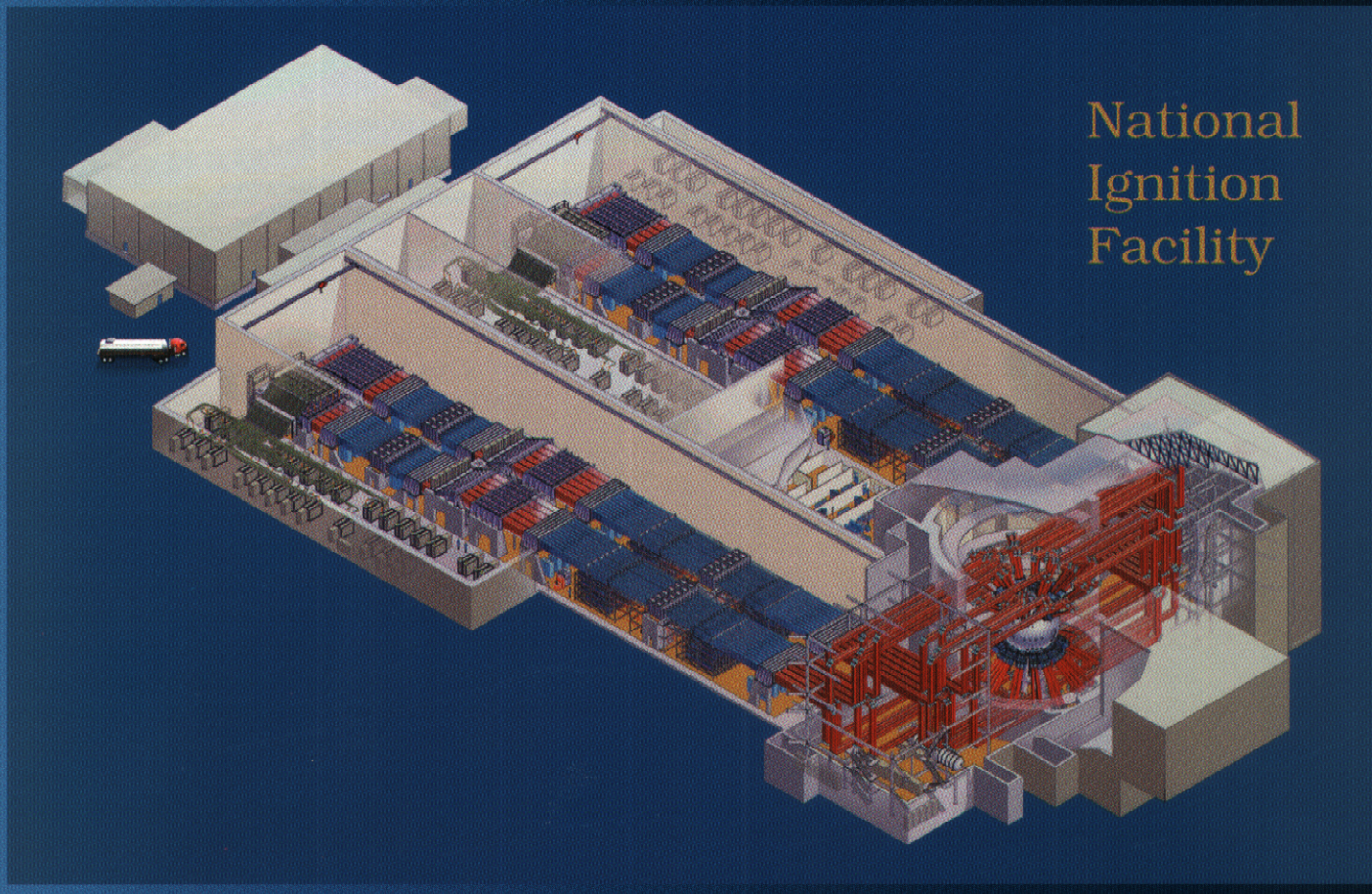
Laser Programs Highlights 1996



University of California
Lawrence Livermore National Laboratory

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Metrics for 1996

- 122 refereed technical publications.
- 33 patents were issued; 29 patent applications were filed; and 68 patent disclosures were submitted.
- 16 licenses were executed resulting in $927,000 in licensing income.
- 5 R&D 100 Awards. Between 1985 and 1996 the Laser Directorate has won 28 R&D 100 Awards, placing it seventh in overall competition for all organizations.
- The Laser Directorate received an "outstanding" (highest) rating in the University of California Science and Technology Assessment for the third consecutive year.
- 3 Federal Laboratory Consortium Awards for Excellence in Technology Transfer. These three awards, representing LLNL's total, rank the Lab among the top 1996 winners out of more than 650 federal government laboratories and research centers that comprise the consortium. Numerous other individual awards. (See pages 12–20).

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On the Front Cover

The National Ignition Facility will contribute to DOE's vision of stockpile stewardship and management without underground testing. The NIF will be housed in a stadium-size building. Partial operation is scheduled for 2001; full operation in 2004.

On the Back Cover

The Atomic Vapor Laser Isotope Separation (AVLIS) Facility will provide the world's lowest-cost enriched uranium for commercial power plant fuel. A plant is scheduled for full production by 2005.

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Laser Programs

Our contributions to laser technology and its applications range from new visions in defense and industry to micro-optics for improving human vision. Our skill in translating our knowledge base into outstanding technological innovation is a vital characteristic and continuing goal of the Laser Programs.

Laser programmatic facilities (including the si of the National Ignition Facility).

Lawrence Livermore National Laboratory's (LLNL) Laser Programs Directorate is a world leader in laser and electro-optic science, engineering, and technology. We are applying this expertise to meet critical needs in the diverse areas of national security, energy, the environment, and the economy. We are also extending our collaborations with industry and other institutions to identify technologies that can be developed and transferred to the private sector.

The scientific and technical excellence of our Laser Programs staff is widely recognized both nationally and internationally. Our researchers include 43 fellows of professional research societies. Over the years, Laser Programs personnel have received two Maxwell awards, ten Excellence in Plasma Physics awards, six E. O. Lawrence awards, four Edward Teller awards, and 34 R&D 100 Awards, among others.

Our principal laser projects derive from the core intellectual and technical capabilities developed for national security and involve the full complement of Livermore's multidisciplinary expertise. Many of the technical staff within the diverse set of Laser Programs activities are matrixed from the discipline organizations within LLNL including Computations, Chemistry, Engineering, and Physics.

The Laser Programs Directorate has two long-standing major programs: the Inertial Confinement Fusion Program (ICF Program) and the Atomic Vapor Laser Isotope Separation Program (AVLIS Program).

- The mission of ICF is to demonstrate thermonuclear fusion ignition and energy gain in the laboratory. LLNL's ICF Program has made great advances in understanding the scientific principles of ICF. Livermore's Nova laser is the main experimental tool for our ICF activities. We are advancing ICF technology in support of national security and as an environmentally clean source of energy. ICF research is providing improved understanding in many areas of basic science and making contributions to meet national economic challenges. The next-generation ICF laser facility, the National Ignition Facility (NIF), is now under development at Livermore, in conjunction with Los Alamos National Laboratory, Sandia National Laboratories, and the University of Rochester.
- The mission of the AVLIS Program is to provide the world's lowest-cost, uranium-enrichment method for commercial power-plant fuel. With this method, precisely tuned laser light and uranium vapor are brought together in a separator vacuum assembly. In the separator, atoms of the ^{235}U minor isotope in an atomic vapor stream of natural isotopic composition are selectively optically excited and photoionized by laser light. The selectively ionized ^{235}U isotope is then collected to generate a product enriched in this isotope. Once enriched, the metal product is processed into nuclear fuel for power plants.

In addition, our Directorate includes the Laser Science and Technology Program (LS&T Program), the Advanced Microtechnology Program (AMP), and the Strategic Materials Applications Program (SMAP).

- The LS&T Program provides technical innovation and leadership in promoting advancements in laser science and in developing new laser technology for applications ranging from laser drivers for generating fusion energy to laser surgery.
- The AMP Program pioneers the use of laser-based microtechnologies such as extreme ultraviolet lithography (EUVL) for integrated circuit manufacturing, micropower impulse radar (MIR) for a wide range of government and commercial applications, and brighter, faster, and less costly flat-panel displays.
- The SMAP Program consolidates a number of existing smaller programs in the general area of technologies for strategic materials emphasizing uranium and plutonium.

Besides major contributions in national security, basic science, technology, and applications over the past decade, these programs have provided significant advances in:

- Optics
- Diagnostics and sensors
- Materials handling and processing
- Microfabrication, microelectronics, and information technologies
- Plasma physics
- Inertial fusion energy research

Highlights for 1996

Inertial Confinement Fusion

- During 1996 all National Ignition Facility (NIF) Project management and staff positions were filled to the required design levels. Major commercial contractors were chosen for the conventional facility architectural design, engineering services support, and construction management. Major contracts were placed with commercial vendors for optics.
- The Petawatt Project reached its goal in May 1996 when the world's first petawatt laser was demonstrated with an output of 500 joules in a pulse length less than 0.5 picosecond. The Petawatt laser will provide LLNL with the capability to test the fast ignitor approach for fusion and explore other ultra-high intensity physics topics.
- A new thrust in heavy-ion inertial fusion energy research began with the start of construction of an experimental research facility to evaluate recirculating induction accelerators for the acceleration of space-charge-dominated ion beams.

Atomic Vapor Laser Isotope Separation (AVLIS)

- In 1996, the United States Enrichment Corporation (USEC) authorized the AVLIS team to continue to move forward with plant-scale enrichment equipment verification testing for ^{235}U.
- Established the operation and engineering team needed to begin plant design and licensing that includes: Bechtel National Inc., Duke Engineering, Babcock and Wilcox, AlliedSignal Corp., and LLNL.

Advanced Microtechnology Program (AMP)

- Intel Corporation directly funded a multimillion-dollar effort in the extreme ultra-violet lithography (EUVL) program at LLNL to form a six-month transition Cooperative Research and Development Agreement (CRADA) while the EUV Limited Liability Corporation (LLC) was formed.
- LLC enters into CRADA agreement with three national laboratories, LLNL, LBNL, and SNL—who, acting as a single unit, forms a "Virtual National Laboratory" for the sole purpose of developing EUVL.

Strategic Materials Applications Program (SMAP)

- Works with Los Alamos National Laboratory to develop a modular system to recover plutonium from retired or excess nuclear weapons.
- Developed femtosecond-pulse laser technology for DOE's Defense Programs to help disassemble nuclear weapons in a manner that will allow reuse of high-cost components within the weapons.

Other Applications

- Established Medical Photonics Laboratory to develop a host of new medical technologies utilizing advanced laser concepts.
- Began design of laser guidestar for Keck Observatory in Hawaii based on successful demonstrations at U.C.'s Lick Observatory. The laser guidestar corrects for the effects of atmosphere turbulence and can increase the resolution of ground-based telescopes up to a factor of 50.

Numerous derivative applications of our scientific base and expanding technologies are being assessed and pursued as potential new programs in such areas as:

- Extreme ultraviolet projection lithography
- Magnetic sensors for high-density data storage
- Laser tracking and adaptive optics for astronomy applications
- Diode-pumped solid-state lasers
- Short-pulse high-irradiance lasers
- Remote materials handling
- Laser and radar remote sensing
- X-ray lasers
- Tactical battlefield weapons

Inertial Confinement Fusion (ICF) Program

LLNL's ICF Program supports activities in two major interrelated areas: target physics and technology (experimental, theoretical, and computational research); and laser science and optics technology development. Experiments on LLNL's Nova laser primarily support target ignition and weapons physics research. Experiments on LLNL's Beamlet laser support laser science and optics technology development.

The continuing objective of the ICF Program is the demonstration of thermonuclear fusion ignition and energy gain in the laboratory. The underlying theme of all ICF activities as a science research and development program is the Department of Energy's (DOE's) Defense Programs (DP) science-based Stockpile Stewardship and Management (SSM) Program.

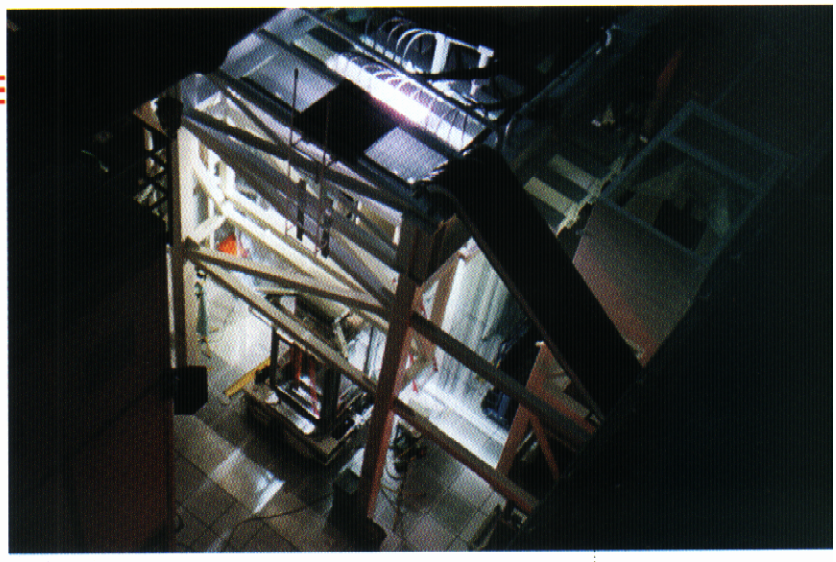
In addition, ICF sciences and technologies, developed as part of the DP mission goals, continue to support other DOE objectives. These objectives are to achieve diversity in energy sources through inertial fusion energy (IFE) research and to maintain a competitive U.S. economy through development of new technologies of interest for government and industrial use, including those developed under the Laboratory Directed Research and Development program (LDRD).

Target Physics and Technology

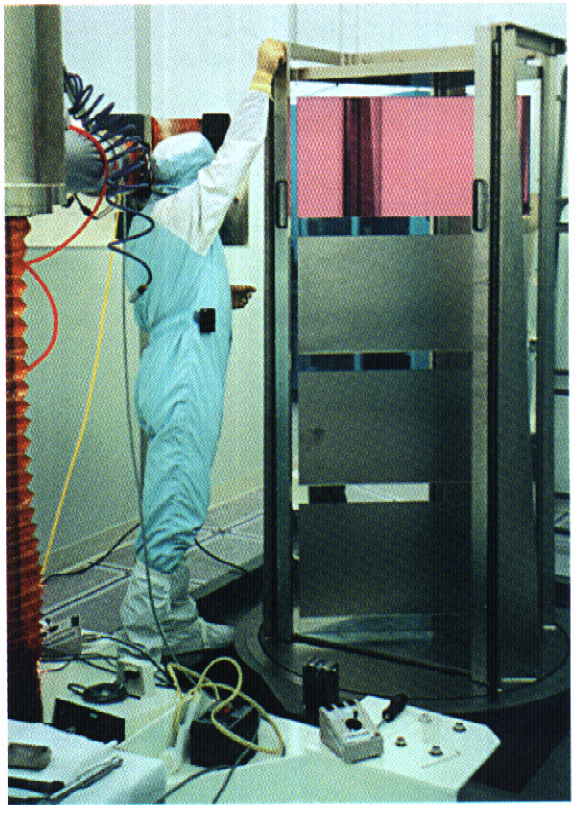
The activities of the Target Physics and Technology (TP&T) Program are directed to ensure the success of achieving ignition on the NIF and supporting the science mission of the DP SSM Program. The activities fall into the following three main areas: Nova target physics, NIF target design and code development, and NIF target area technology development. During 1996, the TP&T Program focused its efforts on goals designed to enhance confidence in successful ignition on the NIF and to expand support for the DP SSM Program. In support of this emphasis, target experiments on the Nova laser and analyses continued in plasma physics, hohlraum (x-ray radiation case) physics, and high-growth-factor implosions. Much of the effort was devoted to extending quantitative understanding of the physics beyond the Nova Technical Contract (NTC) and to better define the limits in target performance for the NIF. In addition, initial indirect-drive laser fusion experiments were done on the Omega laser at the University of Rochester (in collaboration with scientists from Los Alamos National Laboratory and the Laboratory for Laser Energetics, at the University of Rochester) in order to determine the feasibility of using the facility for indirect drive.

The ICF Program and scientists in LLNL's A Division, B Division, V Division, and H Division continued to collaborate on weapons physics experiments on Nova in FY96. During this period, a collaboration between V and A Divisions and the ICF Program demonstrated that very-high-temperature hohlraums can be produced with hohlraums scaled down to a size as small as 1/4 of the Nova scale 1 (2.6-mm length by 1.6-mm diameter). In collaboration with B Division, experiments have begun on Nova that measure the growth of hydrodynamic instabilities and equations of state in the presence of material strength.

In 1996, we also completed and demonstrated a self-contained deuterium and tritium (DT) source for cryogenic target development experiments because all NIF target designs require smooth cyrogenic layers of DT. We underscored the efficacy of heat fluxes on smoothing of solid hydrogen in curved geometries with the same radius of curvature as NIF ignition capsules. For "native" cryogenic layers, heated only by the beta decay of tritium, surface finishes required for the baseline ignition targets were demonstrated. We demonstrated the efficacy of producing heat fluxes in the interior of enclosed solid DT cells by microwave heating the free charges in the vapor space and establishing the smoothing properties of this heat flux. We demonstrated the efficacy of infrared heating of bulk solid hydrogen for smoothing the surfaces. These techniques resulted in enhanced smoothing of layers that contain tritium and provide a way of smoothing layers that contain no tritium. In addition, we designed and analyzed thermal characteristics of cryogenic hohlraums for beta-layering fuel in ignition capsules and are nearing completion of a cryogenic test system for development of cryogenic hohlraums. Conceptual code work continued on the NIF point design robustness by direct 2-D simulation (using LASNEX code) of inner surface and outer surface perturbations. With surface



This time exposure, taken in a darkened AMPLAB shows the prototype NIF amplifier and the slab cassette transfer cart beneath it.



Amplifier technician is shown next to a slab cassette containing one laser glass slab and three aluminum mock slabs.

National Ignition Facility

The National Ignition Facility (NIF) is a key component within the proposed facilities for DOE's science-based Stockpile Stewardship and Management Program. The extension of current program experimental capabilities embodied in the NIF is necessary for the ICF Program to satisfy its stewardship responsibilities.

During 1996 all NIF Project management and staff positions were filled to the required design levels. Major commercial contractors were chosen for the conventional facility architectural design, engineering services support, and construction management. Major contracts were placed with commercial vendors for optics facilitization to ensure an adequate optics production capability that meets the NIF cost goals. Work packages that reflect the national scope of the NIF Project were agreed to and implemented with the participating laboratories (Sandia National Laboratories, Los Alamos National Laboratory, and the Laboratory for Laser Energetics at the University of Rochester).

The technical basis of the NIF design was updated through a formal Advanced Conceptual Design (ACD) technical review process. Concurrent with the ACD activity, the documents that provide a hierarchy of the design requirements were reviewed and updated including the Primary Criteria/Functional Requirements; the System Design Requirements; and the laser system design/performance baseline. At the request of DOE, Defense Programs and other user requirements were included in the NIF design updates.

Key project controls were developed, updated, and implemented including: the NIF Project Control Manual, the Configuration Management Plan, and the DOE-approved Quality Assurance Plan. Change Control boards were established and are functioning. Cost account plans and authorizations for each work breakdown structure element were established. The commercial Sherpa Product Data Management system was selected and implemented to provide a project-wide centralized document, engineering drawing, and configuration control capability. A detailed Title I design schedule was developed, and regular baseline cost and schedule reviews were implemented to track progress. Monthly and quarterly progress reports are prepared and distributed.

Title I design, which was postponed by late release in the Project Total Estimated Cost funding, was completed. An independent cost evaluation, performed by a private company contracted by DOE, agreed with the project office Title I estimate.

The NIF is a part of the Stockpile Stewardship and Management (SSM) Programmatic Environmental Impact Statement (PEIS). In support of the PEIS, write-ups and supporting analysis were provided, and a Preliminary Safety Analysis Statement (PSAR) was completed and approved by DOE. The LLNL site was selected as part of the SSM PEIS Record of Decision made by the Secretary of Energy on December 19, 1996.

smoothness achieved to date in the laboratory, the capsules in these "everything on it" simulations ignited and burned giving nearly 1-D yields.

We further confirmed NIF target design robustness by running simulations in 3D using the HYDRA code (including thermonuclear burn physics) that combined inner and outer surface perturbations, with surface smoothness achieved to date in the laboratory. These too ignited and burned, giving nearly 1-D yields. We also identified a laser beam arrangement for the NIF laser design that not only allows the baseline hohlraum target geometry, but also a tetrahedral hohlraum and direct-drive geometry. In support of this work we identified, along with LLE at the University of Rochester, a direct-drive ignition target design for NIF.

Laser Science and Optics Technology

The Laser Science and Technology (LS&T) Program provides laser technology development and validated performance models for NIF and advanced ICF laser systems. LS&T laser developments have spin-offs that are valuable to Stockpile Stewardship, other national programs, and U.S. industry. Many of these spin-offs, which have then been advanced by other sponsors, are now being applied to ICF needs (e.g., "spin-backs"). The ICF Program is strengthened by this synergistic exchange of information between these diverse activities.

LS&T's primary activity in 1996 has been the laser and optics technology developments for NIF. A four-year focused activity for laser technology development started in 1995 and is described in the *Core Science and Technology Report* (authored jointly with Sandia and Los Alamos National Laboratories). The objectives of the laser developments are to provide validated design packages for the laser components and detailed system modeling and optimization for NIF. The objective of the optics technology developments is to develop industrial production methods for the 8000 full-scale NIF optics that meet performance requirements at the required NIF cost and schedule. The amplifier module prototype laboratory (AMPLAB) was inaugurated, and the first prototype 4×2 laser glass window-pane geometry NIF amplifier and maintenance transport vehicle were designed and fabricated. Work progressed in testing other NIF prototypes such as the multipass regenerative amplifier and the plasma electrode

Pockels cell. Re-optimization modeling of the NIF laser design yielded a 11-0-5 configuration of amplifier slabs in each beamline and a myriad of detailed system specifications. Beamlet was used to study the fluence and power limits and focusability in a NIF-like architecture. By comparing the amplifier temperature with the Beamlet focal spot quality, we placed a quantitative criterion on NIF amplifier cooling. We also designed and began construction of a Beamlet modification (test "mule") to validate the NIF final optics design.

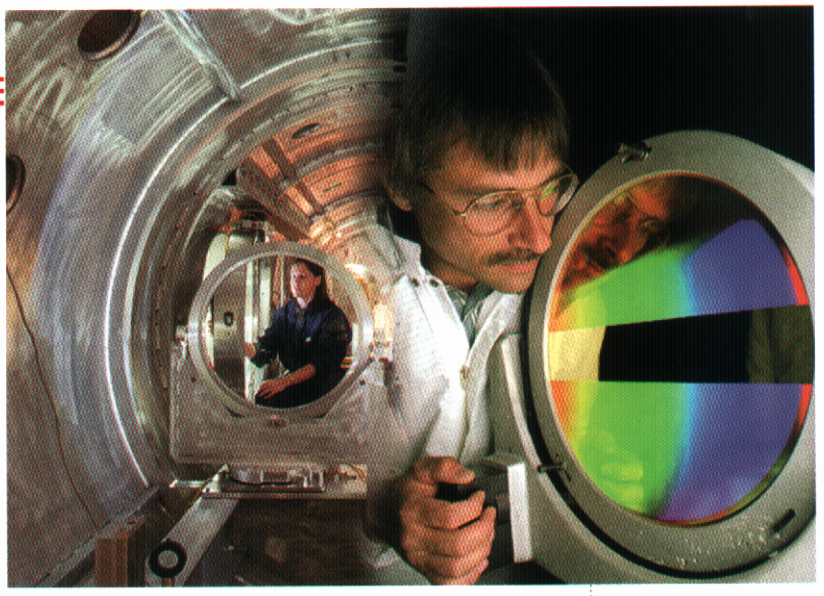
This past year was important for NIF optics development. We demonstrated the viability of continuous melting of phosphate laser glass at vendor facilities by performing quarter-scale runs at Hoya and full-scale runs at Schott using surrogate glass materials. The KDP rapid growth program matured to produce NIF-size boules (up to 43-cm size) and to yield plates which meet all the NIF 1ω optical requirements. The optics finishing companies have all demonstrated processes which meet NIF cost and performance requirements. An important development in diffractive optics capability was making a high-efficiency, high-damage-threshold color separation grating to deflect 1ω and 2ω light from the target while maintaining the focusing of 3ω light on target.

Inertial Fusion Energy/Petawatt Laser

A new thrust in heavy-ion inertial fusion energy (IFE) research began with the start of construction of an experimental research facility to evaluate recirculating induction accelerators for the acceleration of space-charge-dominated ion beams. This testbed, supported by a variety of DOE funding sources including LDRD and LLNL Engineering Thrust Area initiatives, will develop precise beam control and sensing techniques for all IFE accelerator concepts.

The 3-D computational code, WARP3d, was used extensively in the design of the testbed. The recirculator architecture is a leading candidate for major cost reductions in high-current, induction accelerators for IFE.

Our leading candidate for an IFE laser driver is based on a diode-pumped, solid-state laser (DPSSL), for which the gain medium (ytterbium-doped strontium fluorapatite or Yb:SFAP), developed previously at LLNL, is cooled by He gas, known as the gas-cooled slab (GCS) concept. In FY96, an experimental campaign to test a small subscale GCS-DPSSL was completed. Results were encouraging enough to propose a 100-J, 10-Hz GCS-DPSSL (called Mercury) for consideration of LDRD funding in FY97.



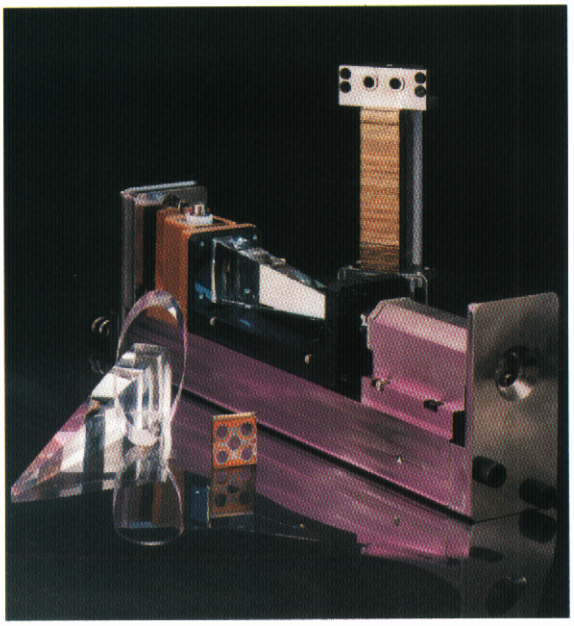
Researchers align optics in the Petawatt compressor chamber.

Since 1993, we have been developing a petawatt (10^{15} W) laser capability on a Nova beamline under LDRD support. The Petawatt laser will provide LLNL with the capability to test the fast ignitor approach for fusion and explore other ultrahigh-intensity physics topics. The Petawatt Project reached its goal in May 1996 when we demonstrated the world's first petawatt laser with an output of 500 J in a pulse length less than 0.5 ps. A major component of the Petawatt Project was developing the technology necessary to make large high-damage-threshold gratings, as well as, developing an entirely new chirped-pulse master oscillator system for Nova with the mechanical hardware and optical diagnostics necessary for pulse compression. The Petawatt laser received a 1996 *Popular Science* "Best of What's New" award and enabled the developments leading to a 1996 R&D 100 Award in "Interference Lithography for Patterning Flat Panel Displays." The Petawatt Project has been generally acknowledged to be the Laboratory's most successful LDRD project to date.

Spin-Off Technologies

In FY 1996, we continued to exploit ICF Program expertise and technology of interest to U.S. industrial and government markets in areas such as:

- *Health-care technology*—Applications of our expertise/technology applied to medicine include (1) modeling laser–tissue interactions, (2) the establishment of a medical photonics laboratory for developing a host of new medical technologies, and (3) the development of user-defined laser diodes and diode-pumped, solid-state lasers for medical procedures (e.g., port-wine stain removal, tattoo removal, and laser surgery).
- *Military visualization systems*—Pulsed microchannel x-ray imaging technologies are now being applied to developing advanced night- and underwater-vision technologies for the Department of Defense.
- *Advanced high-energy particle accelerators*—Areas being developed to support advanced accelerator technology include (1) the development of a high-gradient dielectric-wall accelerator to demonstrate transport of electrons at 1 kA with a record gradient of 20 MeV/m using novel insulating materials, and (2) the development of a high-current electron-induction accelerator for LLNL's B-Division Advanced Hydro-Test Facility proposal (a National Radiographic Facility).



Example of an advanced diode-pumped solid-state laser system used in a wide range of spin-off technologies.

- *Femtosecond material processing*—The use of intense femtosecond laser pulses for precision material processing (cutting) of metals is under development for various government and commercial applications. Processing with ultrashort pulses is qualitatively different from using longer pulses. The energy in an ultrashort laser pulse is deposited in a thin layer at the metal surface. The energy is deposited so quickly that significant thermal conduction or hydrodynamic motion (shock waves) do not have time to occur. Instead, the absorbed energy effectively removes the thin layer of material. Very precise removal of metal has been demonstrated with no modification of adjacent material even at high repetition rates. The laser pulses remove material without significant thermal overlap or bulk heating.

Atomic Vapor Laser Isotope Separation

The mission of the Atomic Vapor Laser Isotope Separation (AVLIS) Program is to provide the world's lowest-cost enriched uranium for commercial power-plant fuel. The major building blocks of the AVLIS process include separators, lasers, and optical systems.

The separation process uses finely tuned, high-power lasers to tag the fissile isotope of uranium by removing one of its electrons. The product stream is formed by collecting ^{235}U ions, as well as a portion of the ^{238}U material on charged plates. This process takes place in a vacuum chamber where the uranium is vaporized and exposed to the lasers. The product is removed as small nuggets of solid uranium metal that, with further chemical processing and fabrication, yields finished fuel for use in nuclear power reactors.

The AVLIS Program is funded by the United States Enrichment Corporation (USEC) and represents the largest and most significant technology transfer activity in the history of LLNL. USEC is presently a government corporation supplying enrichment services to the nuclear fuel industry using existing gaseous diffusion plants located in Kentucky and Ohio. AVLIS will offer USEC a lower-cost option for enriching uranium to meet customer demand with a plant scheduled for full production by 2005.

This year, USEC authorized the AVLIS team to continue to move forward with plant-scale enrichment equipment verification testing and to establish the operation and engineering team needed to begin plant design and licensing. This team includes Bechtel National Inc., Duke Engineering, Babcock and Wilcox, AlliedSignal Corp., and LLNL.

Separator Activities

Efforts in this key area were focused on engineering and demonstrating separators for reliable operations and enrichment performance. The Separator Demonstration Facility (SDF) was reactivated in December 1995 to progressively meet performance goals. These goals will culminate in verification of near plant-level enrichment in a series of integrated separator and laser demonstrations scheduled to begin in early 1998.

Three separator tests were initiated in the second half of this year that increased our total cumulative test time by 50% over prior testing in the 1991–1993 time frame. These demonstrations led to important design and operations advances including (1) automated control of the uranium vaporizer at near-plant rates, (2) testing of improved materials for reliable liquid uranium containment and flow, (3) identification of a need for uranium feed with low impurity content, and (4) closed-loop control of thermal systems.

To prepare for frequent (~2-month interval), long-duration separator testing next year, off-shift operators and refurbishment staff were hired and trained. Significant support logistics for procurement, planning, and parts inventory was also initiated.

Lasers and Optics Activities

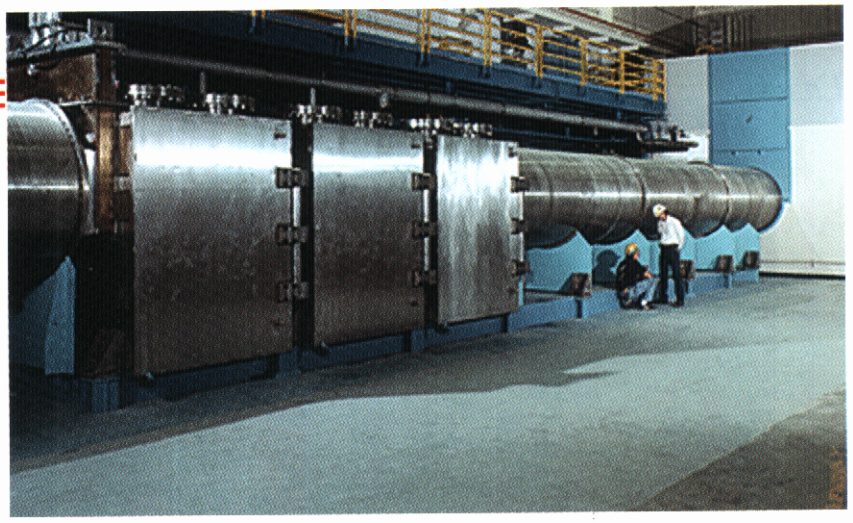
All laser systems were activated this past year including the dye process lasers and copper lasers used to energize these systems. Three plant prototype copper laser chains were activated, and a single-chain output of 1300 watts (86% of plant goal) was demonstrated for long duration. In addition, the reliability growth of the high-average-power pulsed electrical power supply was sufficient to allow demonstration of a mean time between failure at 60% of our plant goal.

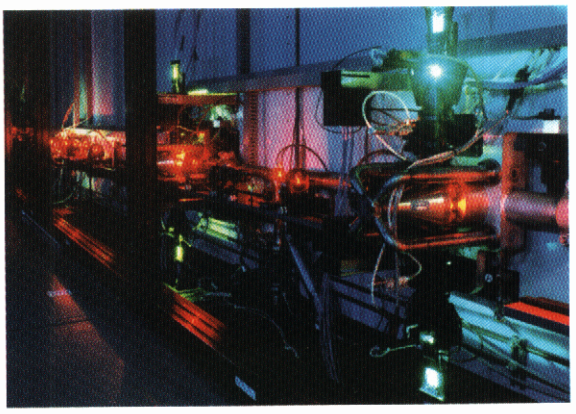
A plant prototypic dye laser chain was operated at >80% plant power goals averaged over the 500-hour test duration. This test achieved all objectives including average power, peak power, efficiency, and availability in 500 hours, and indicates significant progress made toward engineering systems necessary for successful plant operation.

In parallel with these single-chain dye laser tests, the number of dye chains and associated optical systems in the Laser Demonstration Facility (LDF) were doubled from two to four chains to begin preparation for near-plant enrichment level demonstrations in 1998. A new industrial-based computer control system was also installed and activated.

Plant Design Activities

We also achieved our planned objectives in the areas of plant project efforts including completion of general arrangement designs for the plant separator and laser buildings and completion of key design documents for plant interface control and system design requirements. The plant computer control system requirement specifications were also initiated and over one-third were completed by the end of the year.





Plant-scale uranium separator system. (Top) Precisely tuned, high-power AVLIS process lasers. (Bottom)

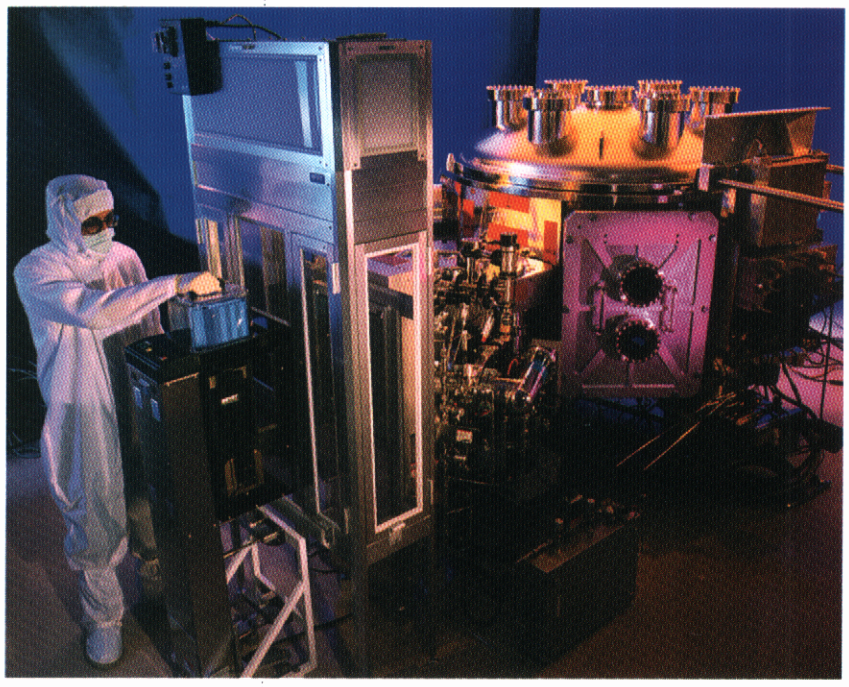
Advanced Microtechnology Program (AMP)

Extreme Ultraviolet Lithography

The Advanced Microtechnology Program (AMP) continues to be one of the fastest growing industrial outreach activities at LLNL. The Program's largest project, extreme ultraviolet lithography (EUVL), has been very successful over the past eight years. During this period, the LLNL EUVL project has transitioned from a patented concept to a completely industrially funded program. In 1996, Intel Corporation directly funded a multimillion-dollar effort in the EUVL programs at LLNL to form a six-month transition Cooperative Research and Development Agreement (CRADA). This CRADA was developed to keep the world-class and uniquely talented LLNL technical team and facilities intact while the EUV Limited Liability Corporation (LLC) was formed with membership limited to U.S. semiconductor manufacturers. The LLC has entered into a CRADA agreement with three national laboratories—Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, and Sandia National Laboratories—who, acting as a single unit, formed a "Virtual National Laboratory" (VNL) for the sole purpose of developing EUVL. The VNL will provide the required research and development. The LLC will engage the industrial base as well as develop machines designated as "steppers." The goal of the project is to provide the capability of short-wavelength (~13 nm) projection lithography for mass production of integrated circuits with features less than 0.10 μm.

The multilayer deposition process to fabricate lithographic masks for the extreme ultraviolet spectral region (wavelengths ~13 nm) must be defect free because there is no viable technical approach to repairing these mask defects. AMP leveraged "standard" handling and characterization tools for 150-mm-diameter Si wafers for process development to reduce particle contamination by orders of magnitude. In close collaboration with AMP, these processes and insights have been incorporated into the Veeco IBSD 350 system, which establishes a new paradigm for the production of precision, low-defect, thin, single, and multilayer film coatings. The system deposits virtually defect-free films of individual atomic layers and reduces defect density by a factor of 10^5 from existing equipment. In addition to the outstanding improvement in defect density, excellent deposition control was demonstrated by reflectivity >65% (at 13 nm) with uniformity better than 1%. This class of films is critical to device fabrication in the $120B semiconductor manufacturing industry and in the $100B magnetic recording industry.

The Veeco LDD-IBSD 350 (Ultra Clean Ion Beam Sputter Deposition System) deposits ultralow-defect density thin films with Ångstrom accuracy.



Absolute Interferometer

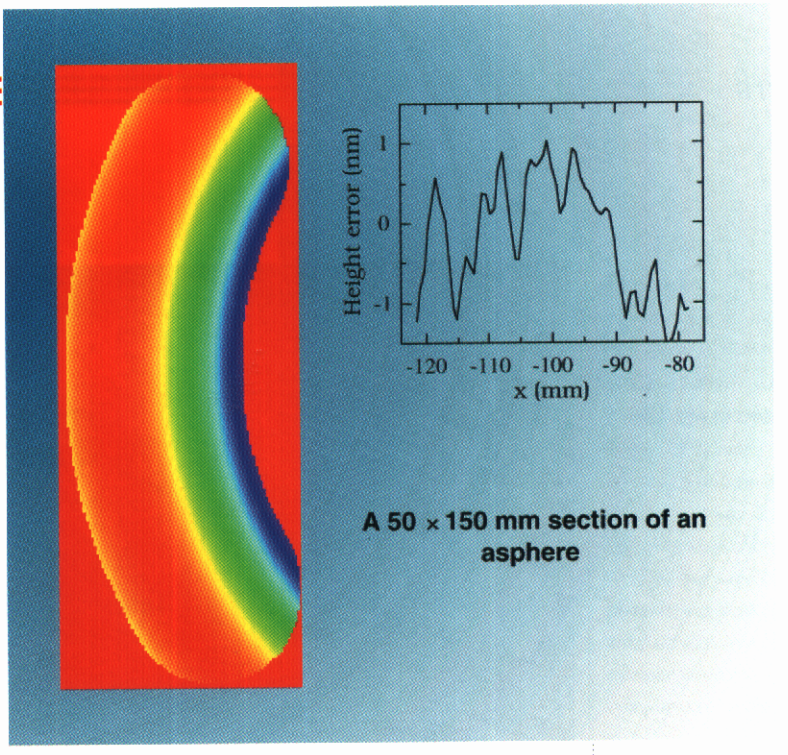
The Absolute Interferometer is a revolutionary new instrument that overcomes the reference wave limitation of classic interferometers by using diffraction to create a perfect spherical wavefront. Over a finite numerical aperture, a diffracted wavefront can be arbitrarily good. Therefore, diffraction can be used to create two perfect and independent wavefronts—one for the reference and one for the test wave, thus eliminating the need for man-made references. Since they are generated independently, their relative amplitude and phase can be controlled yielding the contrast adjustment and phase-shifting capability necessary for the highest accuracy.

The Absolute Interferometer increases prior accuracy 100-fold to measure surfaces absolutely to atomic dimensions, <1 nm. This revolutionary yet conceptually simple, practical, and useful metrology tool relies on a fundamental principle of nature, diffraction, to provide perfect spherical wavefronts.

Magnetic Storage

The dramatic increase in magnetic storage and retrieval capacity is directly related to the ever-decreasing feature size of the sensor heads used to read magnetic discs. As the critical dimensions of these heads decrease, though, a technological barrier is encountered with the standard inductive head design that will not operate at the higher storage densities (1 Gbit/in.^{2} and higher) of future-generation systems. Researchers in AMP have been collaborating with Read-Rite Corporation personnel to develop new materials that provide an intrinsic resistance change to an applied magnetic field—the well-known magnetoresistive effect. These submicron multilayered materials are expected to replace the inductive configuration since their performance will improve with decreasing feature size, thus providing a technologically feasible route to very high storage and retrieval capacity. A record response for the highest usable response of resistance change, a recognized figure of merit, was set for the nickel-iron alloy and copper combination AMP fabricated.

The collaboration between LLNL and Read-Rite has produced a sensor head design capable of reaching the ultrahigh areal density regime of 10 Gbit/in.^{2}. (The group has received an *R&D Magazine* R&D 100 Award for their efforts in this area.) This design uses a patented shielded, biased configuration with multilayered material combinations optimized by workers in AMP. This material combination has been demonstrated to achieve the necessary magnetic field sensitivity for a working device. Furthermore, a robust unique modeling capability has been established within AMP using numerical techniques adapted from plasma physics particle codes to the so-called micromagnetic theory. This theory predicts the formation and movement of magnetic domain walls, which is critically important to the optimal performance of these small devices.



The Absolute Interferometer measures large surfaces to atomic dimensions (<1 nm) with absolute accuracy.

Adaptive Optics

Atmospheric turbulence severely limits the resolution of ground-based telescopes. If the effects of turbulence could be fully corrected, the resolution could be improved up to a factor of 50. Adaptive optics can correct atmospheric distortions, but require a nearby bright reference star, available in less than 10% of the sky. An artificial beacon was created by resonant light scattering from atomic sodium in the mesosphere, at 95 km. In the fall, building on earlier LLNL successes, a team of scientists and engineers successfully demonstrated significant image improvement with the laser guide star adaptive optics system on the 3-m Shane Telescope at the University of California's (Santa Cruz) Lick Observatory, located on Mt. Hamilton. The system included the LLNL-constructed deformable mirror and sophisticated software. These results are the first significant image improvement ever achieved with high-order adaptive optics using a sodium-layer laser guide star. Corrected long-exposure images recorded in the near infrared at a wavelength of 2.2 μm showed a factor of 3 increase in peak intensity and a factor of 2.4 decrease in full width at half maximum to less than 1/3 of an arc second. This technique holds strong promise for the world's largest telescope (Keck Observatory in Hawaii) and is an excellent demonstration of the power of adaptive optics for systems of the future.

View of the laser beam for a laser guide star system at the University of California's Lick Observatory in San Jose.

Micropower Impulse Radar (MIR)

The Micropower Impulse Radar (MIR) has continued its impressive growth and applications development. The ultra-wideband receiver technology for MIR has its roots in development of a transient digitizer for Nova laser fusion diagnostics. Based on emitting and detecting very low amplitude voltage impulses, MIR has a sensitive detection window for accurate ranging that can be varied over time to provide radar return information at various ranges. The hardware package is very small (hand held), made of inexpensive electronics, and has extremely low power requirements. Average emissions are well below 10 mW and are spread over several gigahertz, virtually eliminating both interference and interception.

The MIR technology has over 30 associated patents. It has also won numerous awards and is licensed to over 20 companies. Several MIR products are now on the market, and more are expected in the next year. However, our main program focus has been on several new government projects. Land-mine detection using MIR and advanced image processing concepts from previous radar projects is now being funded by the Defense Special Weapons Agency (DSWA) and the U.S. Army. An array of MIR devices has been demonstrated for finding plastic antipersonnel mines in most soils. The Federal Highway Administration and the California State Department of Transportation have joined with LLNL to design an MIR system for High-Speed Electromagnetic Roadway Mapping and Evaluation Systems (HERMES). One portion of HERMES will provide high-speed mapping of an entire bridge or highway section, whereas the second portion will provide high-detail data of flawed subsurface areas in the roadway. HERMES has the potential of significantly reducing inspection costs while improving the safety of our highway infrastructure. A new Navy project is tasked with developing an MIR-based sensor for tracking helicopter blades in flight. Other applications include law enforcement, respiration and heart-rate measurement, speech processing, and security sensors for DOE and DOD.

Subwavelength Optics Structures

AMP continues to push the frontiers of optics. The Program has developed submicron period resist structures ranging from one-dimensional posts and holes using interference lithography and image reversal to more complex two-dimensional arrays. By transferring the resist patterns into underlying substrates, polarization elements and polarization-insensitive antireflection elements, novel and revolutionary optical components can be produced. For example, in collaboration with the University of Minnesota, AMP fabricated an intra-laser-cavity fused silica device with 16 levels of diffractive phase elements to generate a flat intensity profile (versus the standard bell shape). This required placing the mask with submicron accuracy for the four-step lithography process resulting in a desired pattern.

Strategic Materials Applications Program (SMAP)

The Strategic Materials Applications Program (SMAP) was created in February 1996 to consolidate a number of existing projects within Laser Programs. SMAP aims to develop new initiatives in the area of strategic nuclear materials.

Laser Programs has a long history of research, development and demonstration of nuclear technologies, beginning with the Atomic Vapor Laser Isotope Separation Program (recently transferred to the United States Enrichment

Corporation [USEC]), the Special Isotope Separation Program for plutonium isotope separation, and the Inertial Confinement Fusion Program.

SMAP projects are engaged in developing technologies for processing, manufacturing, storing, and disposal of strategic nuclear materials (principally uranium and plutonium) associated with the nation's nuclear weapons stockpile. We are also developing advanced techniques for safe and secure disposition of excess nuclear materials from the Department of Energy's (DOE) inventory.

Advanced Recovery and Integrated Extraction System (ARIES)

The Program is working with LANL to develop a modular system to recover plutonium from retired or excess nuclear weapons. SMAP will bisect or 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 for cutting and removing the nuclear material, test these systems, and design the final production modules for installation and use at LANL.

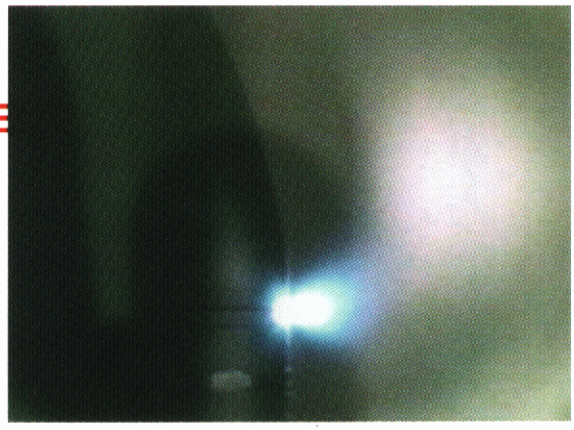
Laser Cutting Project

SMAP is developing laser cutting technology for Defense Programs to help disassemble nuclear weapons in a manner that will allow reuse of high-cost components within the weapons. Using LLNL-developed femtosecond-pulse laser technology, we have demonstrated an ability to make extremely narrow and highly precise cuts in a variety of materials. Cuts narrower than the width of a human hair can be made through thick material sections with no damage to the surrounding material. We carried out a full-scale demonstration of our cutting technology last year, and we are currently designing and constructing a production laser system for DOE's Y-12 Plant in Oak Ridge, Tennessee, for delivery this year. This project recently won a 1997 R&D 100 Award.

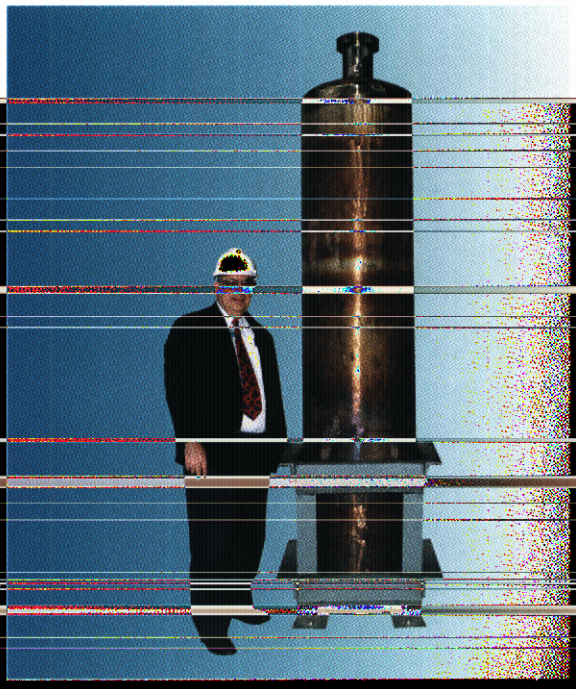
Plutonium Immobilization

SMAP is also collaborating with LLNL's Non-Proliferation, Arms Control and International Security (NAI) Directorate, in DOE's Fissile Material Disposition Program to develop alternatives for disposal or long-term storage of excess nuclear materials. In the aftermath of the Cold War, the U.S. and Russia agreed to large reductions in nuclear weapons. Although disarmament offers hope for improving world security, the retirement or disposition of plutonium used in nuclear weapons must be accomplished in a manner that keeps it safe and out of the hands of terrorists. To aid in the selection of options, the DOE has undertaken a study to select options for storage and disposition of plutonium in accordance with the national policy that excess plutonium must be subjected to the highest standards of safety, security, and international accountability. Russia and other nations with similar interests and experience have been invited to participate in the overall disposition study.

One disposition alternative considered for surplus plutonium is immobilization or encapsulation of plutonium in glass or ceramic. LLNL was selected by DOE as lead laboratory to develop methods for transforming surplus plutonium into long-term immobilized forms that meet environmental, safety, and security objectives. Support laboratories include Westinghouse Savannah River Technology Center, Argonne National Laboratory, Oak Ridge National Laboratory, Pacific Northwest Laboratory, and the Australian Nuclear Science and Technology Organisation.



Photograph of a test part being cut by our femtosecond laser system. This system was designed and constructed by LLNL in 1996 and used to demonstrate a successful surgical disassembly of nuclear weapons components for the DOE.



Full-scale prototype canisters developed for excess plutonium disposition. The plutonium will be mixed with either glass or ceramic that is then sealed in a canister like this. The canisters will then be placed in a secure repository that will later be permanently sealed.

Awards

LLNL's long-standing reputation for excellence has been earned in part through the efforts of its scientists, researchers, engineers, and supporting staff. In 1996, many Laser Programs people were honored with awards.

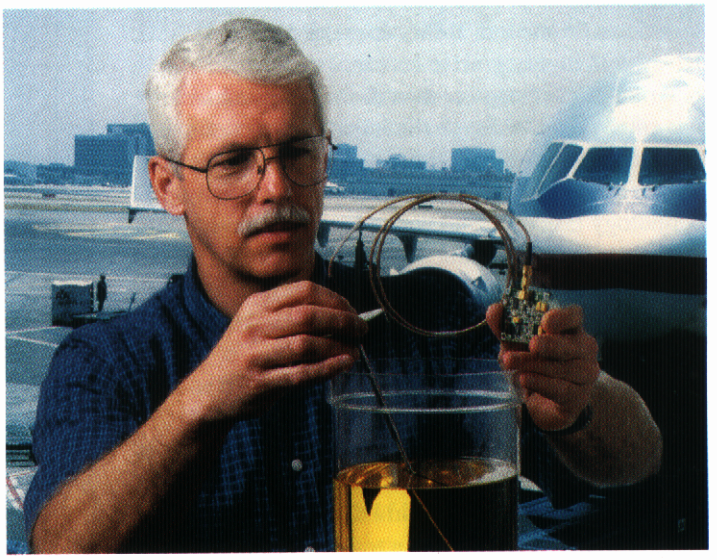
The R&D 100 Awards

Each year *R&D Magazine* selects the 100 most technologically significant products and processes submitted for consideration and honors them with an R&D 100 Award. Winners are chosen by the editors of the magazine and a panel of 75 experts in a variety of disciplines. Corporations, government laboratories, private research institutes, and universities throughout the world vie for this "Oscar" of applied research. The R&D 100 judges look for products or processes that promise to change people's lives by significantly improving the environment, health care, or security. In the years between 1985 to 1996 the Laser Directorate won 28 R&D 100 Awards, placing it seventh in overall competition for all national organizations. In total, to date, the Laser Directorate has received 34 R&D 100 Awards.

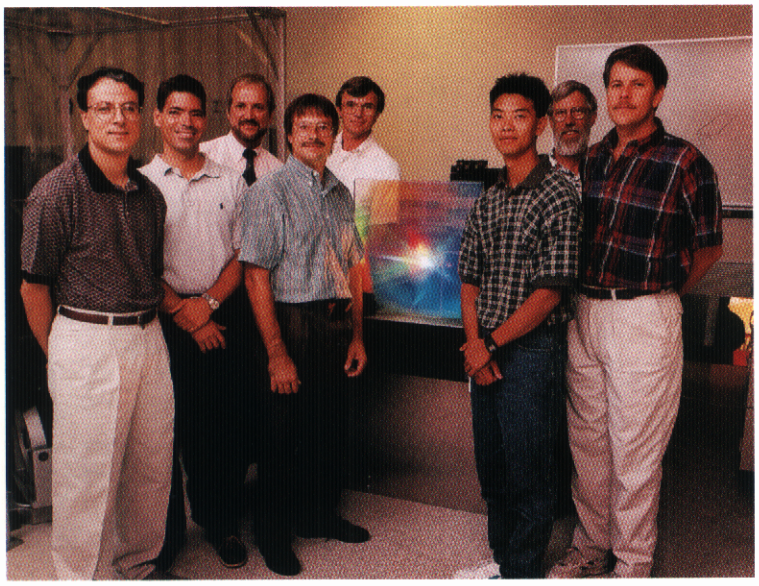
In 1996, **Stephen Payne, Christopher Marshall, Andy Bayramian, John Tassano, Joel Speth, and William Krupke** along with Gregory Quarles and Vida Castillo of VLOC (formerly Lightning Optical Corporation) shared an award for the "Ce:LiSAF, First Tunable Ultraviolet Solid-State Laser Product." The new optical crystal (Ce:LiSAF) makes an all-solid-state, directly tunable, ultraviolet (UV) laser commercially available for the first time. Developed jointly under the terms of a Cooperative Research and Development Agreement with VLOC Inc. (a division of II-VI Inc.) of Tarpon Springs, Florida, the crystal consists of lithium-strontium-aluminum-fluoride doped with cerium, a rare-earth metal. Ce:LiSAF is expected to usher in a new era of laser applications. It is particularly well suited to remote-sensing environmental applications because many targeted molecules, including ozone and aromatic compounds, have characteristic absorption bands in the ultraviolet. Already, a cerium laser has been deployed to remotely detect ozone and sulfur dioxide in the environment. Additionally, the U.S. Army is considering its use to monitor the presence of tryptophan, a common component of biological weapons. Another potential military use could be to secure wireless communications links between infantry units over short distances of approximately 1 kilometer on a battlefield.

The power, simplicity, and reproducibility of Ce:LiSAF will change traditionally difficult, expensive, and sensitive applications into commercially feasible ones. Because of this crystal,

"Ce:LiSAF, First Tunable Ultraviolet Solid-State Laser Product." Back row from left are Andy Bayramian, John Tassano, Joel Speth, and William Krupke. Bottom row from left are Stephen Payne and Christopher Marshall.



Thomas McEwan shown with the highly accurate electronic dipstick.



Development team for flat-panel display technology are Andres Fernandez, James Spallas, Nat Ceglio, Jerald Britten, Andrew Hawryluk, Hoang Nguyen, Robert Boyd, and Michael Perry.

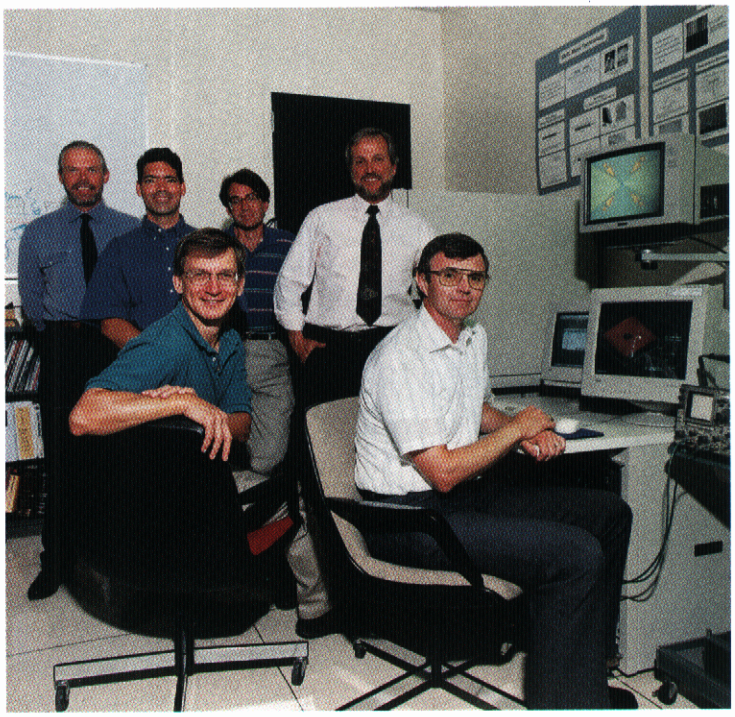
tunable ultraviolet lasers may move rapidly from the domain of scientific research laboratories into industry.

Thomas McEwan received an award for developing a new micropower impulse radar (MIR) application, the "Electronic Dipstick." The result of a string of spin-off technology developments in Laser Programs, the electronic dipstick is a device that measures the time it takes for an electrical impulse to reflect from the surface liquid in a container, so fluid level can be calculated. At better than 0.1% accuracy, extremely low power, and a cost of less than ten dollars, applications include measuring fluid levels in cars, oil levels in supertankers, and even corn in grain elevators. Unlike ultrasound and infrared measurement devices, the electronic dipstick is not tripped up by foam or vapor, extreme temperature or pressure, or corrosive materials. Over time, the technology should make other fluid-level sensing devices obsolete.

Michael Perry, Andres Fernandez, James Spallas, Nat Ceglio, Jerald Britten, Andrew Hawryluk, Hoang Nguyen, and Robert Boyd shared an award for a "Lithography System for Flat Panel Displays." The development of cost-effective, large area, laser interference lithography is a way to precisely and uniformly produce regular arrays of extremely small (less than 100 atoms wide) electron-generating field-emission tips. It will significantly advance the effort to fabricate field-emission display (FED) flat panels. FED flat panels are a major improvement over active matrix liquid crystal display technology because they consume less power and can be made thinner, brighter, lighter, and larger, and with a wider field of view. Potential applications range from more efficient portable computers to virtual-reality headsets and wall-hugging TV sets.

Charles Vann's award-winning "Six Degrees of Freedom Sensor," a small, noncontact optical sensor will improve the manufacturing processes that employ robots by eliminating the time-consuming and expensive process of "teaching" robotic machinery new motions when manufacturing

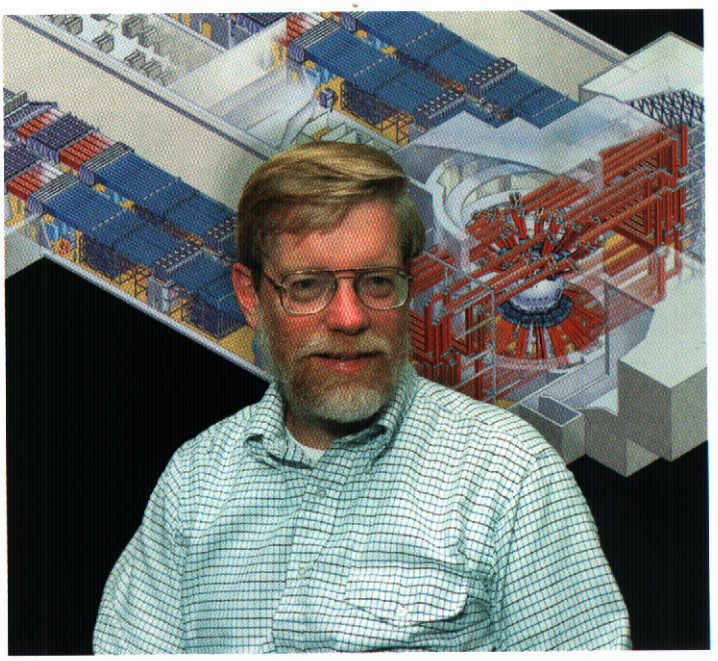
Charles Vann shown with the six-degrees-of-freedom (SixDOF) sensor.



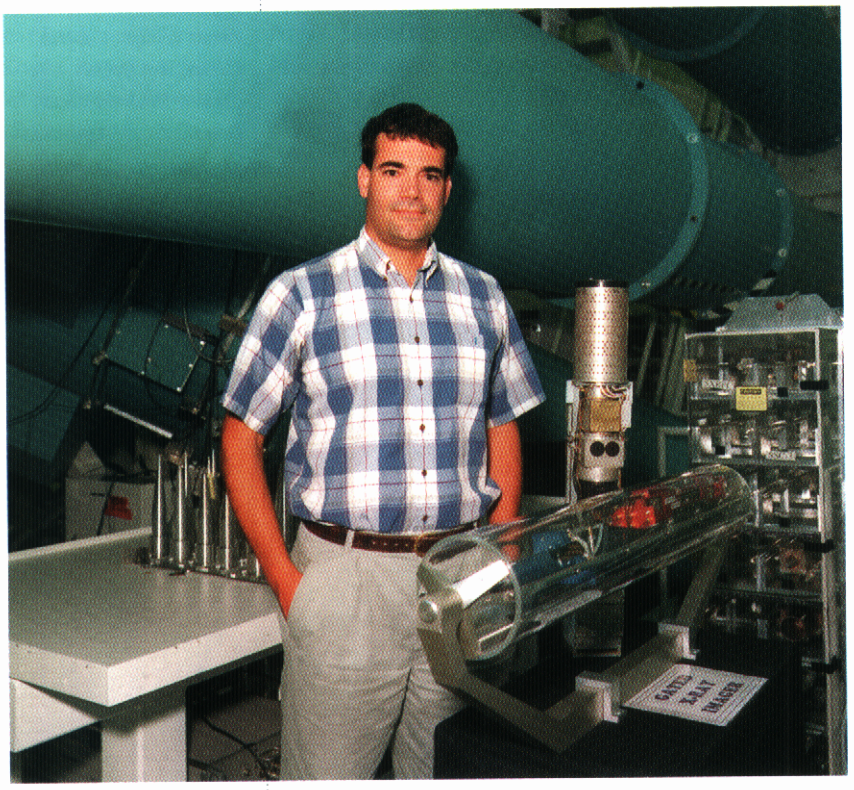
Ultrahigh-Density Sensor team members include (clockwise from top, left) Stephen Vernon, James Spallas, Charles Cerjan, Nat Ceglio, Andrew Hawryluk, and Don Kania. (Not pictured are Benjamin Law and Daniel Stearns.)

changes are required. This six-degrees-of-freedom (called SixDOF) sensor can sense its position relative to a piece being machined, allowing the robot to autonomously follow a predescribed machining or manufacturing path. As its name implies, the SixDOF sensor senses its position in all six degrees of freedom (the x, y, and z axis as well as the turning motion around those axes).

Stephen Vernon, James Spallas, Charles Cerjan, Nat Ceglio, Andrew Hawryluk, Don Kania, Benjamin Law, and Daniel Stearns, with Robert Rottmayer of the Read-Rite Corporation, shared an award for "Ultrahigh-Density Magnetic Sensors." The advanced magnetic sensor is a critical component in magnetic storage devices such as computer hard-disk drives. The new sensor offers greater sensitivity and 100 times greater storage densities than current commercial products. Its storage density limit approaches the projected limit of magnetic disk drive technology of 100 gigabit/1 in.^{2} (6.4 cm^2). Using thin-film technologies previously developed at LLNL, the sensor is built of alternating layers of thin magnetic and nonmagnetic materials.



Laurance Suter



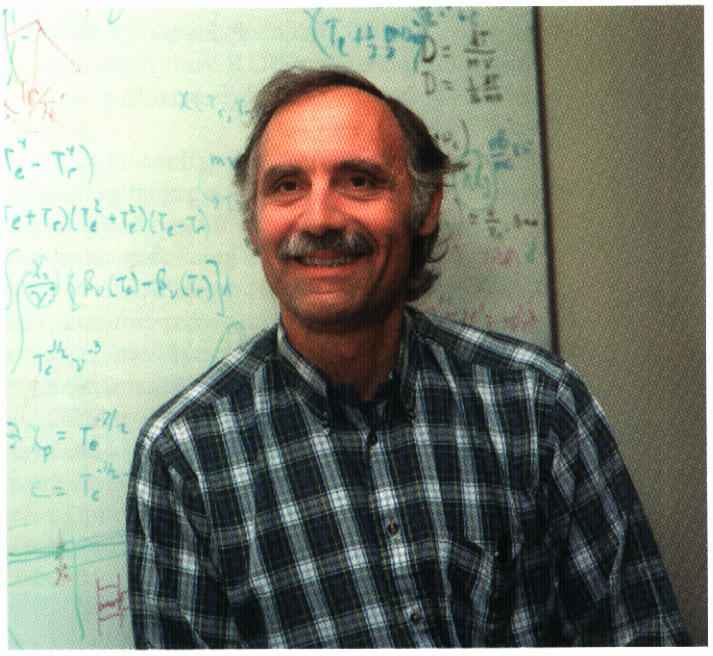
Bruce Hammel

Fellowships

American Physical Society (APS)

Bruce Hammel, Laurance Suter, George Zimmerman, Alex Friedman, and George Caporaso have been made Fellows of the American Physical Society, bringing the total number of APS Fellowships earned by the Inertial Confinement Fusion Program since 1976 to thirty. The APS selects only one-half of one percent of its total membership for fellowships each year.

Hammel received his citation for "measurements and understanding of x-ray driven implosions, x-ray driven hydrodynamic instabilities, and x-ray drive asymmetry." He is currently head of experimental research within the Livermore ICF Program and is responsible for experiments on the Nova laser. An eight-year veteran of the Laboratory, Hammel is a graduate of the Department of Physics at the University of California, Berkeley, and earned his M.A. and Ph.D. degrees from the Department of Astrophysical, Planetary, and Atmospheric Sciences at the University of Colorado at Boulder. Some of his recent work includes measurements and control



George Zimmerman

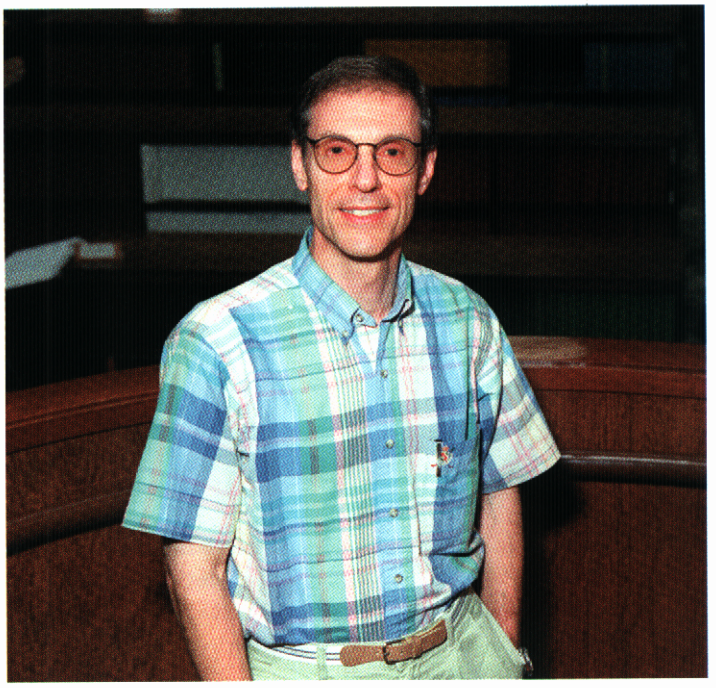
Alex Friedman

of x-ray symmetry in laser-heated hohlraums and investigations of high-intensity laser–matter interaction.

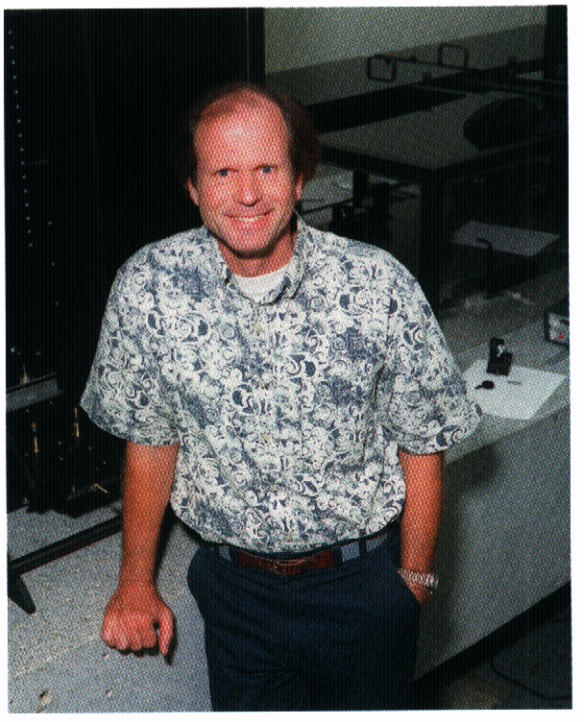
Suter's citation is for "pioneering work and leadership in the design, modeling, and analysis of experiments using laser-heated hohlraums that quantify and control x-ray drive, symmetry, and pulse shaped implosions." A twenty-two year veteran of the Laboratory, Suter is currently Hohlraum Group Leader in the Theory and Target Design (X) Division. A graduate of Union College in New York, he earned his M.S. and Ph.D. degrees from Stanford University and has previously been honored as a National Science Foundation Fellow, a Woodrow Wilson Fellow, and a Caitlin Fellow. Some of his recent work on a new type of source for producing x-rays with high-powered lasers is at the heart of the effort to build nuclear weapons effects testing capability into the NIF.

George Zimmerman, group leader for the Inertial Confinement Fusion Code Development Group in X Division, was cited by the APS for "his creation, and subsequent development, of the LASNEX simulation code, which has been used extensively to guide the development of the National ICF Program from its inception, to this day." Zimmerman has worked on the LASNEX code, whose principal use is for inertial confinement fusion and target simulation, since 1970. A Laboratory employee since 1969, Zimmerman earned his B.A. at Harvey Mudd College in Claremont and his graduate degree at UC Berkeley. He was honored in 1983 with the Department of Energy's Ernest O. Lawrence Award.

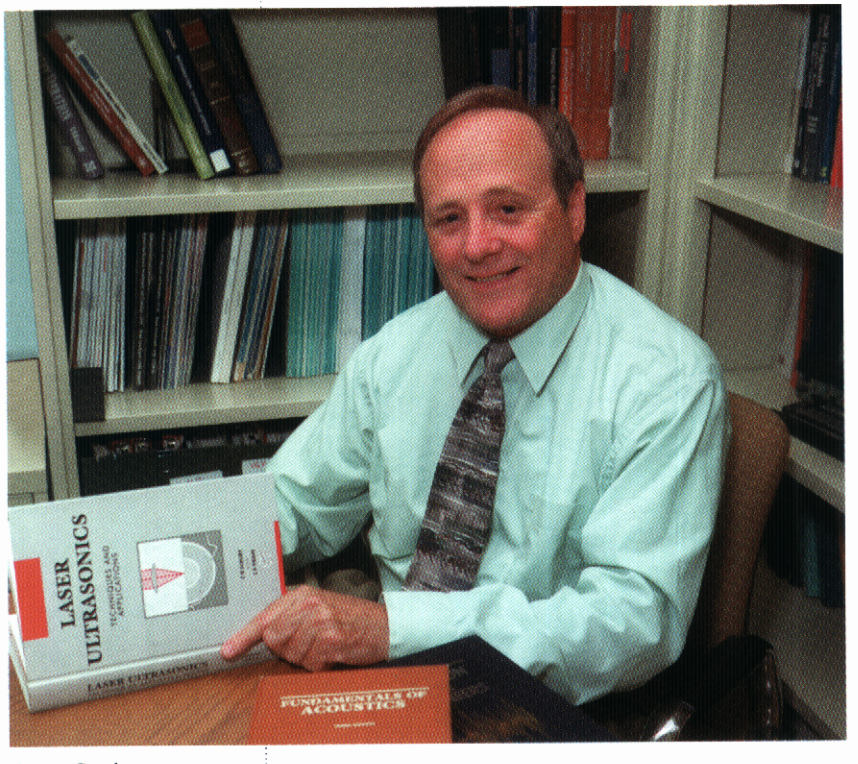
Alex Friedman, who is a project leader for heavy-ion fusion research, was cited for "innovations in computer modeling of fusion plasmas, laser plasma interactions and charged particle beams, and design of high space charge accelerator components." He joined the Laboratory's Physics



George Caporaso



Gary Sommargren



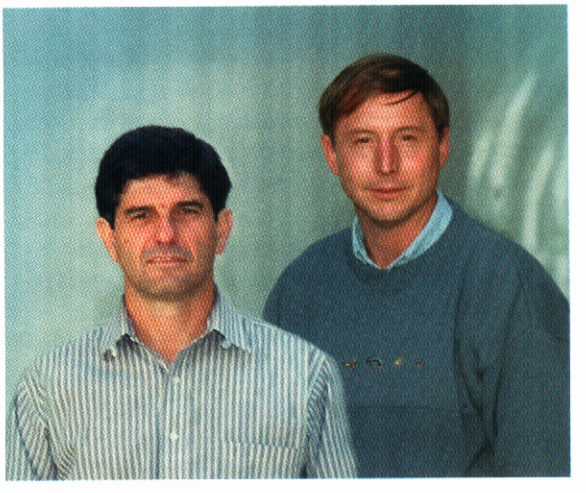
James Candy

Department in 1980 after completing two years of postdoctorate research at UC Berkeley. Friedman earned his undergraduate and graduate degrees at Cornell University.

George Caporaso was cited by the APS for "original contributions to the design and analysis of high-current electron accelerators, especially for instability studies which have greatly extended the utility of induction linacs." A project leader for the Advanced Radiography Machine/Experimental Test Accelerator-II Project, Caporaso has been a Laboratory employee since 1977. He earned both his graduate and undergraduate degrees at MIT.

Optical Society of America

Gary Sommargren was cited for his distinguished service in the advancement of optics.



Pictured from left are Luis Zapata and Lloyd Hackel.

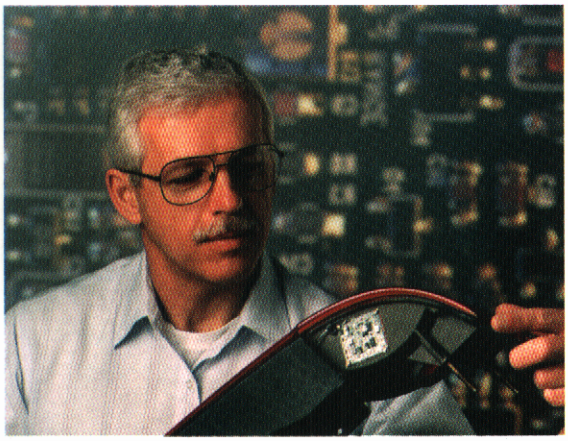
Acoustical Society of America

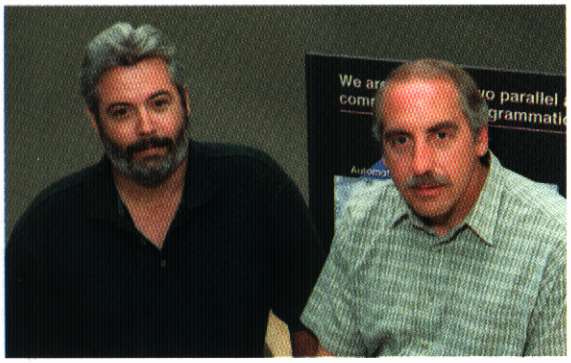
James Candy received a fellow status from the Acoustical Society of America for "outstanding achievement in signal and image processing, sound propagation, ocean acoustics, and laser ultrasonics." Candy, an engineer, is serving as the Director of the Center for Advanced Signal and Image Sciences (CASIS). He has been at the Laboratory for twenty years, working mainly in signal and image processing, sound propagation, and laser ultrasonics. Recently his work has concentrated on acoustic sound (ocean acoustics and heart valve classification). Candy received his B.S. in Electrical Engineering from the University of Cincinnati, and his M.S. in Engineering and his Ph.D. in Electrical Engineering from the University of Florida.

Other Awards

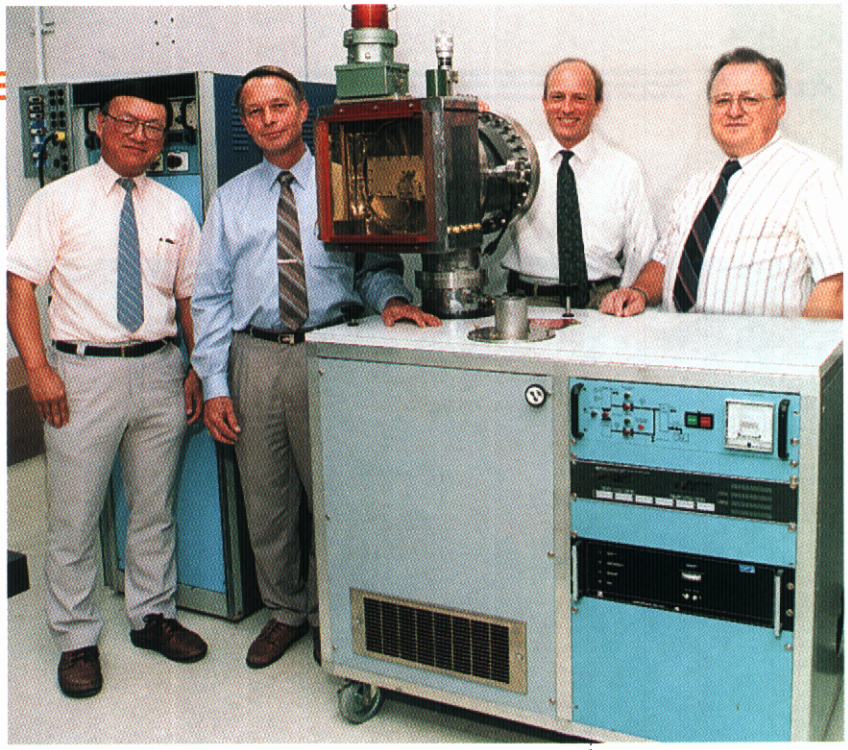
Federal Laboratory Consortium (FLC) Award

The FLC Annual Awards for Excellence in Technology Transfer recognize Laboratory employees who have accomplished outstanding work in the process of transferring laboratory-developed technology. Nominations are made by the Laboratory representative and are judged by representatives from industry, state and local government, academia, and the laboratories. The nominations alone represent a high honor among peers and laboratory management. The three awards (representing all those awarded to LLNL) from the Laser Directorate rank the Lab among the top 1996 winners out of more than 650 federal government laboratories and research centers that comprise the consortium.





Pictured above is Tom McEwan. At the bottom are (from left) Pat Welsh and Greg Dallum.



Pictured from left to right are Hao-Lin Chen, Booth Myers, Glenn Meyer, and Dino Ciarlo.

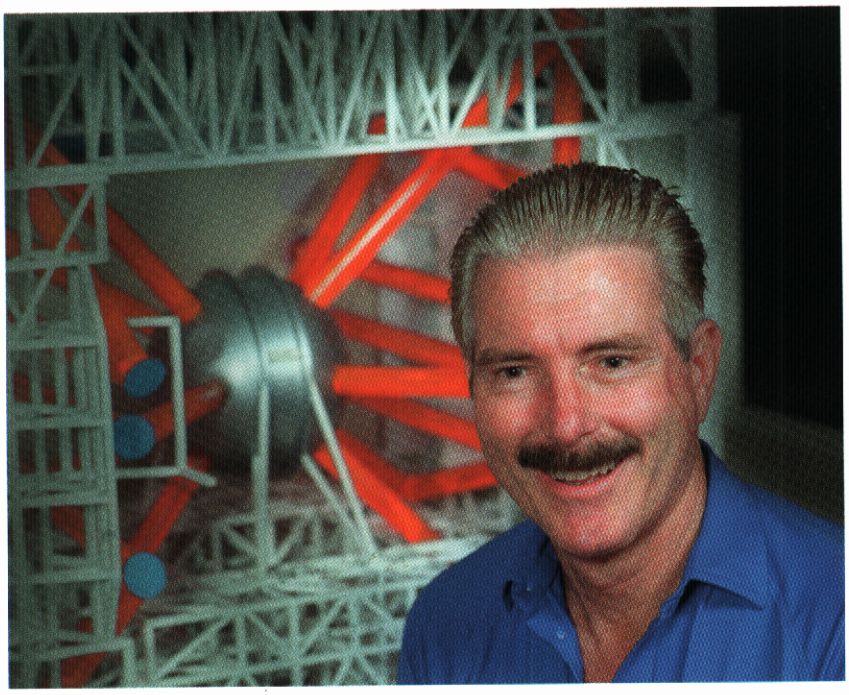
Laser physicists **Luis Zapata and Lloyd Hackel**, plus former lab technology transfer official Damon Matteo, received an award for their work with Intevac Inc., of Rocklin, California, on a machine to help manufacture flat-panel displays.

Electronics engineers **Tom McEwan and Pat Welsh, with technician Greg Dallum**, received an award for their assistance to companies that have licensed McEwan's popular radar as an "electronic dipstick."

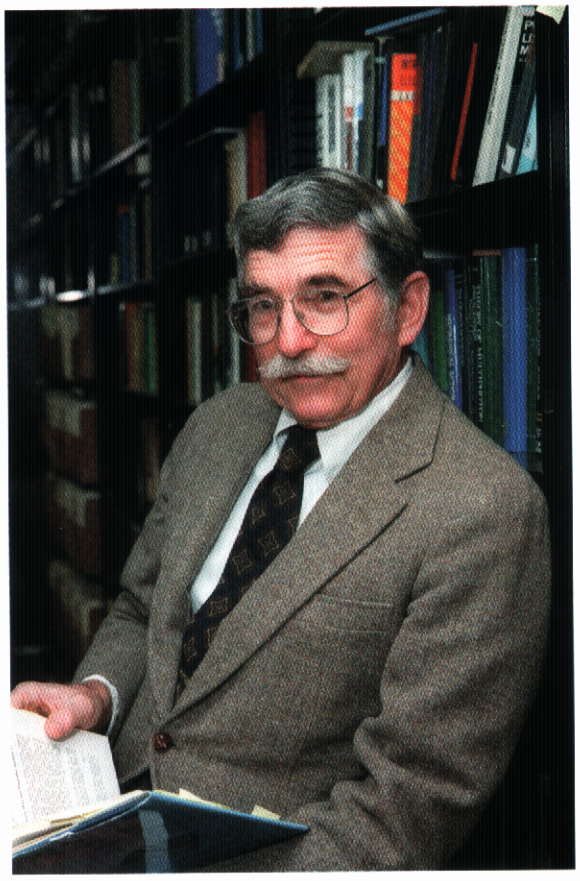
Physicists **Booth Myers and Hao-Lin Chen, and mechanical engineers Glenn Meyer and Dino Ciarlo** received an award for collaborating with American International Technologies Inc. of Torrance, California, in developing a new electron beam system for processing materials.

1996 Outstanding Achievement Award by the Fusion Energy Division of the American Nuclear Society

Bill Hogan received the 1996 Outstanding Achievement Award for his pioneering work in inertial fusion energy. Hogan has been a key player in the development of the field of inertial fusion energy as a respected branch of fusion research. A Laboratory physicist since 1966, he is well known as a spokesman for the NIF and a proponent for inertial fusion energy applications beyond NIF. He is also an advocate of fusion energy internationally, and since 1992, he has served as chairman of the Vienna-based Atomic Energy Agency's advisory committee on fusion energy. He was recently elected vice chairman/chairman elect of the 1000-member ANS fusion division.



Bill Hogan

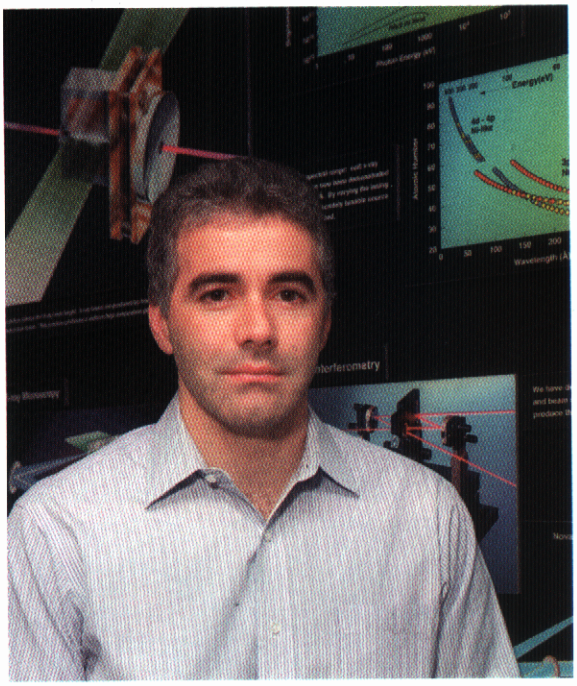


Bruce Shore

Humboldt Research Award

The Alexander von Humboldt Foundation, of Germany, has conferred on **Bruce W. Shore**, a Humboldt Research Award for Senior U.S. Scientists. He is one of 80 prominent U.S. scholars to win this award this year.

This award will enable Dr. Shore and his family to spend 10 months at the University of Kaiserslautern, Germany, where he will continue a collaboration with the Physics faculty investigating the behavior of atoms and molecules exposed to laser radiation. Dr. Shore is a graduate (B.S. in Chemistry, class of 1956) of the College of the Pacific (now part of UOP) in Stockton, California. He earned a Ph.D. in Nuclear-Inorganic Chemistry from the Massachusetts Institute of Technology, Cambridge, Massachusetts, in 1960.



Luis Da Silva

Distinguished Lecturer for Associated Western Universities for 1996–97 Academic Year

Luis Da Silva has been selected as a Distinguished Lecturer for Associated Western Universities for the 1996–97 academic year. In selecting Da Silva as a distinguished lecturer, AWU cited his "accomplishments as a distinguished laboratory scientist," adding that through his presentations he will be able to provide a forum for

Claude Montcalm

the exchange of ideas between the Lab and academic communities as well as lay communities. He will be giving presentations on inertial confinement fusion, borrowing on his work with the Nova laser, as well as his recent work on lasers in medicine. Da Silva has been at the Lab since 1990, working first as a consultant before becoming a career employee. He received his B.S., M.S., and Ph.D. in physics from the University of British Columbia in Vancouver.

Academic Gold Medal of the General Governor for the University of Quebec

Claude Montcalm, a physicist in the Advanced Microtechnology Program has received the Governor General's academic Gold Medal in recognition of his "outstanding academic performance" at the doctorate level. Since 1873, the Governor General's Medal has been awarded to the student who graduates with the highest standing in his or her institution. Montcalm, a native of Quebec, received his undergraduate degree from the University of Montreal and his M.S. and Ph.D. degrees in physics from the University of Quebec.

Industry Week Magazine Award for the Top 25 Technologies of the Year for 1996

Don Kania and the AMP program were honored with this award for their work (in conjunction with Sandia National Laboratories, Ernest O. Lawrence Berkeley National Laboratory, and eight U.S. microelectronics firms) in the use of extreme ultraviolet light (EUVL) for manufacturing computer chips.

Ted Saito, AMP Operations Manager accepting the Industry Week magazine "top 25" award on behalf of the EUVL team.

The Petawatt laser team that includes Mike Perry, Bob Horton, Brent Stuart, John Miller, Greg Tietbohl, Bob Boyd, Mike Regino, Theresa Tutt, and Jerry Britten.

For further information call:
E. Michael Campbell (510)422-5391
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http://lasers.llnl.gov

Popular Science Magazine Award for "Best of What's New" in 1996

Mike Perry and the entire Petawatt laser team received this award for their remarkable achievement—for one-trillionth of a second in May, the Petawatt laser churned out 1,300 times the entire electrical generating capacity of the United States. This represents 1.3 quadrillion watts, or petawatts. This record eclipsed the previous laser power record by more than a factor of ten. One of the many purposes of the Petawatt will be to study advanced laser fusion concepts.

Society for Technical Communications Competition

Each year the internationally renowned Society for Technical Communications sponsors a publications contest in which scientific, technical, and marketing documents are judged for excellence in writing and design. In 1996, **Jack Campbell, Gail Glendinning, John Lindl, Randall McEachern, and James Murray (Scientific Editors), Jason Carpenter, Al Miguel, Peter Murphy, Joy Perez, and Dabbie Schleich (Editorial Staff) and Ken Ball, Dan Moore, and Linda Wiseman (Design and Art Staff)** were honored with the award for two Lasers Directorate publications, the *ICF Quarterly* and the *1995 ICF Annual.*

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