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Science& Technology

REVIEW
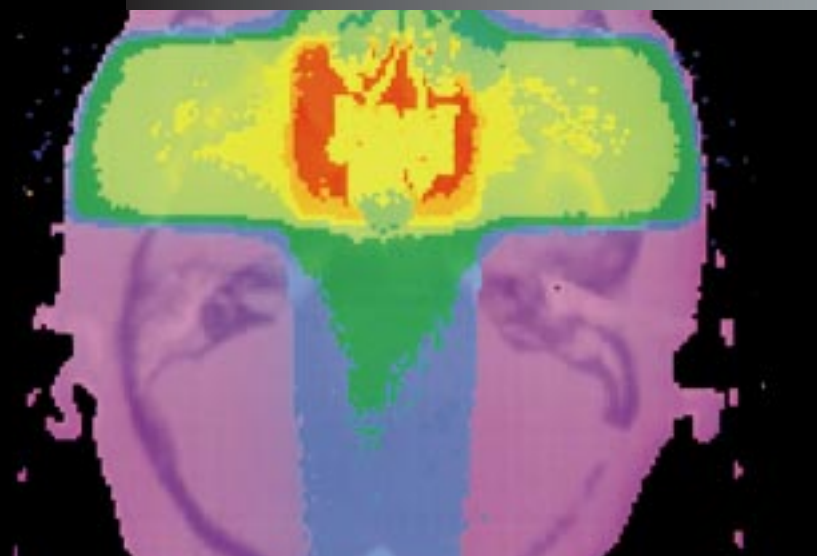
Lawrence

Livermore

National

Laboratory

PEREGRINE

Also in this issue:

- **Regenerative Fuel Cells**
- **Flash X-Ray Upgrades and Gamma-Ray Camera**
- **Nuclear Weapons Information Project**

About the Cover

A cross section of an absorbed radiation dose for treating cancer of the brain is shown after calculation by the Laboratory's PEREGRINE radiation planning system. PEREGRINE combines advanced radiation transport methods with the most accurate and comprehensive nuclear transport databases to ensure the accuracy of its calculations. Radiation treatments will soon be planned at a cost and speed practical for widespread medical use.
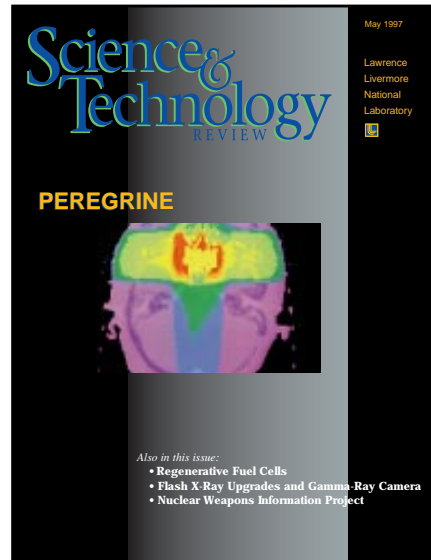
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About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy. At Livermore, we focus science and technology on assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published ten times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

Please address any correspondence (including name and address changes) to *S&TR*, Mail Stop L-664, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551, or telephone (510) 422-8961. Our electronic mail address is *hunter6@llnl.gov*.

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Defense research yields commercial benefits

Defense research at Lawrence Livermore may help U.S. companies get a head start in the fiercely competitive international computer chip market, according to Dena Belzer, author of a new study about the Laboratory's effect on the economy.

Belzer, a principal consultant with Bay Area Economics in Berkeley, quoted industry giants Intel Corp. and Microsoft as saying that breakthroughs at Lawrence Livermore have been critical to putting more information onto tiny microchips. The companies said the Laboratory's cutting-edge research tools and large pool of scientists from diverse disciplines enabled microchip breakthroughs like extreme ultraviolet (EUV) lithography, a technique for putting information on chips that will allow manufacturers to write on the chips with more precise strokes that are about a thousandth the width of a human hair.

Belzer's report said that the planned National Ignition Facility laser could push the state of the art in several technology areas over the next 10 to 15 years, but it cautioned that "economic benefits can only be realized if the national labs continue to have strong interactive relationships with private industry."

Contact: LLNL Media Relations (510) 422-4599 (garberson1@llnl.gov).

Lab seeks source of mystery gamma-ray bursts

A telescope developed at Livermore and housed at its Site 300 research center in San Joaquin County, California, is scouring the heavens in search of answers to one of the great mysteries of the universe—gamma-ray bursts. Detected approximately once a day by orbiting satellites, the flashes of gamma rays of unknown origins reach peak energy in a few hundredths of a second and typically last about 1 to 100 seconds.

The telescope, called the Livermore Optical Transient Imaging System (LOTIS), was developed to help reveal clues about the origins of the bursts by searching for light flashes that may accompany them. The telescope consists of a high-resolution, wide-field-of-view system on a mount designed for rapid response and movement. LOTIS has an 18-degree field of view, compared to 0.5 degrees for the typical astronomical telescope.

The system relies on the orbiting Compton Gamma-Ray Observatory for initial detection of a gamma-ray event. Data are then transmitted to NASA's Goddard Space Center and relayed to Site 300.

The gamma-ray burst research is being conducted in collaboration with NASA's Goddard and Marshall Space Centers, the University of California at San Diego, and Clemson University.

Contact: Hye-Sook Park (510) 422-7062 (park1@llnl.gov).

Predicting floods more accurately

Winter floods that swept across northern California in December and January provided proof that the Laboratory's Regional Climate System Model works. Using this system—which includes elevation, topography, soils, vegetation, and forecasted weather variables—scientists Norman Miller and Jinwon Kim simulated the Russian River area's flooding within 85% of the observed river flow. (See *S&TR*, July 1995, pp. 28–30, for more information on this work.) Using forecasts from the National Weather Service, Miller and Kim predict precipitation at a spatial resolution of 31 square kilometers (12 square miles) to simulate river channel flow. Future plans include adding impacts such as urban development to the model, which will give planning organizations help in making critical decisions on water resource, agricultural, and sustainability issues.

Contact: Jinwon Kim (510) 422-1848 (kim1@llnl.gov) or Norm Miller (510) 422-3244 (norm@llnl.gov).

Cooper appointed to special technology panel

President Clinton named Computation Associate Director Dave Cooper to the newly formed Advisory Committee on High-Performance Computing and Communications, Information Technology, and the Next-Generation Internet. The advisory committee will provide guidance and advice on all areas of those fast-changing technologies.

Cooper came to the Laboratory in 1995 after serving as director of information systems at the NASA Ames Research Center, California. In 1994, he received the NASA Medal for Outstanding and Exceptional Service for his pioneering in high-performance computing.

Livermore and Savannah River begin collaboration

Lowering costs and speeding up development are two of the goals in collaborations of Lawrence Livermore and DOE's Savannah River Site. On February 4, Livermore director Bruce Tarter and president of Westinghouse Savannah River Co. Ambrose Schwallie signed a memorandum of mutual intent that outlined technologies involved. They include: disposition of fissile materials, centered on the immobilization of plutonium; stabilization of plutonium residue; modular production systems for replacement components for the enduring stockpile; and nonproliferation and arms control, including nuclear forensics, materials protection, environmental monitoring, and domestic safeguards. Livermore will be developing and testing ways to stabilize plutonium on a small scale, after which the technology will be transferred to Savannah River, which has larger-scale facilities and experience with large-scale processing and handling of special nuclear materials.

Using Physics Research to Help Cure Cancer

THE PEREGRINE program, a new approach to planning radiation therapy, has joined the more than 4,000-year search for a cure for cancer. This search has been an arduous journey, traceable in recorded history to the ancient Egyptians, who used surgical techniques to remove tumors. The quest has touched many fields of modern science including biology, chemistry, genetics, and—somewhat surprisingly—physics.

In 1895, William Roentgen, a physicist studying electricity and magnetism, discovered x rays. Almost immediately, the ability of x rays to penetrate many materials and to expose film led to an appreciation that x rays could be used as a tool for diagnosing a variety of human ailments. Only a short time later, the idea of using x rays to not only "see" cancer, but also to treat it, was being studied.

In the century since this exciting discovery, physicists, engineers, and doctors have been working together to build new types of radiation sources and methods of treatment—striving to understand how radiation therapy works and how to make it more effective. Today, nearly two million people worldwide are treated with various forms of radiotherapy each year. But like surgery and other forms of treatment, radiotherapy is not without its risks—too little radiation does not destroy the cancer; too much radiation causes damage to healthy tissue. The safety and effectiveness of radiotherapy depend on the accuracy of the treatment, that is, where the radiation is aimed and where its energy is deposited.

This is where PEREGRINE comes into the story.

PEREGRINE brings a radically new level of accuracy to the field of radiotherapy by its unique ability to predict where radiation deposits energy in the body. PEREGRINE will open the way to more accurate prescriptions for radiation therapy, more aggressive treatment of tumors, lower risk to normal tissue, better clinical trials, and a variety of advanced approaches to treating cancer.

What special expertise does the Laboratory bring to this endeavor?

Like Roentgen's discovery of x rays, the development of the PEREGRINE program fits the paradigm of "unexpected consequences." Ironically, much of our knowledge of the physics of radiation that is needed to develop better treatments for cancer— how radiation is produced, how it travels, and how it interacts with various materials—comes from our research into and development of nuclear weapons. Over the last 40 years, the Laboratory has developed unmatched capabilities in radiation transport and nuclear physics.

But these capabilities alone are not sufficient to make PEREGRINE useful outside a very limited research environment. Because the diagnosis of cancer has long been considered a death sentence, our goal has always been to go beyond proof of principle and put PEREGRINE into the hands of the health-care community. We have melded the Laboratory's core competencies in physics, medical physics, computer science, and engineering to achieve the breakthrough in accuracy, speed, and cost necessary to make PEREGRINE a viable product for medical professionals. We also have established a network of collaborations with the leading medical research institutions in the U.S. to understand and respond to the real needs of their community.

PEREGRINE is now fast enough for everyday use and economical enough to be used in all clinical environments. PEREGRINE may soon help to save lives by bringing superior radiation treatment to all cancer patients.

The combination of choosing the most difficult problems, building expert multidisciplinary teams to find breakthrough solutions, and working with world experts to complement our capabilities is the hallmark of successful Laboratory programs. With this process, we are fulfilling our charter to shape the tools of world-class science and to meet national needs.

■ Edward Moses is the Director for Programs in the Physics and Space Technology Directorate.

PEREGRINE: Improving Radiation Treatment for Cancer

PEREGRINE "... is a unique system of enormous value to society in terms of improving local control and reducing complications in radiation treatment of cancer."

—*Noted medical physicist Dr. Radhe Mohan*

Figure 1. Livermore is using its PEREGRINE radiation therapy planning process to improve major parts of the cancer treatment process, which includes (a) diagnosis using high-resolution CT (computerized tomography) scans, (b) treatment planning, and (c) actual treatment.

EVERY year, about 1.25 million people in the United States are diagnosed with life-threatening forms of cancer. About 60% of these patients are treated with radiation; half of them are considered curable because their tumors are localized and susceptible to radiation. Yet, despite the use of the best radiation therapy methods available, about one-third of these "curable" patients–nearly 120,000 people each year–die with primary tumors still active at the original site.

Why does this occur? Experts in the field have looked at the reasons for these failures and have concluded that radiation therapy planning is often inadequate, providing either too little radiation to the tumor for a cure or too much radiation to nearby healthy tissue, which results in complications and sometimes death.

What can be done to improve this prognosis? Since 1993, Lawrence Livermore National Laboratory has combined its renowned expertise and decades of experience in nuclear science, radiation transport, computer science, and engineering to adapt nuclear weapons Monte Carlo techniques to a better system for radiation dose calculations. Mentored in particle interactions and nuclear data by Lawrence Livermore physicists Bill Chandler and Roger White, and armed with seed money from Livermore's Laboratory Directed Research and Development, medical physicist Christine Siantar began directing a small project to develop PEREGRINE, with the mission of providing better cancer treatment.

What resulted is a radically new dose calculation system that for the first time can model the varying materials and densities in the body as well as the radiation beam delivery system. According to program manager Edward Moses, the PEREGRINE team is moving these unique radiation therapy planning capabilities into the hands of the medical community so that doctors will have the most accurate tool available to plan radiation treatments that cure cancer.

PEREGRINE Breakthrough

PEREGRINE breaks the barriers to accurate dose calculation with the first full-physics model of the radiation treatment process. It uses Monte Carlo calculations, in which statistical sampling techniques are used to obtain a probabilistic approximation of a problem's solution. This enables PEREGRINE to model how trillions of radiation particles interact with the complex tissues and structures in the human body and where they deposit their energy. In the past, Monte Carlo calculations, known to be the best way to model these interactions, would have required days or weeks of supercomputer resources—impractical for radiation treatment planning. The PEREGRINE team has designed and built the Monte Carlo system to plan accurate radiation treatments at a cost and speed practical for widespread medical use. PEREGRINE uses advanced algorithms integrated with off-the-shelf computer hardware configured in sophisticated architectures to bring Monte Carlo–based treatment planning to the desktop.

Better Treatment Strategies

Experts have looked at the diagnosis and treatment planning process to try to explain why current cancer treatments are not more effective.
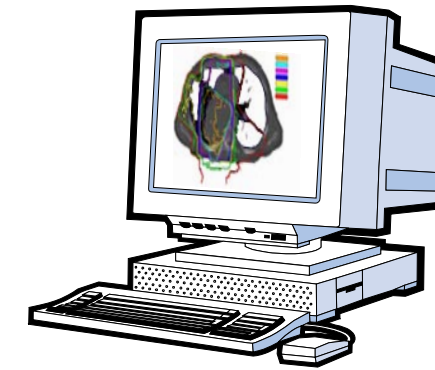
When a physician suspects malignancy, a computerized tomography (CT) scan is made of the suspected area to determine the exact position and extent of the tumor. If the cancer has not yet metastasized and is susceptible to radiation, the next step is to develop a plan for radiation treatment (Figure 1). Although CT scans provide radiation planners with a three-dimensional (3D) electron-density map of the body, current dose calculation methods model the body as a virtually homogeneous "bucket of water." Inhomogeneities, such as bone and airways, are ignored or highly oversimplified.

Furthermore, interpolated data from dose measurements made in water are used to calculate radiation treatments. These calculations are also based on a variety of simplifications in the way radiation is produced by the source, how radiation travels through the body, and how its energy is deposited.

Some tumors are particularly difficult to treat with radiation because of their proximity to vital organs, the abundance of different tissue types in the area, and the differences in their susceptibility to radiation. Cancers of the head and neck, lungs, and reproductive organs are examples. Radiation planners know that too small a dose to the tumor can result in recurrence of the cancer, while too large a dose to healthy tissue can cause complications or even death. Because of the inaccurate dose provided by today's calculations, doctors trying to avoid damage to healthy tissue sometimes undertreat cancerous tissue (Figure 2).

PEREGRINE is a tool that meets these clinical challenges. It is the only dose calculation system that can be used for all types of radiation therapy, can exactly model the radiation beam delivery system being used for each treatment, and uses each patient's CT scan as a basis for the dose calculations. "Most importantly, the PEREGRINE 3D Monte Carlo algorithms, used with Livermore's atomic and nuclear databases, enable the most accurate dose calculations," Moses says. "These breakthroughs could profoundly impact cancer treatment and the lives of patients who might otherwise die."

When PEREGRINE becomes available for commercial distribution, it will deliver dose calculations economically in today's competitive health-care industry. Because it also can
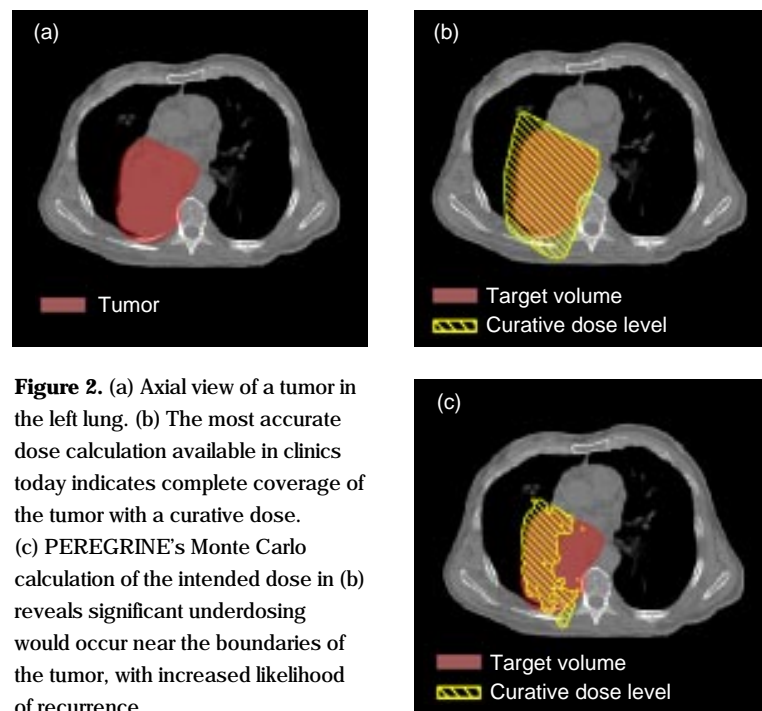
Figure 2. (a) Axial view of a tumor in the left lung. (b) The most accurate dose calculation available in clinics today indicates complete coverage of the tumor with a curative dose. (c) PEREGRINE's Monte Carlo calculation of the intended dose in (b) reveals significant underdosing would occur near the boundaries of the tumor, with increased likelihood of recurrence.

be integrated into existing radiation treatment planning systems through standard network connections, PEREGRINE can be installed in every cancer clinic. With PEREGRINE in the hands of radiation oncologists, patients will have access to an unprecedented level of accuracy in treatment planning. Armed with improved knowledge of predicted dose, physicians will be able to develop aggressive new treatment strategies that minimize the risk to patients. (See the box below for more information on radiation therapy.)

Lawrence Livermore has applied for two patents for key software and hardware elements and intends to submit its first application to the U.S. Food and Drug Administration (FDA) later this year. "Our goal is to make PEREGRINE available for use in cancer treatment centers by late 1998," Siantar says.

Radiation Therapy

Radiation has been used to treat cancer for almost 100 years. However, in most cases, a radiation dose sufficient to kill a tumor may also injure or damage nearby vital tissues or organs. Successful therapy thus depends on choosing the right type of radiation and applying the right amounts to the right places.

Today, tumors usually are treated by beams of particles from a particle accelerator, a process known as teletherapy, which is performed with any of four types of radiation. Photon or electron beams are the most frequently used, while therapies using neutrons or heavy charged particles such as protons are largely experimental. Occasionally, treatment may derive from a radioactive source that is planted inside the body, a treatment known as brachytherapy.

Photon beam energies are high enough for them to be considered x rays. They have moderate to long ranges (tens of centimeters), so they can be used for internal tumors. Photon therapy accounts for about 90% of all radiation treatments in this country.

About 10% of cancer patients receive electron therapy. Electron beams are useful for shallow cancers because electrons have limited penetrating power. Electron treatment spares deeper-lying tissues but is not effective for internal tumors.

High-energy proton beams can be designed to deposit most of their energy at one predictable depth or range. By controlling the

beam energy, oncologists can control their range. A planner can tailor a proton beam to deliver most of its radiation dose into the tumor while avoiding healthy surrounding tissue. Unfortunately, proton therapy is very expensive and is available at only two centers in the U.S.

Neutron radiation has the advantage of being more effective than photons for treating some types of radiation-resistant tumors. But neutron treatment is also very damaging to healthy tissue. Experimental treatment is available at just 20 centers worldwide.

New radiation therapies are being developed to treat highly invasive tumors and cancer that has already metastasized. In experimental boron neutron-capture therapy, neutron-absorbing boron is injected into the body where it is absorbed by cancerous cells. When the body is irradiated by neutrons, the neutrons are preferentially absorbed by the boron in the tumors and the tumors are destroyed. Radio-immunotherapy, another approach under study by the research community, uses the chemistry of the body's immune system to target radioactive compounds at metastasized cancerous tumors.

PEREGRINE is now being used in research on photon, electron, proton, and neutron treatment at several leading hospitals across the country. Plans for research with PEREGRINE in the next year include collaborations on boron neutron-capture therapy, brachytherapy, and other advanced methods.

PEREGRINE in Action

The PEREGRINE dose calculation includes two main steps: defining the treatment by describing the radiation source and the patient, and calculating the dose.

Treatment Definition

The treatment-definition generator prepares the data for the specific treatment. As input, the generator requires three data sets for each treatment: the patient transport mesh, the treatment radiation source, and the particle interaction database.
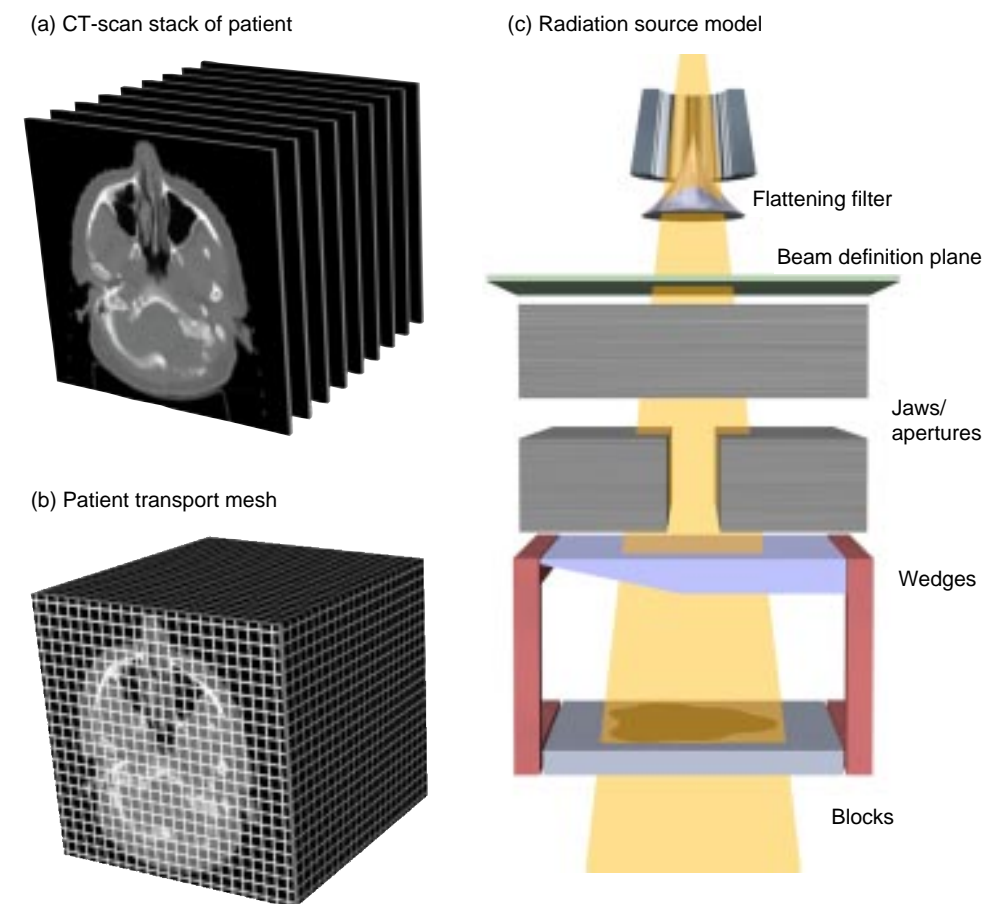
Patient Transport Mesh. The patient's CT scan is composed of a stack of image "slices" (Figure 3a). From these, PEREGRINE creates a 3D map—the patient transport mesh—of the density and composition of all the matter in the vicinity of the radiation beam (Figure 3b). The system creates this map from the CT scan by assigning a material and density value to each volume element (voxel) in the scan. The transport mesh enables PEREGRINE to model details of the patient's body—including irregularities on the body surface, air cavities, and differences in tissue composition—with unprecedented, submillimeter accuracy.

The Radiation Source. Accurate dose calculations also depend on reliable information about the characteristics of the radiation beam delivery system. PEREGRINE is the first dose calculation system to use a complete model for the radiation source of each type of accelerator. The system models the source by dividing the beam delivery system into two parts (Figure 3c). The upper portion of the delivery system is the accelerator itself, with components that do not change from treatment to treatment. The lower portion of the model has components such as collimators, apertures, blocks, and wedges, which are used to customize the beam for each patient's treatment to ensure coverage of the tumor.

PEREGRINE draws from built-in source libraries to model the upper portion of the system and combines that information with the treatment-specific configuration of the lower portion to produce a model of the radiation being delivered. The source model is the first to provide an accurate, comprehensive description of photon, electron, neutron, or proton treatment beams as they enter the body.

Particle Interaction Data. In support of its national security missions, Livermore has developed and maintains the world's most extensive set of atomic and nuclear interaction databases. These huge databases contain information about particle interactions that enable the all-particle tracker to calculate how every

Figure 3. PEREGRINE models both the patient and the radiation source to ensure accurate treatment planning. (a) The CT scan is a stack of image slices less than 1 centimeter (cm) apart. From these, PEREGRINE creates (b) a 3D transport mesh of the patient to model how radiation will interact with the materials in the body. (c) PEREGRINE also models the radiation beam source in two parts: the accelerator itself (above the beam definition plane) and the components that customize the beam for each treatment.
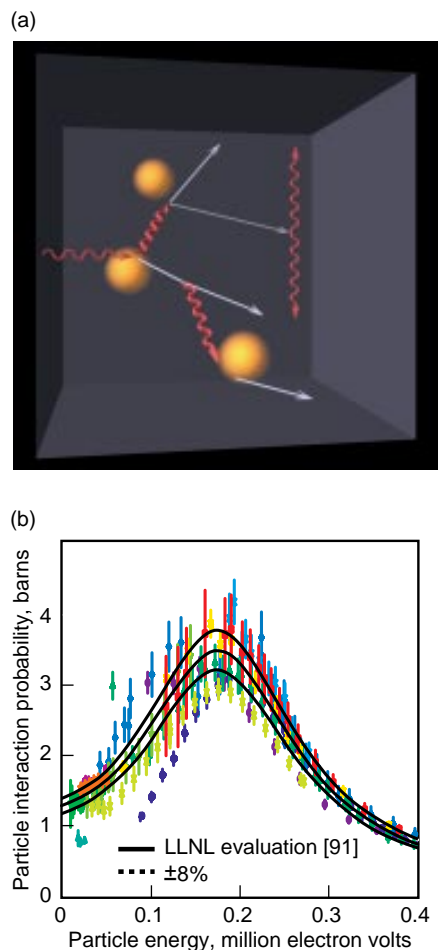
(a) CT-scan stack of patient

(b) Patient transport mesh

(c) Radiation source model

(a)

(b)

LLNL evaluation [91]
±8%

Particle interaction probability, barns

Particle energy, million electron volts

Figure 4. (a) When a particle interacts with the atoms in the body, it creates a shower of secondary (daughter) particles, which in turn move through the body. Lawrence Livermore's all-particle Monte Carlo codes predict these interactions based on the information in the Laboratory's comprehensive atomic and nuclear reaction databases. These databases are derived from the best available measurements and theoretical calculations. (b) The probability of particle interaction depends on the type of particle and the particle's energy.

isotope of every element on the periodic table will interact with any radiation particle. To describe the interaction of radiation particles with the muscle, fat, air, bone, lung, and other tissue in our bodies, PEREGRINE uses interaction data for combinations of these elements (Figure 4). Fatty tissue, for instance, is 12% hydrogen, 64% carbon, 1% nitrogen, and 23% oxygen by weight. Knowing how various radiation particles will behave with these elements enables the system to predict how they will behave in our bodies.

Monte Carlo All-Particle Tracker

The tracker selects a particle from the radiation source and tracks it through the patient transport mesh until it undergoes a collision. PEREGRINE then consults the interaction database and retrieves information on the incident particle and all secondary (daughter) particles resulting from the collision. All the daughter products are tracked as they travel through the transport mesh until they are absorbed in the body or leave the patient. During the simulation, PEREGRINE records the energy deposited at each interaction, building up a map of absorbed dose in the patient transport mesh. By repeating the process for millions of the trillions of particles a patient receives in a treatment, the Monte Carlo algorithm produces a statistically realistic picture of an entire irradiation.

Figure 5 illustrates the dose buildup in a radiation treatment. The more particles that are tracked, the more accurate is the simulation of the treatment and the better is the information for the doctor. But tracking particles takes time, and therein lies the challenge—attaining both accuracy and speed.

Supercomputer to Desktop

The historical problem with Monte Carlo has been that the radiation treatment

planning community cannot afford a turnaround time of more than an hour to meet its caseload. Previously, even on a $20-million Cray-1 supercomputer, a single dose calculation took weeks to complete. So Monte Carlo calculations remained in the weapons, reactor, and high-energy-physics research communities where the turnaround time for calculations could stretch over months.

Livermore computer experts have combined state-of-the-art computation techniques and advanced computer architecture to bring Monte Carlo treatment planning to the hospital desktop and office network environment. Taking advantage of recent strides in microcomputer technology, the PEREGRINE dose calculation engine is constructed from economical, off-the-shelf computer components originally developed for file- and Internet-server applications. PEREGRINE can be integrated into any treatment planning system via conventional network connections. Adding it to an existing system will be as easy as adding a file server.

The system design uses multiple processors interconnected by an internal high-speed network. The physics software distributes the calculations for a problem so that the dose is calculated by many microprocessors in parallel. The number of microprocessors can be determined by the user. For example, a big-city clinic that plans many radiation treatments each day would require a larger number of microprocessors to enable the fastest possible turnaround time. A suburban or rural clinic that does fewer radiation treatments might order a smaller, less expensive system. The system design supports hardware upgrades to increase calculational capability and to adapt to future technological changes. Now, a PEREGRINE calculation takes about 30 minutes. As code refinements
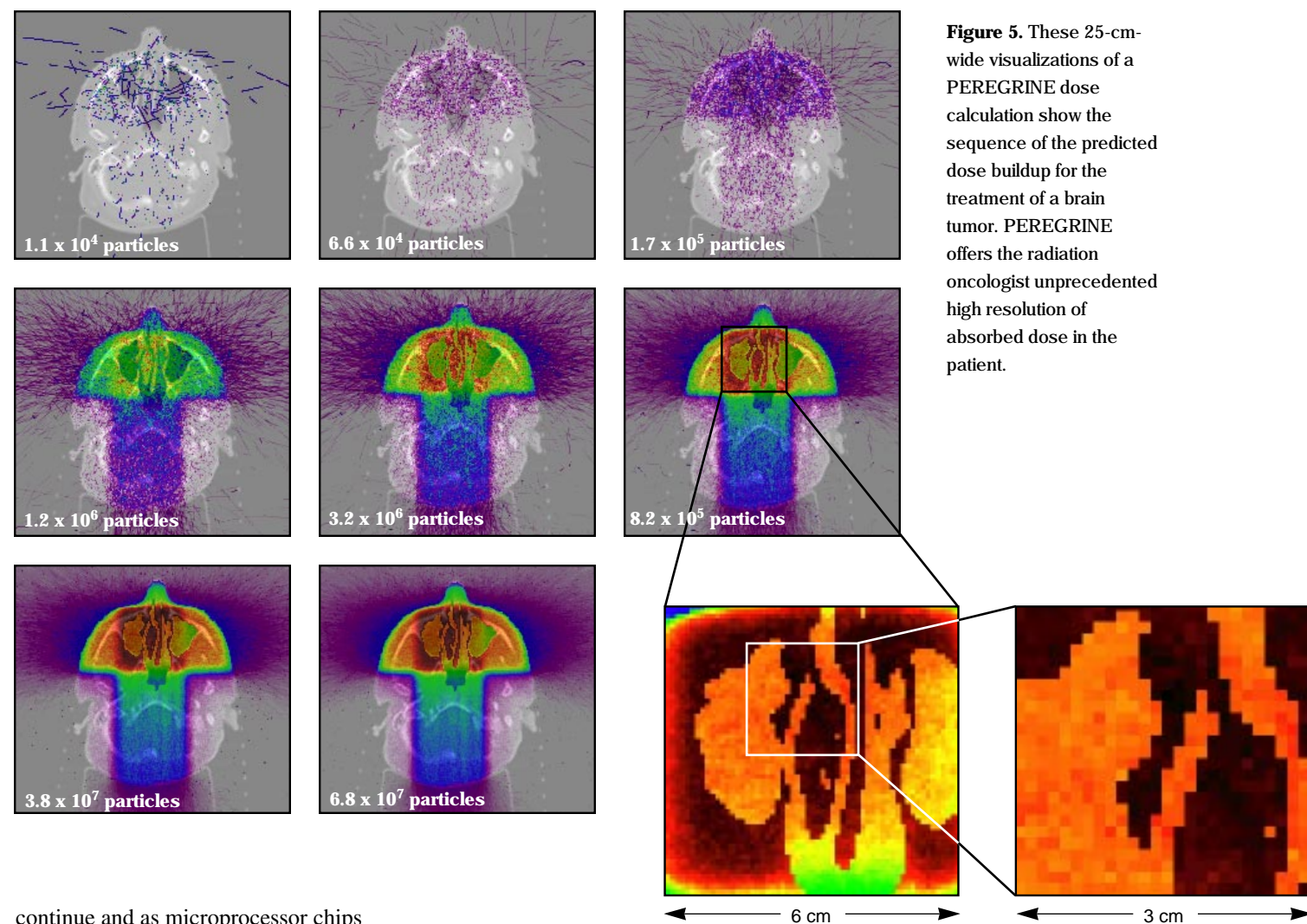

1.1 x 10⁴ particles

6.6 x 10⁴ particles

1.7 x 10⁵ particles

1.2 x 10⁶ particles

3.2 x 10⁶ particles

8.2 x 10⁵ particles

3.8 x 10⁷ particles

6.8 x 10⁷ particles

6 cm

3 cm

Figure 5. These 25-cm-wide visualizations of a PEREGRINE dose calculation show the sequence of the predicted dose buildup for the treatment of a brain tumor. PEREGRINE offers the radiation oncologist unprecedented high resolution of absorbed dose in the patient.

continue and as microprocessor chips improve, the system will be even faster.

Clinical Verification

Almost since work began on PEREGRINE, the Livermore project team has worked closely with an advisory board of internationally respected medical physicists and physicians in radiation oncology. (See the list of organizations on p. 10.) Dubbed the MEDPAC (Medical Physics Advisory Committee), the group ensures that PEREGRINE incorporates the best physics and that this new technology is relevant in a clinical setting.

The project team is particularly interested in validating the accuracy of PEREGRINE dose calculations against clinical measurements for photon beam (or x-ray) therapy, the most frequently used form of radiation therapy (Figure 6). The University of California, San Francisco (UCSF), has provided over 650 dose distribution measurements in a variety of materials and geometries that simulate conditions in the patient. UCSF and the Medical College of Virginia have provided retrospective cases for dose calculation comparisons for patients with

tumors in the head and neck, spine, lung, and larynx. Livermore has also begun a collaboration with the Radiation Therapy Oncology Group, a team sponsored by the National Cancer Institute, with the goal of using PEREGRINE in their new 3D lung cancer treatment protocol to calculate doses on all their patients.

Through these efforts, Livermore is working to improve the reliability of radiation source characterizations, validate the PEREGRINE dose calculations against clinical measurements, and evaluate the

impact of accurate dose calculations on the patient's outcome. Ultimately, the system should facilitate more accurate standardized clinical trials and more reliable implementation of those results throughout the medical community.

A Look Ahead

Livermore is now working with the radiation treatment-planning community to assure that PEREGRINE integrates easily into existing treatment-planning systems as a simple upgrade. Lawrence Livermore plans to license PEREGRINE to treatment-planning vendors so that it will be widely available.

In the near future, the project team plans to make PEREGRINE fully applicable to electron-beam therapy, stereotactic radiosurgery, and brachytherapy. (See box on p. 6.) Later, the team will study applications for heavy-particle (neutron and proton) therapies, which are used for cancers in and around the salivary glands, spinal cord, and eye.

The team is also pursuing collaborations in the application of the system to cancers of the breast and prostate. PEREGRINE is the only dose calculation algorithm today that can fully model the dose buildup near the surface of the breast, which is very important because of the area's sensitivity to radiation burns. Accurate dose calculations for prostate cancer are critically important because of the sensitivity of nearby structures to radiation injury.

As PEREGRINE becomes more sophisticated, it may change the way radiation treatments are planned. Today, a radiation oncologist studies a patient's CT scans to determine where radiation should and should not be delivered and what the absorbed dose must be to destroy the tumor. The medical physicist and dosimetrist then recommend a plan to deliver the radiation (numbers of beams, angles, etc.) prescribed by the oncologist. The PEREGRINE project team plans to bring "inverse planning" to this process, whereby treatment goals are established by the oncologist and input into PEREGRINE, which then determines how best to deliver the radiation to the patient.

"PEREGRINE may soon help to save thousands of lives," Siantar says. "Its high accuracy, speed, and affordability add up to the likelihood of widespread use at research hospitals and small clinics, which will bring superior radiation dose calculations and better treatment to more patients."
—Katie Walter

About the Team

EDWARD MOSES, PEREGRINE program leader since 1994, received a Ph.D. (1977) in electrical engineering from Cornell University, where he specialized in quantum electronics. His earlier Lawrence Livermore experience includes program manager of the AVLIS (Atomic Vapor Laser Isotope Separation) Program from 1986 to 1990.

CHRISTINE SIANTAR, principal investigator of the PEREGRINE program, received her Ph.D. (1991) in medical physics from the University of Wisconsin. Prior to joining Lawrence Livermore in 1994, she gained experience in cancer treatment planning at the Medical College of Wisconsin. Her present duties also include validation and verification of the Monte Carlo calculations for PEREGRINE.

Abstract

PEREGRINE: Improving Radiation Treatment for Cancer

The Lawrence Livermore National Laboratory has developed a radiation dose calculation system that will provide the most accurate and highest resolution treatment planning capability available. PEREGRINE is designed to be fast and affordable and will run on low-cost computer hardware in a hospital network environment. The availability of such accurate dose calculations will improve the effectiveness of radiation therapy by providing quality radiation treatment planning for patients in every clinical environment and facilitating accurate clinical trials. PEREGRINE will provide accurate estimates of required doses for tumor control and normal tissue tolerance and will advance the field of radiation oncology. It can be used for all methods of radiation therapy and could help save thousands of lives each year.

Figure 6. Comparison of PEREGRINE calculations and clinical measurements of radiation dose in water from the University of California, San Francisco, show PEREGRINE's unparalleled accuracy in predicting the delivered dose of radiation
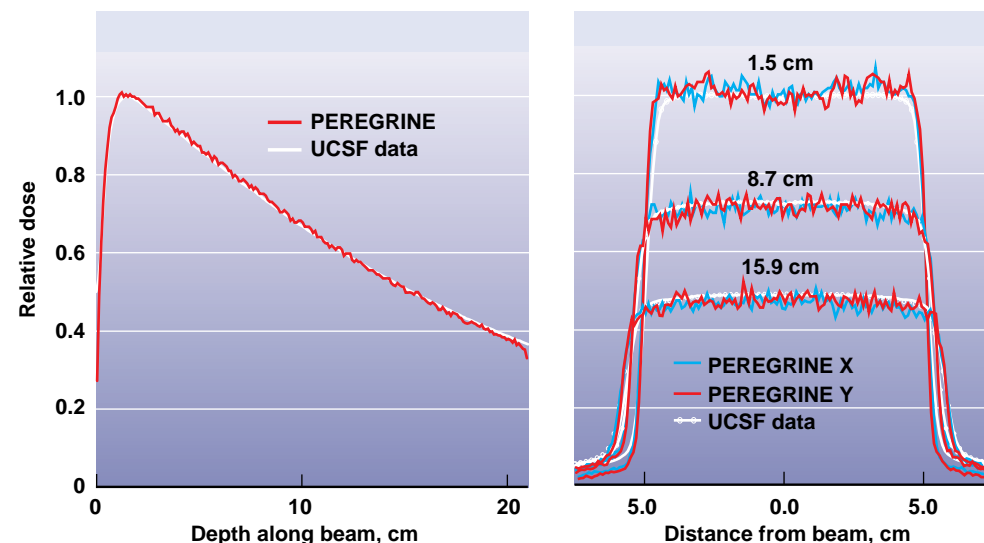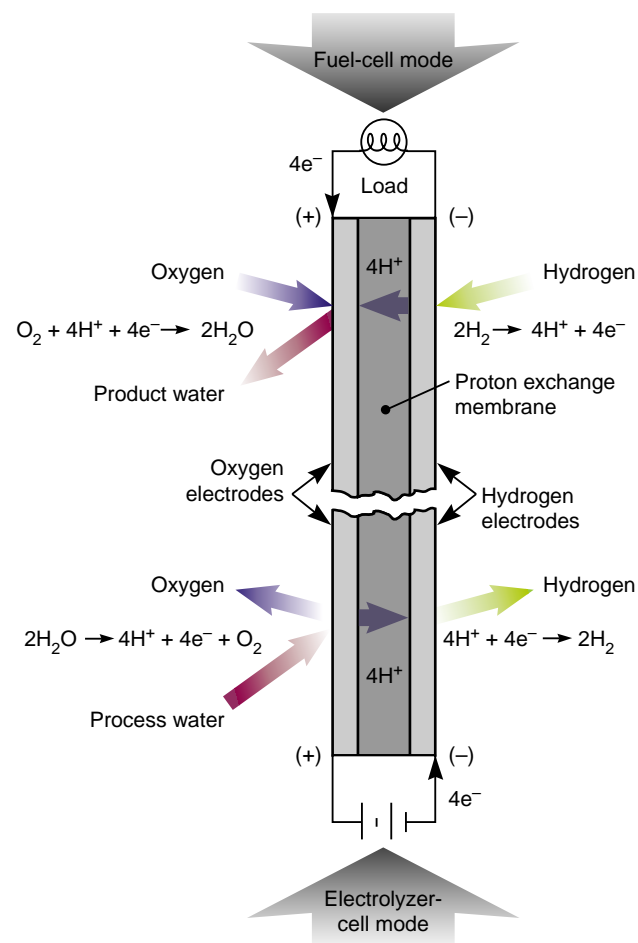
The Unitized Regenerative Fuel Cell

Figure 1. The electrochemistry of a unitized regenerative fuel cell. In the fuel-cell mode, a proton-exchange membrane combines oxygen and hydrogen to create electricity and water. When the cell reverses operation to act as an electrolyzer, electricity and water are combined to create oxygen and hydrogen.

SCIENTISTS are searching for cleaner ways to power vehicles and to make better use of domestic energy resources. The fuel cell, an electrochemical device that converts the chemical energy of a fuel directly to usable energy without combustion, is one of the most promising of these new technologies. Running on hydrogen fuel and oxygen from the air, a 50-kilowatt fuel cell can power a lightweight car without creating any undesirable tailpipe emissions.

If the fuel cell is designed to operate also in reverse as an electrolyzer, then electricity can be used to convert the water back into hydrogen and oxygen. (See Figure 1.) This dual-function system is known as a reversible or unitized regenerative fuel cell (URFC). Lighter than a separate electrolyzer and generator, a URFC is an excellent energy source in situations where weight is a concern.

Weight was a critical issue in 1991 when scientists at Lawrence Livermore National Laboratory and AeroVironment of Monrovia, California, began looking at energy storage options for an unmanned, solar-powered aircraft to be used for high-altitude surveillance, communications, and atmospheric sensing as part of the Strategic Defense Initiative. Called Pathfinder, the aircraft set an altitude record for solar-powered flight in 1995, flying to 15,400 meters (50,500 feet) and remaining aloft for about 11 hours. Pathfinder's successor, Helios, will remain aloft for many days and nights. For that aircraft, storage devices were studied that would provide the most energy at the lowest weight, i.e., the highest energy density. The team looked at flywheels, supercapacitors, various chemical batteries, and hydrogen–oxygen regenerative fuel cells. The regenerative fuel cell, coupled with lightweight hydrogen storage, had by far the highest energy density—about 450 watt-hours per kilogram—ten times that of lead–acid batteries and more than twice that forecast for any chemical batteries.

The Prototype

Fuel cells have been used since the 1960s when they supplied on-board power for the Gemini and Apollo spacecraft. Today, fuel cells are being used for Space Shuttle on-board power, power plants, and a variety of experimental vehicles. However, none of these applications uses the URFC because early experience did not uncover the usefulness of the reversible technology, and little research had been funded. Recent results of Livermore research indicate otherwise, based on more thorough systems engineering and improved membrane technology.

Challenged by a lack of information on the technology, Livermore physicist Fred Mitlitsky was determined to uncover just how to make the combination of technologies work. Mitlitsky continued in 1994 with a little funding from NASA for development of Helios and from the Department of Energy for leveling peak and intermittent power usage with sources such as solar cells or wind turbines. (See Figure 2.)

The 50-watt prototype that Mitlitsky's team developed is a single proton-exchange membrane cell (a polymer that passes protons) modified to operate reversibly as a URFC. It uses bifunctional electrodes (oxidation and reduction electrodes that reverse roles when switching from charge to discharge, as with a rechargeable battery) and cathode-feed electrolysis (water is fed from the hydrogen side of the cell). By November 1996, the prototype
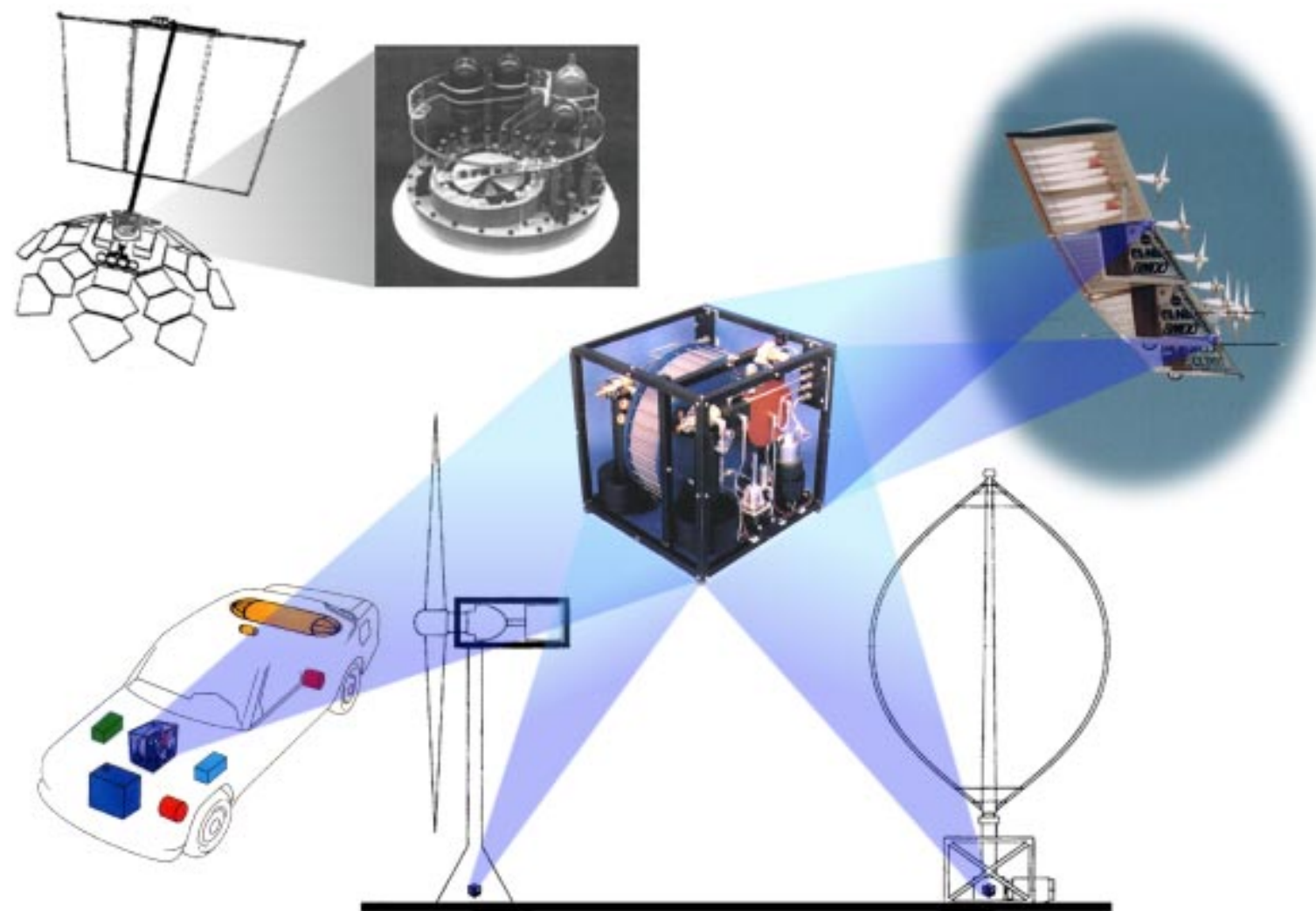
Figure 2. Unitized regenerative fuel cells will someday find a multitude of applications. URFCs are ideal for cars, solar-powered aircraft, energy storage, propulsion in satellites and micro-spacecraft, and load leveling at remote power sources such as wind turbines and solar cells.

had operated for 1,700 ten-minute charge–discharge cycles, and degradation was less than a few percent at the highest current densities.[1]

Testing will continue in a variety of forms. Larger, more powerful prototypes will be created by increasing the size of the membrane and by stacking multiple fuel cells. For use on Helios, a prototype will likely provide 2 to 5 kilowatts running on a 24-hour charge–discharge cycle. As funding becomes available, prototypes may also be tested for other uses. A lunar rover, for example, would require cycles of about 29 days.

URFC-Powered Electrical Vehicles

In a 1994 study for automotive applications, Livermore and the Hamilton Standard Division of United Technologies studied URFCs. They found that compared with battery-powered systems, the URFC is lighter and provides a driving range comparable to gasoline-powered vehicles. Over the life of a vehicle, they found the URFC would be more cost effective because it does not require replacement.[2]

In the electrolysis (charging) mode, electrical power from a residential or commercial charging station supplies energy to produce hydrogen by electrolyzing water. The URFC-powered car can also recoup hydrogen and oxygen when the driver brakes or descends a hill. This regenerative braking feature increases the vehicle's range by about 10% and could replenish a low-pressure (1.4-megapascal or 200-psi) oxygen tank about the size of a football.

In the fuel-cell (discharge) mode, stored hydrogen is combined with air to generate electrical power. The URFC can also be supercharged by operating from an oxygen tank instead of atmospheric oxygen to accommodate peak power demands such as entering a freeway. Supercharging allows the driver to accelerate the vehicle at a rate comparable to that of a vehicle powered by an internal-combustion engine.

The URFC in an automobile must produce ten times the power of the Helios prototype, or about 50 kilowatts. A car idling requires just a few kilowatts, highway cruising about 10 kilowatts, and hill climbing about 40 kilowatts. But acceleration onto a highway or passing another vehicle demands short bursts of 60 to 100 kilowatts. For this, the URFC's supercharging feature supplies the additional power.

A URFC-powered car must be able to store hydrogen fuel on board, but existing tank systems are relatively heavy, reducing the car's efficiency or range. Under the Partnership for a New Generation of Vehicles, a government–industry consortium dedicated to developing high-mileage cars, the Ford Corporation provided funding to LLNL, EDO Corporation, and Aero Tec Laboratories for development of a lightweight

hydrogen storage tank (a pressure vessel). The team combined a carbon fiber tank with a laminated, metalized, polymeric bladder (much like the ones that hold beverages sold in boxes) to produce a hydrogen pressure vessel that is lighter and less expensive than conventional hydrogen tanks. Equally important, its performance factor—a function of burst pressure, internal volume, and tank weight—is about 30% higher than that of comparable carbon-fiber hydrogen storage tanks. In tests where cars with pressurized carbon-fiber storage tanks were dropped from heights or crashed at high speeds, the cars generally were demolished while the tanks still held all of their pressure—an effective indicator of tank safety.

Unlike other hydrogen-fueled vehicles whose refueling needs depend entirely on commercial suppliers, the URFC-powered vehicle carries most of its hydrogen infrastructure on board.[3] But even a highly efficient URFC-powered vehicle needs periodic refueling. Until a network of commercial hydrogen suppliers is developed, an overnight recharge of a small car at home would generate enough energy for about a 240-kilometer (150-mile) driving range, exceeding the range of recently released electrical vehicles. With the infrastructure in place, a 5-minute fill up of a 35-megapascal (5,000-psi) hydrogen tank would give a 580-kilometer (360-mile) range.

Commercial development of unitized regenerative fuel cells for use in automobiles is perhaps 5 to 10 years away. With their long life, low maintenance requirements, and good performance, URFCs hold the promise of someday supplying clean, quiet, efficient energy for many uses.

—Katie Walter

Key Words: electric cars, fuel cell, Helios, hydrogen, Partnership for a New Generation of Vehicles, zero-emission vehicles.

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Better Flash Radiography Using the FXR

IMAGINE a very powerful x-ray machine, several billion times more powerful than the one your dentist aims at your jaw. X rays can penetrate more than a foot of steel and record the motion of materials moving at ultrahigh speeds, making it an excellent tool for peering into the interior of a nuclear weapon's imploding primary stage.

Non-nuclear hydrodynamic experiments reveal the behavior of a nuclear weapon from ignition to the beginning of the nuclear chain reaction. These experiments consist of wrapping inert (nonfissile) material in a high explosive that is then detonated. The resulting explosive compression deforms the material,

makes it denser, and even melts it. This process replicates the effects in the core of a nuclear device. High-speed radiographic images of the implosion process are taken with the powerful x-ray machine known as the Flash X Ray, or FXR, which was developed by scientists at Lawrence Livermore National Laboratory in the early 1980s'

Data from the FXR's x-ray images are used to verify and normalize Livermore's computer models of device implosions. In the absence of nuclear testing, scientists must rely on these computer calculations to develop the judgment necessary to certify the safety and reliability of nuclear weapons, a critical part of the Laboratory's role in the stewardship of our nation's nuclear stockpile.

This photograph of a typical experiment using the Flash X Ray was taken almost 20 milliseconds after detonation, long after the FXR had finished its data collection. The FXR is housed in the building to the left of the firing table.

To improve capabilities for science-based stockpile stewardship, Lawrence Livermore has been upgrading many diagnostic facilities at Site 300, the Laboratory's experimental test site. The FXR was already the most sophisticated hydrodynamic flash radiography system in the world. In response to the need for data supporting ever more exact computer modeling codes, it has been made more powerful and capable of producing sharper, more useful radiographs.

The FXR in Action

The FXR is an induction linear accelerator specifically designed for diagnosing hydrodynamic tests and radiographing the interior of an imploding high-explosive device. Its x rays penetrate and are scattered or absorbed by the materials in the device, depending upon the density and absorption cross section of the various interior parts. The x rays that are neither absorbed or scattered by the device form the image on photographic emulsions or on the recording surface in a gamma-ray camera.

An injector introduces an electron beam into the FXR accelerator. After passing through the accelerator, the beam enters a drift section that directs it toward a 1-millimeter-thick strip of tantalum, called a target. As the high-energy electrons pass through the target, the electric field created by the stationary charged particles of the heavy tantalum nuclei causes the electrons to decelerate and radiate some of their energy in the form of x rays. The product of this slowing process is called bremsstrahlung (braking) radiation.

The x-ray photons travel toward the exploding device, where most are absorbed. The photons that make it to the camera are the image data.

A Better Radiographic Process

The upgrades to the FXR centered on improving the quality of the beam and adding a new gamma-ray camera system that is 70 times more sensitive than radiographic film. In this camera, designed by Livermore scientists, the beam hits an array of bismuth–germanate crystals with which the x rays interact to generate visible light. This light is recorded on photographic film.

The first task in increasing FXR beam quality was to improve the magnetic field that transports the electron beam through the accelerator. New focus solenoids and printed-circuit magnetic steering coils were installed in each of the accelerator and injector cells. Transverse magnetic forces that had been pulling the beam out of alignment were reduced by a factor of 10 to 20.

The next task was to double the injector beam voltage from 1.2 megavolts to 2.5 megavolts. At the same time, the injector electron beam current was increased from 2.2 kiloamperes to 3 kiloamperes. The number of cells in the injector was increased from six to ten, and the electron diode and the injector magnetic transport solenoids were redesigned.

With the completion of these upgrades, the FXR is producing a higher overall x-ray dose and

a smaller spot size. Today, the central portion on the x-ray spot is twice as intense compared with pre-upgrade levels. Because tuning the FXR is an ongoing process, improvements in performance are expected to continue.

Prior to the addition of the gamma-ray camera, the size of the beam where it hits the tantalum target was a major concern; a smaller "spot size" increases the sharpness and clarity of the radiographs. Achieving a smaller effective spot size was accomplished by passing the x rays through a small hole in a thick plate near the target, a process known as collimation. But because x rays emitted outside the collimation diameter are lost to the radiographic process, collimating the beam meant that thicker materials could not be studied.

Today, however, the increased sensitivity of the gamma-ray camera and the increased current density of the central portion of the electron beam combine to more than compensate for the losses due to collimation. The gamma-ray camera can produce much sharper, clearer images than before even with a lower available dose. The camera's sensitivity combined with the newly increased x-ray dose at the target means that collimation can be used for experiments involving even
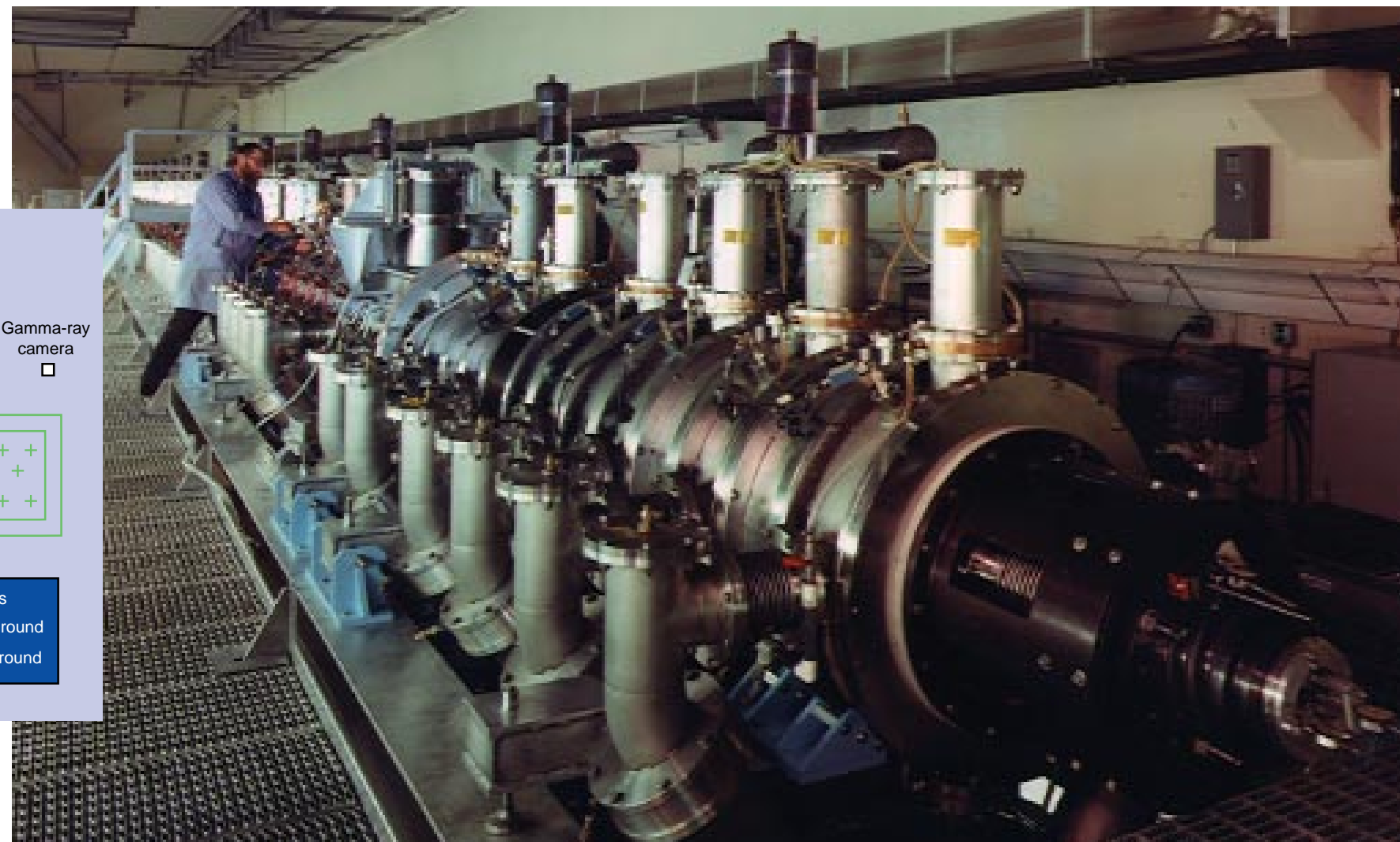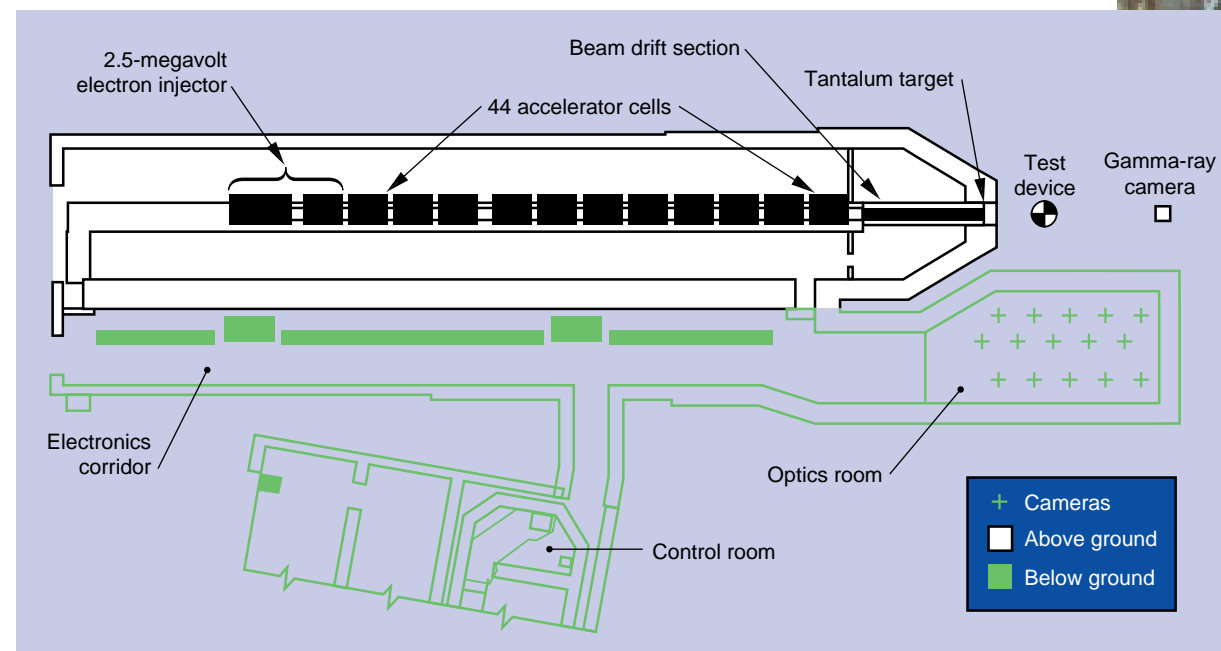
higher density materials. Preliminary results indicate that the FXR upgrade—in conjunction with the gamma-ray camera—have significantly improved the radiographic capability at Livermore.

In the near future, the Laboratory will be adding a double-pulse feature to the FXR to provide two radiographs of a single explosion–implosion separated by 1 to 5 microseconds. Researchers can use this information to follow the time evolution of an implosion and learn more about how an implosion progresses. Restoring single-shot, full-energy operation will require simply setting the pulse interval to zero. Livermore scientists are also developing a two-frame gamma-ray camera to capture the fast successive images of double-pulsed FXR radiography and record them on a charged-coupled device camera. Work on the double-pulse feature and the two-frame camera is expected to be complete in 1998.
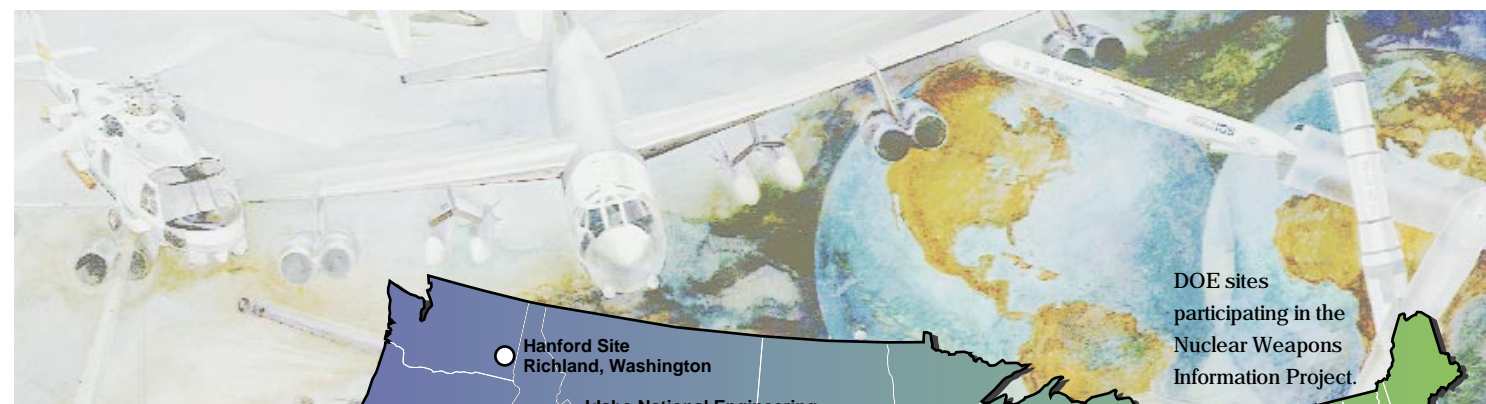
Key Words: flash x radiography (FXR), gamma-ray camera, hydrodynamic testing, induction linear accelerator, pulsed electron beam, pulsed x-ray source, stockpile stewardship.

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The Flash X-Ray beam area is on the same level as the firing table outside the building. The electronics corridor, optics room, and control room are underground, one level below the beam area and offset from the accelerator as shown in this schematic. Several of the accelerator cells can be seen in the photograph to the right.

2.5-megavolt electron injector

44 accelerator cells

Beam drift section

Tantalum target

Test device

Gamma-ray camera

Electronics corridor

Optics room

Control room

+ Cameras
□ Above ground
■ Below ground

Preserving Nuclear Weapons Information

DOE sites participating in the Nuclear Weapons Information Project.

HISTORICALLY, the primary mission of DOE's nuclear weapons laboratories has been weapon development and testing. The goal was to get the job done better and faster than anyone else in the world.

Access to the full documentation today is sometimes difficult, in part because weapons-related data were often classified and/or compartmentalized to limit the risk of inadvertent disclosure or access. Also, older data are dependent on old computer codes, operating systems, or media that cannot be read, and old notes and memos are fading. But even more vulnerable is the critical knowledge still residing only in scientists' heads or stashed in individual repositories.

The thrust of the weapons program today is science-based stewardship of the U.S. nuclear stockpile. Scientists at Lawrence Livermore National Laboratory are responsible for four of the nine weapon systems in the enduring U.S. stockpile, including the only ones that incorporate all modern safety features. Maintaining and managing those systems will be Livermore's responsibility for years to come.

With rare exceptions, the people who will manage the stockpile in the next century will do so without the direct knowledge that comes from having designed and tested a nuclear weapon. Because the generation of designers responsible for the current stockpile is reaching retirement age, "downloading" essential information from their heads is critical for future scientists.

Scientists and engineers at Livermore, proud of their work, enthusiastically embraced the Nuclear Weapons Information Project (NWIP), an archiving effort established in early 1993 to rescue at-risk data and knowledge. Bill Bookless, Principal Deputy Associate Director in the Defense and Nuclear Technologies Directorate, is the project leader. Late in 1993, the Defense Nuclear Facilities Safety Board issued Recommendation 93-6, which emphasized retaining safety-related capabilities and capturing weapons knowledge. That directive enhanced the visibility and priority of NWIP work.

The Nuclear Weapons Information Project will preserve Livermore's portion of the Department of Energy's Stockpile Stewardship and Management Program. It will also preserve data for training future scientists, engineers, and technicians and will provide immediate critical information for emergency response to nuclear weapon incidents.

The information archived in NWIP will support proliferation analyses to deter the spread of nuclear weapons to other countries and to terrorist organizations. And the database will provide the fundamental information necessary to resume weapons design, development, testing, and production if required by changes in a volatile world situation.

Because scientists at Livermore depend on access to information at all DOE nuclear weapon facilities, in 1994 Livermore also took a leading role in implementing an information preservation collaboration across the DOE weapons complex. The Nuclear Weapons Information Group (NWIG) today includes participants from the DOE sites shown in the figure, the Department of Defense's Defense Special Weapons Agency, and the United Kingdom's Atomic Weapons Establishment.

The Task at Hand

When work began on the DOE project, the most critical needs were learning what information existed and how to get appropriate access to it. Some DOE sites have as many as 300 different databases or catalogs of relevant data. And some data shelved in unmarked boxes have never been catalogued. Consequently, the initial focus of the group was on "metadata," which are data about data—typically bibliographic data—and on standardization efforts.

Terminology has changed over time, and various organizations across the DOE complex use different terms for the same thing. Local glossaries have been developed and are being shared and integrated, and a categorization system is being developed to define common subject areas. Livermore leads the working group that is developing metadata standards and has led the pilot implementation of searches on and across multiple catalogs.

Capturing documents and data is actually the easy part of the project. Capturing the knowledge that is in people's heads and that cuts across program boundaries is more difficult. Videotapes are being made of panel discussions, tours, lectures, and operations to save undocumented anecdotal technical information and historical perspectives.

Livermore has already adopted the NWIG standards and methods for access by implementing commercial "browser" software to provide access to its electronic archives. A pyramidal need-to-know model is also being implemented, such that individuals authorized at the top of the pyramid may have access to nearly everything while those authorized at other levels have access only to information in a particular domain or perhaps about specific weapon systems. By enhancing its classified network infrastructure, Livermore can balance the increased access to information against the increased threat of compromise.

Translating archived files into such standard formats as HyperText Markup Language (HTML) and Portable Document Format (PDF) minimizes the number of platform-sensitive formats that must be translated indefinitely as the technology changes. Settling on a few standard formats also allows the search engine to index every word of every document for retrieval. Links can then be made to the actual archived online documents, or for catalog searches, the search engine can indicate where the documents can be found.

Cutting-Edge Technologies

Several advanced technologies are being applied to the Nuclear Weapons Information Project at Livermore. An example is the online video search and retrieval system, which will provide authorized users of the archives access to videotaped information through a search of the automatically generated transcripts. A search will yield both words in the transcript and matching video images.

The access control mechanisms work together with state-of-the-art identification and encryption technology to ensure authorization, authentication, and secure delivery of information on distributed classified networks. Administrators in weapons-related divisions at Livermore are also making use of this new commercial technology to better protect sensitive unclassified information. Livermore is leading the effort across the DOE complex to establish and implement access control policies and procedures.

Information Is a National Asset

Downloading the knowledge from scientists' heads and archiving those stashed personal files—plus organizing and categorizing more accessible data—are essential tasks. The project team is establishing the archives so that this accumulated information, an important national asset, is preserved for the long term and readily accessible whenever needed. The success of much of DOE's Stockpile Stewardship and Management Program depends on these new archives.

Key Words: archives, Nuclear Weapons Information Project, Stockpile Stewardship and Management Program.

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Patents

Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
Kenneth W. Neufeld	**Electromechanical Cryocooler** U.S. Patent 5,582,013 December 10, 1996	A device for cooling instruments, such as radiation detectors, while minimizing vibrations. It contains a compressor with a linear motor and a piston and measuring device to measure the direction and force of the compressor's vibrations. It also has a controller, mechanically coupled to the compressor, that takes signals generated by the measuring device and responds with a counterforce, which reduces the vibrations. The input of signals to the compressor and the counterbalance minimize the total acceleration of the cooler while it performs its thermodynamic function.
Alan T. Teruya John W. Elmer	**Tomographic Determination of the Power Distribution in Electron Beams** U.S. Patent 5,583,427 December 10, 1996	A technique for determining the power distribution of an electron beam using electron-beam profile data acquired from a Faraday cup to create an image of the current density in high- and low-power beams. A refractory metal disk with a number of radially extending slits is placed above the cup. The beam acquires the data by sweeping in a circular pattern so that its path crosses each slit in a perpendicular manner. A computer generates the signals to actuate the sweep, acquires data, and does the reconstruction.
Laura N. Mascio	**Automated Analysis for Microcalcifications in High Resolution Digital Mammograms** U.S. Patent 5,586,160 December 17, 1996	A computer-aided method and apparatus for diagnosing breast cancer. A computer algorithm using gray-scale morphology is implemented to automatically detect, analyze, and flag microcalcifications in digitized film mammograms to reduce the percentage of false-negative diagnoses. For each potential microcalcification detected in these images, a number of features are computed to distinguish between the different kinds of objects detected. A selective erosion or enhancement filter helps weed out false alarms. The algorithm determines which portions of a mammogram to store at the highest resolution, thereby reducing data volume and image storage space.
M. Allen Northrup Raymond P. Mariella, Jr. Anthony V. Carrano Joseph W. Balch	**Silicon-Based Sleeve Devices for Chemical Reactions** U.S. Patent 5,589,136 December 31, 1996	A chemical reaction chamber made of doped polysilicon for heating and bulk silicon for convective cooling combined in a critical ratio so that the material can be uniformly heated using a small amount of power. The reaction sleeve allows for the introduction of a secondary tube that contains the reaction mixture, thereby avoiding any potential material incompatibilities. The chamber can be used in chemical reaction systems for synthesis or processing of organic, inorganic, or biochemical reactions, such as the polymerase chain reaction and other DNA reactions.
Thomas E. McEwan	**Short Range Radio Locator System** U.S. Patent 5,589,838 December 31, 1996	A wireless transmitter that outputs periodic bursts of radar carrier signals. A receiver system determines the position of the transmitter by the relative arrival of the radar burst at several component receivers specially located. One receiver provides a synchronizing gating pulse to itself; the other receiver samples the radar pulse. The rate of the synchronizing gating pulse is slightly offset from the rate of the radar bursts, so that each sample collects one finely detailed piece of information about the time of flight of the radar pulse to each receiver for each pulse period.
John S. Taylor	**Precision Non-Contact Polishing Tool** U.S. Patent 5,591,068 January 7, 1997	A tool with an adjustable footprint geometry that can meet stringent shape and finish tolerances on precision surfaces during fabrication. Two orthogonal slurry flow geometries provide flexibility in altering the shape of the removal footprint. The tool is applicable for x-ray optical surfaces, x-ray lithography, and lenses that have very tight geometrical tolerances. Several operating parameters are available for varying the relative influences of the mechanism.

Patents (continued)

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
Michael A. Doty	**System and Method for Simultaneously Collecting Serial Number Information from Numerous Identity Tags** U.S. Patent 5,591,951 January 7, 1997	A system that simultaneously collects and reports serial number information from numerous colliding, coded radiofrequency identity tags. Each tag's multidigit serial number is stored in nonvolatile RAM. A reader transmits an ASCII-coded "D" character on a 900-MHz carrier and a 1.6-GHz power illumination field. A 1-MHz tone is modulated on the 1.6-GHz carrier as a timing clock for a microprocessor in each of the identity tags. Each identity tag looks for the "D" interrogator modulated on the 900-MHz carrier, using a digit of its serial number to time a response.
Edward J. Kansa Ananda M. Wijesinghe Brian E. Viani	**Nontoxic Chemical Process for In Situ Permeability Enhancement and Accelerated Decontamination of Fine-Grain Subsurface Sediments** U.S. Patent 5,593,248 January 14, 1997	A remediation method for the removal of certain liquid and solid phase contaminants from low-hydraulic-conductivity, fine-grained sediments. The contaminants must be miscible or appropriately soluble in at least one of the treatment chemicals. Cationic flocculants or organic solvents are introduced to increase the hydraulic conductivity and carry away mobilized contaminants, including hydrophilic hydrocarbons, hydrophobic fuel hydrocarbons, and halogenated hydrocarbons.
Paul D. Sargis Ronald E. Haigh Kent G. McCammon	**Subcarrier Multiplexing with Dispersion Reduction and Direct Detection** U.S. Patent 5,596,436 January 21, 1997	A system that provides both a dispersion reduction and a direct detection to a receiver, with microwave mixers and lithium–niobate external modulators that produce sidebands separated by a few gigahertz from a principal laser optical carrier. Digital data streams are independently impressed upon these sidebands for transmission over an ordinary single-mode fiber. Independent high-speed data streams are converted to microwave frequencies. These subcarriers are then combined with a microwave power combiner and amplified.
Thomas J. Karr	**Passive Infrared Bullet Detection and Tracking** U.S. Patent 5,596,509 January 21, 1997	A detector that is focused onto a region where a projectile is expected to be located. Successive images of infrared radiation in the region are recorded. Background infrared radiation present in the region is suppressed such that successive images are produced of infrared radiation generated by the projectile as the projectile passes through the region. A projectile-path calculator determines the path and other aspects of the projectile by using the successive images of infrared radiation generated by the projectile. The apparatus can also determine the origin of the projectile's path and photograph and/or fire a projectile at that area.
George D. Craig Robert Glass Bernhard Rupp	**System and Method for Forming Synthetic Protein Crystals to Determine the Conformational Structure by Crystallography** U.S. Patent 5,597,457 January 28, 1997	A method for forming synthetic crystals of proteins in a carrier fluid by using dipole moments of protein macromolecules that self-align in the Helmholtz layer adjacent to an electrode. The voltage gradients of such layers exceed 106 V/m. The voltage promotes formation of the protein macromolecules into pearl chains and three-dimensional crystals. The synthetic protein crystals are subjected to x-ray crystallography to determine the conformational structure of the protein involved. This fast electrocrystallization method can be applied to a wider range of proteins than conventional methods.

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