors. Shown is an artist's view of a uranium enrichment plant equal in capacity to the existing gaseous diffusion plants now used. U-AVLIS offers the promise of lower capital and operating costs as well as adherence to recent environmental requirements.

The Uranium Demonstration System at LLNL tests the AVLIS process at plant scale.

Plant-scale enrichment demonstrations and conceptual design (1986–1992)

The Uranium Demonstration System (UDS) and the Laser Demonstration Facility (LDF) at LLNL were constructed to test the U-AVLIS process at plant scale and are the basis for developing a complete plant conceptual design. Cost and performance projections are based on results from these demonstrations and the conceptual design. Pilot operation of selected plant qualified subsystems is planned to take place in these facilities up to the turn of the century.



The proposed USEC plant will be constructed with private funding and will provide enrichment services for the power industry.

United States Enrichment Corporation (USEC) takes over AVLIS sponsorship (1992–present)

Congressional action to privatize DOE's enrichment enterprise created the USEC. Included was the change in sponsorship of the U-AVLIS Program from DOE to USEC. Final development work and initial plant design work are presently taking place at LLNL. This drawing shows the USEC plant situated in an as yet to be determined site. Recent legislation signed by President Clinton allows USEC to become a private corporation charged with commercializing the enrichment operations previously run by the Department of Energy.

Spin-off and Core Technology Programs

Strategic Materials Applications Program (SMAP)

The Laser Programs have a long history of work with nuclear materials, beginning with the U-AVLIS Program in the early 1970s. In carrying out experiments showing that lasers could be used to convert natural uranium into a form usable as fuel in the nation's electric power-generating reactors, Laser Programs scientists, engineers, and technicians gained a great deal of experience in handling uranium and other radioactive materials.

In 1980, the DOE funded the Laboratory to develop a laser process to convert their stock of plutonium-based reactor fuel into material usable in nuclear weapons. In 1981, the Special Isotope Separation Program was created, and in 1982, it built and demonstrated a prototype plutonium system in the Laboratory's Plutonium Facility. Successful demonstrations in 1982 led to construction of a larger unit in 1984, whose performance exceeded expectations.

1982—A small-scale plutonium isotope separation system was successfully demonstrated.

By the mid-1980s the shortage of plutonium for weapons became a serious concern, and the DOE funded the Laboratory to build a full-scale prototype laser separation system, a task completed by the late 1980s. With the end of the Cold War, the need for plutonium production disappeared, and the plans for the plutonium separation plant were halted. However, the DOE recognized LLNL's expertise in nuclear materials and funded the application of several advanced processing technologies for the ongoing cleanup of DOE's production complex. In 1996, the Strategic Materials Applications Program (SMAP) was created as a separate program in the Laser Directorate.

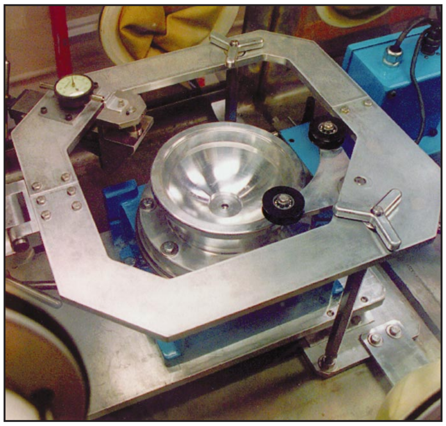
SMAP projects today are engaged in developing technologies for processing, manufacturing, and storing nuclear materials associated with the nation's nuclear weapons stockpile. They are also developing advanced techniques for the safe and secure disposition of excess nuclear materials from the DOE's inventory.

1988—The production prototype hardware neared completion in the LLNL Plutonium Facility.

SMAP is working with Los Alamos National Laboratory (LANL) to develop the Advanced Recovery and Integrated Extraction System to recover plutonium from retired or excess nuclear weapons. SMAP has developed the hardware to cut apart the returned pits and recover the plutonium in a stable form for long-term storage or disposition. LLNL will develop the prototype hardware, test the systems, and design the final production module for installation and use at LANL.

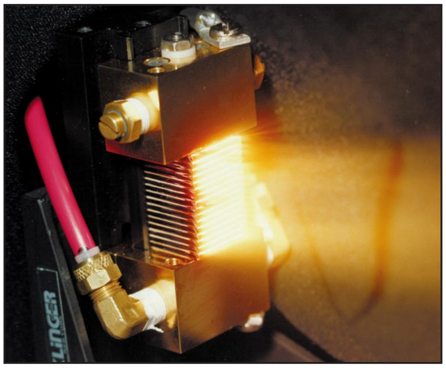
A laser cutting technology is also being developed for DOE Defense Programs to help disassemble nuclear weapons in a manner that will allow reuse of high-cost components within the weapons. Using LLNL-developed short-pulse laser technology, SMAP demonstrated an ability to make extremely narrow and highly precise cuts narrower than the width of a human hair with no damage to the surrounding material. SMAP is currently designing and constructing a production laser system for DOE's Y-12 Plant in Oak Ridge, Tennessee, for delivery this year.

In another project, SMAP is developing techniques of mixing plutonium with glass and ceramic for long-term storage and disposal that will keep it out of the hands of terrorists in a manner that is also environmentally safe.



1996—This machine was developed to split plutonium pits apart to recover the plutonium.

A flashlamp assembly is being tested in the AMPLAB.



A high-power (1.45-kW) semiconductor laser diode array using a microchannel cooler was demonstrated at LLNL in 1990.

This pair of large gratings inside a vacuum compression chamber at the output of Nova was used to produce a petawatt (million-gigawatt) laser output pulse in 1996.

Laser Science and Technology (LS&T) Program

Although the present Laser Science and Technology Program was established in 1994 to provide laser technology development and validated performance models for the NIF and advanced ICF laser systems, laser science and technology has been the cornerstone of the Laser Programs since its inception. The laser work has been continuously driven by the extreme demands of inertial confinement fusion, both in precision control and overall power and energy, as well as the needs of laser isotope separation and other government and industrial applications. In the first ten years, the Laser Programs pursued a dual track in both solid-state and gas lasers for fusion, assuming fusion power plant needs could only be provided by a gas laser using gas flow to remove waste heat. Although pioneering advances were made in gas lasers, the solid-state approach was pursued in the early 1980s when John Emmett, Bill Krupke, and others recognized that advanced solid-state lasers could potentiallly meet the average-power needs of fusion and many other high-power applications.

Following the completion of the Nova laser in 1984, Laser Programs began to envision megajoule-energy lasers to achieve fusion ignition and gain. Subsequently, many of the elements needed for this, such as compact multisegment amplifiers based on stacks of rectangular laser slabs, a large-aperture optical switch to allow multipass amplification, and higher-damage-threshold optics were developed. These advances were brought together in the Beamlet laser, completed in 1994 as a scientific prototype of a beamline for the NIF (see page 6). In 1996, the LS&T Program, in collaboration with researchers working on the Laser MegaJoule (the French counterpart to the NIF), designed a new laser beam amplifier that will be assembled and tested in a newly created amplifier module prototype lab (AMPLAB) located at LLNL. The new amplifier design accommodates eight beams closely packed together that store short bursts of light from flashlamps (360 millionths of a second long) and transform them into amplified laser pulses that are several billionths of a second long. The French collaboration to share ideas and costs for development of megajoule lasers has been highly successful.

In parallel with these developments toward a single-shot megajoule laser, technologies relevant to average-power lasers were also pursued. In 1990, the kilowatt-scale average-power semiconductor diode lasers were developed for the first time. Replacing the gas-filled flashlamps with efficient (~50%) solid-state laser diode pumps allowed the construction of compact, efficient (~10%), high-beam-quality solid-state lasers operating at kilowatt-power levels. With the start of the new Mercury Project, the LS&T Program is now beginning to envision diode-pumped solid-state lasers operating at the energy of the NIF at several times per second (megawatt power level), which could satisfy the driver needs of fusion power plants. Diode-pumped solid-state lasers are also being developed for remote sensing, Department of Defense directed energy, and industrial applications.

Pushing the limits on peak laser power in the 1980s, lasers based on “chirped-pulse compression” were developed in which the color spectrum inherent in a short pulse is stretched out in time, amplified separately, and then recompressed at the output to produce an energetic short pulse on target. This principle led to tabletop lasers having the peak-power capabilities of terawatts (thousands of gigawatts) equal to that of a Nova beamline but in a one-thousand-times-shorter pulse. One gigawatt is the continuous output power of a typical power plant. In 1996, LS&T completed a petawatt (million-gigawatt) beamline on Nova that is now being used to study the “fast-ignitor approach” to fusion in which such an ultrapowerful laser provides a “spark” to ignite a compressed fusion capsule. An eventual goal is to repetitively produce such ultrahigh peak-power pulses. Such lasers would open up new applications in energy production, materials processing, basic science, and other fields.

Advanced Microtechnology Program (AMP)

Since the early 1990s, the Advanced Microtechnology Program (AMP) has become one of LLNL's fastest growing industrial outreach activities. AMP includes the Imaging and Detection Group, which is breaking new ground in obtaining, processing, and analyzing images. AMP's successful partnering with industry is both a payoff from DOE's Technology Transfer Initiative and a model for future industry interactions of developing and spinning off commercial technology.

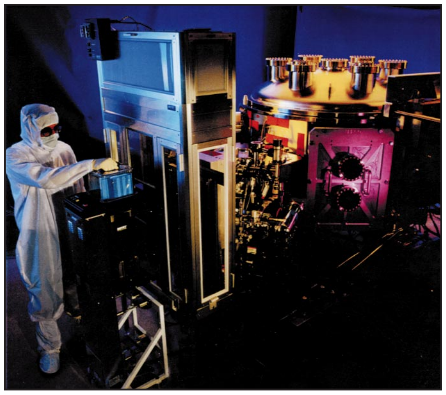
AMP's largest project, extreme ultraviolet lithography (EUVL), has transitioned from a Technology Transfer Initiative-sponsored partnership with industry to a completely industrially funded program. The EUV Limited Liability Corporation has signed a Cooperative Research and Development Agreement with three national laboratories—LLNL, Sandia National Laboratories, and Lawrence Berkeley Laboratory—who formed a "Virtual National Laboratory" to act as a single unit to provide short-wavelength [approximately 13 nanometers (nm)] projection lithography capability for mass production of integrated circuits [features less than 0.10 microns (μm)]. Many award-winning inventions have been developed as a result, including the Veeco IBD 350 system that reduced defect density by a factor of 10^5 on films critical to device fabrication in the \$120 billion semiconductor and the \$100 billion magnetic recording industries. To build the world's most accurate optics, AMP developed the Absolute Interferometer, a revolutionary yet conceptually simple optical measuring tool increasing accuracy 100-fold to measure surfaces *absolutely* to atomic dimensions, less than 1 nm.

The Micropower Impulse Radar, a spin-off of a transient digitizer for ICF's fusion diagnostics, has also won numerous awards (over 30 associated patents; licensed to more than 20 companies). Current applications include finding plastic land mines and using High-Speed Electromagnetic Roadway Mapping and Evaluation Systems (HERMES) to detect and analyze road defects, thus improving the safety of our highway infrastructure. Other applications include law enforcement, respiration and heart-rate measurement, speech processing, and security sensors for DOE and the Department of Defense.

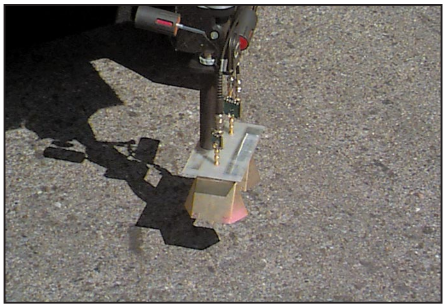
AMP has created other revolutionary technologies: A flat-panel display project to produce field-emission display structures that should be brighter, faster, and less costly than liquid-crystal displays; a microthin (~25 μm) lens for the human eye to potentially make conventional cataract surgery obsolete and perhaps eliminate the need for conventional eyeglasses and contact lenses; and (collaborating with Read-Rite Corporation) new materials for a sensor head capable of ultrahigh information area density of greater than 10 gigabytes per square inch, well beyond current head technology.

The Imaging and Detection Group activities have been multiproject efforts encompassing advanced imaging concepts, remote sensing, signal processing and detection, and novel airborne platforms for conducting experiments. One of the major early projects was Radar Ocean Imaging, advancing radar and signal-processing systems for remote sensing of the sea to detect surface manifestations of undersea phenomena.

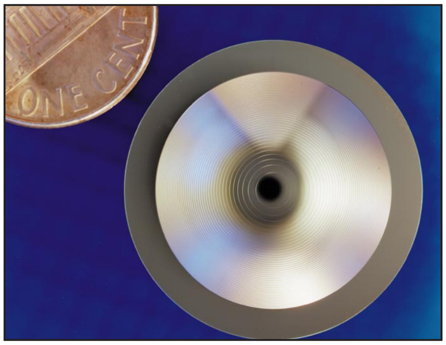
The Laser Guide Star combined AVLIS laser technology and Imaging and Detection Group signal processing expertise to compensate for atmospheric turbulence that severely limits the resolution of ground-based telescopes. A laser guide star is created in the portion of the sky observed, and a deformable mirror is used to provide a threefold improvement in image clarity.



This EUVL tool deposits virtually defect-free, ultrathin films on integrated circuits.



The antenna element on the HERMES robotic cart analyzes road defects.



This microthin lens can correct human vision.

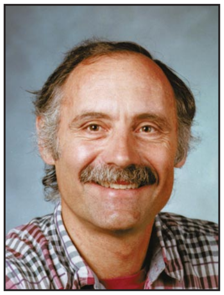
The Laser Guide Star is used for improved image resolution.

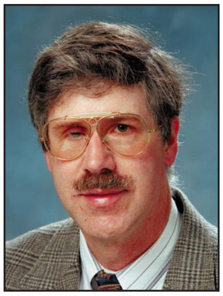
Awards


John Nuckolls
E. O. Lawrence award, 1969
Maxwell Prize, 1981
FPA Leadership award, 1982
Edward Teller award, 1991


John Emmett
E. O. Lawrence award, 1977
FPA Leadership award, 1983


Grant Logan
E. O. Lawrence award, 1980


George Zimmerman
E. O. Lawrence award, 1983
Edward Teller award, 1996


John Lindl
Edward Teller award, 1993
E. O. Lawrence award, 1994

The scientific and technical excellence of our Laser Programs staff is widely recognized nationally and internationally. Our researchers include 55 fellows of professional research societies. Over the years, Laser Programs personnel have received two American Physical Society/Division of Plasma Physics Maxwell Prizes, two Excellence in Plasma Physics awards (shared by ten researchers), six E. O. Lawrence awards, four Edward Teller awards, four Fusion Power Associates (FPA) Leadership awards, and four Excellence in Technology Transfer awards (shared by ten people). From 1985 to 1997 the Laser Directorate has won 32 R&D 100 Awards, placing it seventh in overall competition. The Directorate has received 34 awards in total; one-half of LLNL's total of 68. In addition, since 1981, the AVLIS and ICF Programs have obtained 430 invention disclosures, filed 345 patent applications, and been awarded 241 patents. The Laser Programs also publish an average of 300 documents each year.

Fellowships

The following is a list of Laser Programs scientists who have received society fellowships.

American Physical Society Fellows

James R. Albritton (1986)
Hector A. Baldis (1983)
E. Michael Campbell (1985)
George J. Caporaso (1997)
Donald L. Correll (1993)
Jacques Denavit (1977)
R. Paul Drake
John L. Emmett
Kent G. Estabrook (1980)
Michael D. Feit (1988)
Joseph A. Fleck Jr.
Richard R. Freeman (1982)
Alex Friedman (1997)
Steven W. Haan (1994)
Bruce A. Hammel (1996)

R&D 100 Awards

Year	Research area	Scientists
1978	Diamond machining process	Ted Saito, Jim Bryan, and Phil Steger (with Union Carbide Nuclear Div., Los Alamos Scientific Lab, and the Air Force)
1979	Nd-doped fluorophosphate laser glass	Marvin J. Weber, S. E. Stowkowski, Perry Wallersten (LLNL); and T. Izumitani (Hoya Optics), P. Vergano, C. Rapp (Owens Illinois); K. Mader, N. Neuroth (Schott Glass Technologies); W. Haller (National Bureau of Standards)
1985	Time-resolved imaging x-ray spectrometer	Natale Ceglio, Hector Medecki, and Robert Kauffman
1986	Beam splitter for low-energy x rays	Natale Ceglio, Andrew Hawryluk, Dan Stearns, and Troy Barbee
1986	Precision engineering research lathe	Dan Thompson
1987	Platinum-free phosphate laser glass	John Campbell (with Schott Glass Technologies and Hoya Optics)
1987	Zone-plate coded microscope	Natale Ceglio
1987	Highly dispersive x-ray mirror	Natale Ceglio, Andrew Hawryluk, and Dan Stearns
1987	Planar triode pulser	Rex Booth (with Grant Applied Physics)
1988	X-ray laser cavity	Natale Ceglio, David Gaines, Andrew Hawryluk, and Dan Stearns
1988	Neutron penumbral-aperture microscope	Richard Lerche, David Ress, Ray Ellis, Steve Lane, and Keith Nugent (University of Melbourne, Australia)
1988	Composite polymer-glass edge cladding	Laser Programs Research Team (with Eastman Kodak and Zygo Corp.)
1989	Reflective x-ray mask for lithography	Natale Ceglio, Andrew Hawryluk, and David Gaines
1990	Ultrathin diffractive lens	Andrew Hawryluk, Natale Ceglio, and John Stanley (UC San Francisco)
1990	Ultralow-density silica aerogel	Thomas Tillotson, Lawrence Hrubesh, and Ian Thomas
1991	CR:LiSAF and Cr:LiCAF lasers	William Krupke, Stephen Payne, and Lloyd Chase
1991	Thyratron replacement solid-state switch	Gary Drifuerst and Bernard Merritt
1993	Modular high-power laser diode array	William Benett, Barry Freitas, and Raymond Beach
1993	Single-shot transient digitizer	Thomas McEwan and Joseph Kilkenny
1994	A process for rapid growth of KDP	James De Yoreo, Kenneth Montgomery, Russell Vital, and Natalia Zaitseva; Leonid Rashkovice (Moscow State University)
1994	Ytterbium-doped apartite laser crystals	Stephen Payne, William Krupke, Laura DeLoach, Larry Smith, and Bruce Chai (CREOL)

E. Michael Campbell
Weapons Program Award of Excellence, 1985
Excellence in Plasma Physics award, 1990
E. O. Lawrence award, 1994
Edward Teller award, 1994
FPA Leadership award, 1995

William Kruer
Maxwell Prize, 1990

Erik Storm
FPA Leadership award, 1991

Booth Myers
Excellence in Technology Transfer award, 1996

Hao-Lin Chen
Excellence in Technology Transfer award, 1996

R&D 100 Awards

Year	Research area	Scientists
1994	Efficient multilayer dielectric gratings	Michael Perry, Robert Boyd, Jerald Britten, Derek Decker, Howard Powell, Bruce Shore, and Hugh Garvin. Earl Shults, Clay Shannon, and Roger Withington (Hughes Electrooptic Systems)
1995	All-solid-state laser with diode irradiance conditions	Raymond Beach, Chris Marshall, Mark Emanuel, Steve Payne, Bill Benett, Barry Freitas, Steve Mills, Scott Mitchell, Charles Petty, and Larry Smith
1995	High-average power solid-state laser with high pulse energy and low-beam divergence	Cliff Dane, Lloyd Hackel, and Mary Norton
1995	Sealed tube electron beam guns for material processing	Booth Myers, Hao-Lin Chen, Jim Davin, Glen Meyer, George Wakalopulos, Peter Bond
1996	Micropower impulse radar dipstick to measure fluid levels	Tom McEwan
1996	Computer hard disk reading sensor	Stephan Vernon, Daniel Stearns, James Spallas, Benjamin Law, Don Kania, Andrew Hawryluk, Charles Cerjon, and Natale Ceglio
1996	Flat-panel display lithography technique	Michael Perry, Jerald Britten, Hoang Nguyen, Andrew Hernandez, Robert Boyd, Andrew Hawryluk, James Spallas, and Natale Ceglio
1996	Nonoptical sensor for computer-controlled machines	Charles Vann
1996	Cerium lithium strontium aluminum fluoride laser	Christopher Marshall, Andy Bayramian, Joel Speth, John Tassano, Stephen Payne, and William Krupke
1997	Absolute interferometer	Gary Sommargren, Eugene Campbell, Don Phillion, and Frank Snell
1997	Ultra Clean Ion Beam Sputter Deposition System	Don Kania, Patrick Kearny, Richard Levesque, and Steve Vernon (with Alan Hayes, Boris Druz, Edward Osten, Renga Rajan, Hari Hedge, and Manny Lakios from Veeco Instruments Inc. of Plainview, N.Y.)
1997	Femtosecond laser materials processing	Brent Stuart, Michael Perry, Hoang Nguyen, Steve Herman, Paul Armstrong, Paul Banks, Michael Feit, Alexander Rubenchik, Booth Myers, Howard Powell, and Joseph Sefcik (D&NT)
1997	Ultra high gradient insulator	Steve Sampayan, Ted Weiskamp (D&NT), Dave Trimble (Engineering), Bob Stoddard (D&NT), and Dave Sanders (Engineering) (with Mike Krogh, Steve Davis, and Bryan Schultz from AlliedSignal Federal Manufacturing & Technology Plant)

American Physical Society (cont.)

Charles D. Hendricks
Dennis W. Hewett (1994)
Ralph R. Jacobs (1994)
Roy R. Johnson (1982)
Ray Kidder
Joseph D. Kilkenny (1990)
William L. Kruer (1978)
Kenneth C. Kulander
A. Bruce Langdon (1980)
John D. Lindl (1984)
B. Grant Logan (1980)
Richard A. London (1992)
Brian J. MacGowan (1995)
Dennis L. Matthews (1985)
Claire E. Max (1982)
William Mead (1980)
Ralph W. Moir (1981)
John H. Nuckolls (1979)
Bruce Remington (1995)
Mordecai D. Rosen (1985)
Bruce W. Shore
Laurance J. Suter (1996)
Jeffrey Thompson (1978)
Ernest Valeo (1982)
Edward A. Williams (1987)
George Zimmerman (1997)

American Nuclear Society Fellows

Ralph W. Moir (1989)
Carl Henning (1994)

Optical Society of America Fellows

Michael D. Feit (1992)
Ricard R. Freeman (1979)
Ralph R. Jacobs (1991)
William F. Krupke (1993)
Dennis Matthews (1996)
John R. Murray (1993)
Jeffrey A. Paisner (1983)
Gary Sommargren (1996)
Marvin J. Weber

Acoustical Society of America Fellows

James Candy (1996)

Institute of Electrical and Electronics Engineers Fellows

Ralph R. Jacobs (1991)

American Association for the Advancement of Science Fellows

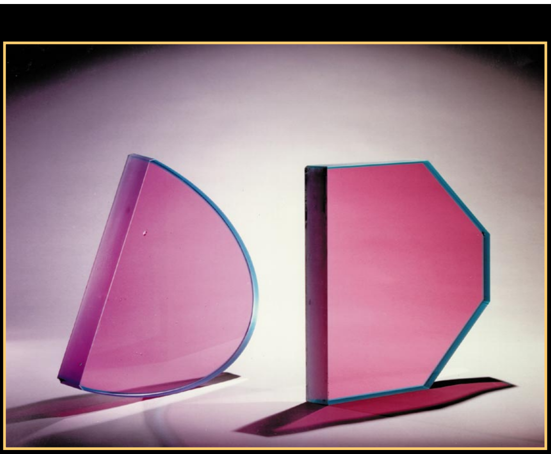
John H. Nuckolls (1992)

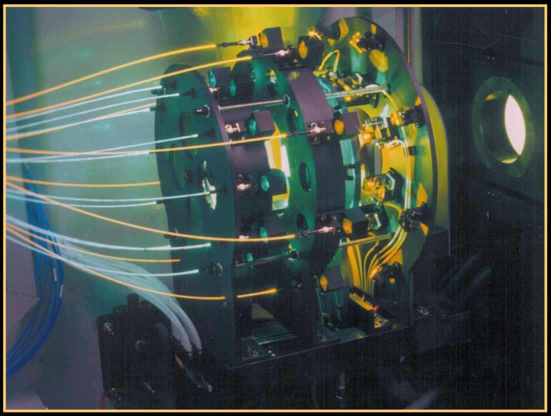
Conclusion

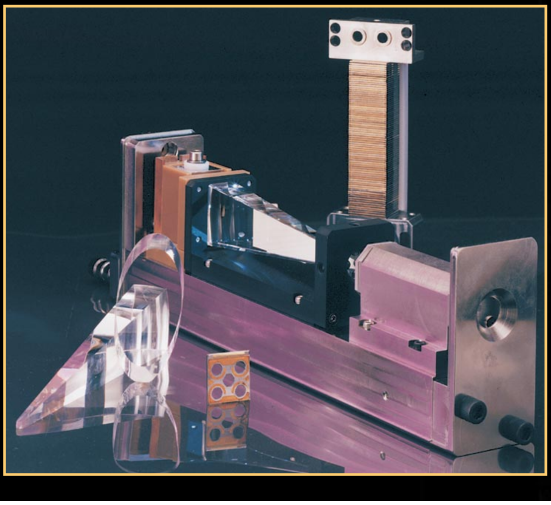
In the past 25 years, the Laser Programs have become the teachers of the world in the field of lasers through their pioneering research, thousands of publications, and laser facilities to which people from across the nation and the world come to conduct experiments. As a result, Japan, France, England, and China have all developed laser facilities based on the lasers created in Livermore.

The successes of the Laser Programs have been achieved because key people in the program have been motivated to do something that has never been done before on the face of the earth. Progress continues in this endeavor because the excellence that spawned the Laser Programs has generated further excellence, each team ensuring that its quality of work is maintained and rejuvenated with those who follow. The unique melding of scientists and engineers, both vigilant and flexible, has in essence created a whole bigger than its parts—a renowned laser program that has acquired, nurtured, and maintained world-class inertial confinement fusion and uranium separation research and spin-off developments for the betterment of the future needs of humanity.


LASER POWER







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