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About S&TR

The Lawrence Livermore National Laboratory, operated by the University of California for the United States Department of Energy, was established in 1952 to do research on nuclear weapons and magnetic fusion energy. Science and Technology Review (formerly Energy and Technology Review) is published monthly to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments, particularly in the Laboratory's core mission areas—global security, energy and the environment, and bioscience and biotechnology. The publication's goal is to help readers understand the accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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Terawatt laser tests are prelude to petawatt

Laboratory researchers have been putting their new 100-terawatt, high-power, ultrashort pulse laser through its paces, testing some of the basic concepts underlying a petawatt laser they plan to debut in January. Ramped up to full power for the first time on July 31, the terawatt system produced 125 trillion watts of power in an extremely short pulse—less than 0.5 milliseconds of a second.

The laser was made possible by a revolution over the last few years in the ability of scientists to produce extremely short high-power and high-intensity pulses. “The regime of physics accessible with the 100-terawatt laser is only now beginning to be explored,” said Mike Campbell, Associate Director for Lasers at LLNL.

The system will have applications in basic laser-plasma physics, x-ray lasers, fast-ignitor research, and many other areas, while simultaneously serving as an engineering prototype for the Laboratory’s petawatt (1-quadrillion-watt) system. Initial testing of the petawatt is slated for December, when it will produce 10 to 20 times the power of the 100-terawatt laser.

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Upgraded FXR back in business this month

Shut down since June to complete a $3.5-million performance upgrade, the Laboratory’s Flash X-Ray Radiography (FXR) facility was scheduled, at S&T press time, to be back in business in mid-October.

In the era of science-based stockpile stewardship, FXR is viewed as a key tool to help assure the safety and reliability of the nation’s nuclear weapons stockpile. In addition to these primary mission needs, the Laboratory is a major user of petawatt laser science and is a key provider of science and technology to the Department of Energy.

Lab scientists aid in discovery of dwarfism gene

Recent advances in genetic research offer the hope of a better understanding and prevention of ailments ranging from cancer to arthritis, as well as the ability to measure the severity of disease.

One of the Smithsonian scientists, Greg Lennon, says that in the long run the discovery may lead to “a better understanding of joint and bone disorders—including osteoarthritis—and ways to treat them.”

Lennon and his colleagues Harvey Molenrenweiser, Anne Olsen, and Susan Hoffman provided the research teams with expertise that helped localize the region of chromosome 19, with which both diseases and the COMP gene were associated. They were also resources for detailed analysis of the normal gene.

Lennon worked with scientists from the University of Texas—Houston Health Science Center, the University of Texas—Houston Medical School, the National Center for Human Genome Research at the National Institutes of Health, and Harvard Medical School. Molenrenweiser, Olsen, and Hoffman collaborated with scientists from the Cedars—Sinai Medical Center in Los Angeles and the Jefferson Medical College in Philadelphia.

Contact: Greg Lennon (510) 422-5717 (lennon5@llnl.gov).

Lab joins study of childhood thyroid disease

Members of the Laboratory’s Environmental Programs directorate are on a U.S.–Ukrainian team that is undertaking what has been described as the largest and most detailed study of its kind of the effects of radiation exposure on the incidence of thyroid disease in children.

The work focuses on 70,000 children who lived in areas of Ukraine that were heavily contaminated in the 1986 accident at the Chernobyl nuclear power plant. A primary objective of the study, estimated to last 15 years, is to determine to what extent exposure to radiiodine, especially iodine-131, results in thyroid disease in children.

The scientific protocol that lays out a plan for the study was signed in May by the U.S. Ambassador to Ukraine and the acting Ukrainian Minister of Health. Work under the protocol is expected to cost roughly $1 million annually, which will be funded primarily through Department of Energy funds.

As a designated “Center of Excellence” for the epidemiological study, the Laboratory will play a lead role in the dose-reconstruction efforts and will purchase and deliver medical and other supplies needed to keep the study functioning over its 15-year lifetime.

Other U.S. participants in the study are the National Cancer Institute and the Nuclear Regulatory Agency. Ukrainian participants include the Ministry of Health of Ukraine, the Ukraine Academy of Medical Sciences, the Ukrainian Research Institute of Endocrinology and Metabolism, the Ukrainian Scientific Center for Radiation Medicine, and the Ukraine Radiation Protection Institute.

Contact: Lynn Anspaugh (510) 424-6409 (anspaugh1@llnl.gov).

Climate models may have ignored sulfate aerosols

Conventional climate-modeling studies may have omitted an important factor in predictions of greenhouse warming—the effects of sulfur aerosol pollutants, which result from photochemical reactions of sulfur dioxide emitted by fossil-fuel combustion.

That is the assessment of Laboratory researchers who developed a computer model to track the effects on the atmosphere of both sulfate aerosol pollutants and greenhouse gases, such as carbon dioxide emissions, from burning fossil fuels.

During the past 100 years, average temperatures have increased 0.5°C, instead of the 1°C predicted by conventional computer climate models. The predictions, however, considered the effects of greenhouse gases only, not sulfate aerosols pollutants, which tend to lower temperatures.

Predictions of climate change in response to both greenhouse gases and sulfate aerosols are a closer match to actual observed temperatures, the new Livermore studies indicate. The work by physicist Joyce Penner and Karl Taylor and climatologist Ben Santer is discussed in the June 16, 1995, issue of Science.

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MIR crosses $1-million royalty, licensing fee mark

Teleflex of Plymouth Meeting, Pennsylvania, has become the tenth company to license the Laboratory’s new radar technology—micropower impulse radar, or MIR. Originally developed by engineer Tom McElvan as part of a diagnostic system for our Nova laser, MIR has earned more than $1 million in royalties and fees.

All companies that receive a license for the radar technology are required to have their MIR-based products substantially manufactured in the U.S., thus creating jobs inside the country. Teleflex, which specializes in four industries (aerospace, marine, automotive, and medical), said it plans to construct a new manufacturing facility in Florida, partly to turn out products based on our radar technology.

In recent months, the technology has generated more than 2700 calls to the Laboratory from businesses and individuals. Because of continuing interest from business, we held the first MIR trade show in August. At press time, a second one is planned for October.

Michael Odzi, publisher of Technology Access Report, an industry newsletter, said he believes “the Livermore radar is the fastest growing technology license in the entire federal laboratory system.”

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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**

<table>
<thead>
<tr>
<th>Patent issued to</th>
<th>Patent title, number, and date of issue</th>
<th>Summary of disclosure</th>
</tr>
</thead>
<tbody>
<tr>
<td>George Kramer</td>
<td>Linear Phase Compressive Filter</td>
<td>U.S. Patent 5,422,607; June 6, 1995. A filter circuit and process consisting of a ladder or series of stages of low-pass filters in each stage each has an inductor with a voltage-dependent gain and/or phase response.</td>
</tr>
<tr>
<td>Joseph Sefcik</td>
<td>Method and Apparatus for Capacitive Deionization, Electrochemical Purification, and Regeneration of Electrodes</td>
<td>U.S. Patent 5,425,858; June 20, 1995. An electrochemical separation process and apparatus for removing ions, contaminants, and impurities from water and other aqueous process streams and for subsequently electrically placing the removed ions back into the water.</td>
</tr>
<tr>
<td>William Chandler</td>
<td>Valving for Controlling a Fluid-Driven Reciprocating Apparatus</td>
<td>U.S. Patent 5,427,507; July 26, 1995. An improved valve control system for a pair of free-piston pumps that use valve assemblies operatively connected to each pump and interconnected so as to have fluid pressure communication between them. The valve arrangement permits rapid switching between the pumps' intake and exhaust and provides large cross-sectional areas for the flows with a short stroke as well as minimal hardware mass and size.</td>
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**Awards**

In mid-August, 16 Laboratory employees received Weapons Recognition of Excellence awards from the Department of Energy. Rear Admiral Charles Beers, Jr., DOE Deputy Assistant Secretary for Military Applications and Stockpile Support, presented the awards in a ceremony attended by over 300 people. The Awards, which represent achievements over the past three years, are as follows:

- **Weapons Recognition of Excellence Award**
- **Scientific and Technical Excellence Award**
- **Exemplary Performance Award**
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**Commentary on Energy Research**

LAWRENCE Livermore National Laboratory’s distinguished history in energy R&D is rooted in its beginnings, when work began on harnessing nuclear fusion for energy production. This early work made our Laboratory one of the first to apply its technologies to civilian energy purposes. This work has since broadened to many aspects of energy and has had a deep impact on the energy industry. As an example, Laboratory-developed models of petroleum formation are now used routinely in the search for oil worldwide.

Reasons for emphasizing energy research in our early years were straightforward: deep convictions that energy is vitally important to society and that there is a role for government in achieving long-term goals that are partly or totally external to the marketplace. Energy is the fuel that has driven all economies since the beginnings of civilization, providing mobility, communication, comfort, and relaxation. A good example of goals external to the marketplace is proving the scientific and technical feasibility of fusion.

In the U.S., gasoline is readily available and is cheaper than it has ever been, adjusting for inflation. However, significant changes are now taking place that will affect all of us in the developed world. The economies of the developing countries are growing so rapidly that their energy use will soon tax the capacity of known energy sources. The developing countries have four-fifths of the world’s population and are rapidly developing their economies. The Chinese have increased their energy use more than 50% in 10 years and have recently become the second largest energy market in the world, after the U.S. The trends mentioned above must make us seriously question whether the current situation is sustainable and what the role of the U.S. will be in future energy markets.

The Laboratory has led in advancing technologies to help sustain world economies while protecting the environment. One example is research on hydrogen as a future fuel, particularly for use in vehicles (see Science and Technology Review, July 1995). Conservative economic analyses indicate that hydrogen can be used as a fuel at a cost comparable to the cost of fueling today’s vehicles, with essentially none of the associated detriments to air quality. Hydrogen burns very efficiently, and the product of its combustion is water.

The advanced flywheels that we are developing will help store energy for advanced vehicles and allow superior power conditioning and storage in our homes and workplaces. We will no longer need to suffer power interruptions and surges. Another vehicle technology is the zinc/air power system described in this issue. Our research into the technologies used for manufacturing will result in energy savings by reducing the machining time and materials needed. These technologies will reduce our dependence on foreign oil, along with associated vulnerabilities to interruptions and price shocks.

Nuclear fission power has real potential for greatly reducing the amount of carbon dioxide we put into the atmosphere as a result of electricity generation. No one can say for sure what will be the consequences of greenhouse-gas-induced climate change, but evidence grows relentlessly that the temperature rise over the past half century is due to such emissions. We are working to resolve the technical issues inhibiting public acceptance of nuclear power as well as those relating to the prudent and safe disposition of nuclear waste.

At present there is a crisis in energy R&D, particularly over the role and size of the government’s funding. Can and should the private sector do it all? Energy now accounts directly for $500 billion of the $6-trillion U.S. economy. Yet we are spending only $2 billion (less than 0.5%) on government energy R&D, and the budgets appear to be heading significantly lower. That $2 billion represents about 2¢ per gallon of gasoline we use. By comparison, our total government R&D budget is about $60 billion; so we spend 3% of the government’s R&D money on energy, which contributes 8% to the economy, clearly an underinvestment. Industry spends an amount similar to what government spends, on both energy R&D and on all research. Can we as a nation afford to spend so little on something so important to our livelihood and productivity now and in the future? If we need additional impetus, it comes from world markets for energy technologies, currently $1.5 trillion a year and growing rapidly.

For these reasons, energy R&D must continue to be an important facet of the Laboratory’s mission of fulfilling the strategic objectives of the nation.
Powering Future Vehicles with the Refuelable Zinc/Air Battery

A recent road test at LLNL underscored the zinc/air battery’s capacity to give electric vehicles some of the attractive features of gas-driven cars: a 400-km range between refueling, 10-minute refueling, and highway-safe acceleration.

The battery’s inventor, LLNL electrochemical engineer John Cooper, was one of a handful of bus riders that day, monitoring the battery’s performance and occasionally driving the remarkably powerful vehicle. The road test underscored the potential of the battery to give electric vehicles some of the attractive features of gas-driven cars: a 400-km range (250 miles) between refueling, rapid refueling (10 minutes), and highway-safe acceleration. The positive test results also cleared the way for discussions with a host of interested commercial partners about further development. For all of its advancements, the chemistry of the zinc/air battery is relatively simple (Figure 2). The device combines atmospheric oxygen and pellets of zinc metal in a liquid alkaline electrolyte to generate electricity with byproducts of zinc oxide and potassium zincate. In operation, the battery consumes all of the zinc. Refueling is easily accomplished by replacing spent electrolyte with fresh electrolyte containing recycled zinc pellets. Such a refuelable battery has clear advantages over rechargeable and reconstructible batteries. For example, it can be “topped off” and even refueled on the roadway in an emergency. Except for the alkaline electrolyte (which contains the same hydroxide found in popular liquid drain cleaners), all of the materials making up the battery are relatively safe and do not pose the environmental dangers found in other battery types containing lead, concentrated acids, flammable metals, and other toxic or hazardous materials.

Because new zinc fuel can be generated from spent zinc oxide in the electrolyte by using relatively small and simple equipment designed by Laboratory researchers, the battery needs only a modest investment to support it. Refueling would be done at a company’s home base using existing maintenance personnel. Quick, easy
refueling is a particular advantage for companies needing rapid refueling or extended use throughout the day for their fleets of shuttle buses, taxis, delivery vans, passenger vans, forklifts, or aircraft support vehicles.

**Fast Development**

The successful bus test capped a remarkably short development period for the battery. It started in 1991, when Cooper noticed a Lab energy program poster display of a proposed oil shale retort. One display pictured crushed shale rock falling by gravity through a narrow channel before it was heated for oil extraction.

“The rock formed an open matrix by bridging small gaps, which slowed the feed rate,” Cooper recalls. “I reasoned that the same principle could be used to advantage in designing a particle electrode in a small gap, where we want an open matrix, allowing electrolyte to flow through freely.”

Some months later, he had successfully tested a self-feeding design for a zinc/air battery, with a hopper from which zinc particles fell through a restricted opening into a reaction cell (Figure 3). This novel design, the basis for Cooper’s 1993 patent on the battery (see box p. 10), solved a persistent problem with previous zinc/air battery designs, in which the zinc particles and reaction products would eventually clog the cell, preventing complete oxidation and reducing power generation.

Cooper is no stranger to battery design. In the early 1980s, he was the Department of Energy’s national program leader for an aluminum/air battery project with five corporate partners. That program advanced to the stage where it was transferred to industry, but the battery did not see commercial development in autos because of ample and relatively cheap worldwide petroleum supplies and the battery’s chief drawback—aluminum corrosion. The technology instead evolved into batteries for emergency power reserve units, submarine propulsion, and forklift trucks.

With Livermore’s Laboratory Directed Research and Development funding in hand, Cooper worked for two years beginning in mid-1992 with a small team of mechanical and chemical engineers and technicians as a part of the Laboratory’s Energy, Manufacturing, and Transportation Technologies (EMATT) program. The project’s goals were to develop an engineering zinc/air prototype battery based on Cooper’s design, optimize its energy storage and power characteristics, and show that the self-feeding cells could operate under realistic road vibrations and accelerations.

Finally, to be successful in the marketplace, the zinc/air battery had to be able to be refueled quickly, easily, and safely without the need for a new infrastructure of expensive, complex equipment. Energy researchers have long recognized that if a way could be found to refuel a battery simply and rapidly, it could provide an electric vehicle acceptable to consumers. Quick and easy refueling is important in fleet electric vehicles such as shuttle buses and delivery vans, which often must operate more than 8 hours daily.

The alternatives to refueling pose significant disadvantages. For example, exchanging batteries doubles the investment in batteries and specialized equipment; adding a gasoline or diesel engine produces air emissions; and electrical recharging takes hours to complete. (The traditional lead/acid batteries used in Santa Barbara’s 12 electrically powered city buses require 4 to 8 hours of recharging after 4 or more hours of use.)

During the development phase, the battery was tested in various configurations of cells and air electrodes. Cells were tested with air electrodes of 80, 250, 600, and 1000 cm², with the 250-cm² size judged the most...
The LLNL zinc/air battery is constructed in modular form of unit cells (see the drawing below), each of which is made up of a hopper, a self-feeding galvanic cell, and refueling ports. The cells are joined together in a battery module that is compatible with the LLNL zinc/air battery's potential savings in vehicle weight, battery weight and volume, and cost to operate over a lead/acid battery. Nevertheless, the lighter weight of the zinc/air battery cut a total of 1.7 metric tons from a 5.7-ton bus, so the total energy use is 17% less than that of a lead/acid-powered bus because of the lower vehicle mass. Additionally, the marked reduction in vehicle weight means reduced tire and brake wear, which are major cost factors in large vehicles.

The Savings Are Long-Term

When commercialized, zinc/air batteries will probably be the least expensive advanced battery on the market. Cooper estimates a unit sized appropriate for bus-size vehicles. Cells were operated for as long as 16 hours, with intermittent refueling. Stacks of 12 cell modules were refueled in only 4 minutes. Batteries were discharged in units of 1, 3, and 6 cells. To simulate road conditions, the research team used a vibration table for some tests.

Road Testing the Prototype

With laboratory tests complete by the end of 1994, the team prepared for a vehicle test sponsored by the U.S. Department of Transportation’s Federal Transit Administration. Early this year the Santa Barbara Metropolitan Transit District provided the Laboratory with a 6.6-m (22-ft), 5.7-metric-ton electric shuttle bus. For the bus test, one six-cell, 7-V engineering prototype zinc/air battery was cabled in electrical parallel with a three-cell, 6-V lead/acid battery. This hybrid unit then was placed in series with the standard 216-V lead/acid battery power plant of the bus, using diodes to prevent reverse polarization of the zinc battery (Figure 4). The bus was driven on a 1.2-km loop around the Lab for about 5 hours for a total of 120 km (75 miles), at which point the lead/acid batteries were 80% discharged. The road test validated the design of the self-feeding zinc/air cells under typical driving vibrations from starts, stops, turns, and accelerations. The self-feeding cells functioned correctly without becoming clogged with zinc particles or starved for fuel, and they operated well in the hybrid configuration. In addition, the test validated the integrity of the electrolytic air seal, the weak link in all metal/air batteries. Fatigue of this crucial seal caused by variations in full particle flow and stresses from the road surface could limit a battery’s lifespan: long-term tests will be necessary before commercialization of the battery. The test run also indicated the zinc/air battery’s potential savings in vehicle weight, battery weight and volume, and cost to operate over a lead/acid battery.

Zinc/Air Battery

Figure 4. Developer John Cooper, left, and electronic technician Douglas Haigrove, inside the Santa Barbara bus during its test run at the Laboratory.
Zinc/air battery

Lead/acid battery

Electricity cost

Battery weight

Savings, comparing lead/acid and zinc/air batteries in vehicles of fixed range and power.

Commercial interest in zinc/air batteries for powering electric vehicles has grown significantly during the 1990s. An Israeli company in 1994 demonstrated a zinc/air-battery-powered van that had a range of more than 420 km with highway acceleration and sustained speeds. However, unlike the LLNL design, that battery is not refuelable; the battery’s spent electrodes must be delivered to a plant for reconstruction.

Commercial Development

The LLNL refuelable zinc/air battery is now ready for advanced development as part of a commercialization effort with one or more industrial partners. Cooper has received scores of requests for more information from battery manufacturers and potential users. Many inquiries have been in response to news articles about the battery that appeared earlier this year in the London Times newspaper and Design News magazine. “There is an enormous world market, with literally millions of units that could take advantage of the zinc/air battery,” says Cooper. “More than 90% of new battery concepts fail, so no one talks to you until you’ve demonstrated a prototype unit that works on the bench and in a vehicle.”

Cooper cautions that before commercial units find their way into vehicles, more work needs to be done, particularly in determining the longevity of the air electrode under actual or simulated road use and how many times the zinc reaction products can be recycled. Cooper believes these challenges are not insurmountable and that full-scale production can begin as early as 2000. One strong selling point is that, because of its modular design, the battery can easily be tailored to accommodate varying needs, from small forklifts to large urban buses to silent military vehicles.

Down the road, passenger cars might also be powered by zinc/air batteries. As the cars proliferate, they could be refueled at service stations. Cooper says some oil companies are interested in the idea because it is a potential new market for their stations. In the long run, commercial zinc recovery plants could take advantage of large-scale production using electrolysis cells combining electrical and hydrogen energy to reduce zinc oxide to zinc. This process would operate with a substantially smaller amount of the purely electrical route to recovery and would give the zinc/air battery an almost unbeatable total energy efficiency. The zinc/air battery’s total energy use would be comparable to a fuel cell at one-tenth the cost.

Another factor favoring electric vehicles is energy flexibility. The U.S. transportation sector depends almost exclusively on crude oil, most of it imported. To better accommodate varying needs, from small forklifts to large urban buses to silent military vehicles. The switch from gasoline power plants to zinc/air batteries for passenger cars would make the most economic and environmental sense in urban areas, where gasoline-powered cars burn excessive fuel and generate significant pollution in start-and-stop driving. Such a fundamental shift to electric propulsion is no longer just an environmentalist’s dream. In 1998, the state of California enacted regulations requiring 2% of all cars sold in the state to run without any polluting emissions by the year 1998. The exact benefit to the environment, however, depends on the emissions generated by local power plants that produce the electricity to build, recharge, or refuel the batteries.

Cooper says that the new technology is likely to have its greatest impact on fleets of electric vehicles. “Buses, vans, and industrial vehicles have a unique combination of high daily usage, low power requirements, and in-place service infrastructure. This combination makes their owners and operators an ideal market for refuelable zinc/air batteries.”

Key Words: alternative fuel, electric vehicle; refuelable, zinc/air battery

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(cooper3@llnl.gov)


dering equipment depends on how much fuel is needed each day. For buses running 12 hours a day, the recycling unit would cost about 25% of the battery it serves. The recycling unit has no expensive components and uses metal sheets instead of the more expensive air electrode.

Although the zinc/air battery has sufficient power by itself to power large electric vehicles, combining it with another power source (lead/acid battery, supercapacitor, or flywheel) is recommended. The hybrid power plant allows better acceleration and greater flexibility in selecting routes with varying grades. Finally, with few peaks in the current, the life of the electrodes in the battery is expected to be as great as 12,000 hours. Regenerative braking, in which the considerable braking energy turns magnets to recharge a flywheel or capacitor, will decrease total energy use by another 10%.

Cooper’s interest in zinc/air batteries has been shared by many energy researchers. Zinc/air batteries have been developed for both mobile and stationary power applications because of their low cost and high energy density. The batteries have found other uses in hearing aids, military field electronics, and laptop computers. In these applications, however, zinc/air batteries are very expensive for the low power they provide, and they cannot be refueled.

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Key Words: alternative fuel, electric vehicle; refuelable, zinc/air battery

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Advances in position-sensitive detector technology, coupled with advances from gamma-ray astronomy, have allowed researchers to design and build a gamma-ray camera (GRIS) that can locate and identify materials.

Looking at Gamma Rays

The gamma-ray imaging spectrometer (GRIS) we have assembled comprises four coaligned, independent imagers, each with its own detector and coded-aperture mask. Each detector "sees" incoming gamma rays only through its mask, which serves as the imaging optic for the gamma rays. This mask is mounted on a movable mask plate in front of the detector plane; moving the plate provides different levels of zoom for the gamma-ray images.

Applications and Results

Although the spectrometer was developed to control the special nuclear material (SNM) associated with nuclear weapons, there are a myriad of applications in other areas, including environmental cleanup, medicine, the nuclear power industry, and any other enterprise where radioactive sources are used.

Arms Inspection

GRIS was initially designed for use in arms inspections called for by the Strategic Arms Reduction Treaty (START)—specifically, to count the number of warheads on board a missile without requiring either close access to the missile or its disassembly. Inspections would be conducted remotely, based on the premise that the gamma-ray signature from the on-board warheads, although weak, is strong enough to be detected through the top of the missile. GRIS was constructed with four detectors to decrease the time it takes to obtain a good image approximately 10 m from the source.

Confidence through Transparency

As the U.S. and Russia strive to reduce their respective nuclear stockpiles, each must have the ability to identify and verify the location of the other’s weapons components throughout the demolition process. Each...
rods inside a storage drum. To simulate shielding, we placed a depleted uranium plate about 3 mm thick outside the drum. The uranium serves as shielding, as a source of confusing radiation, and as a different radioactive isotope.

Figure 5 indicates both the energy resolution of the system and how images using data from different spectral regions can show the locations of different materials. The image obtained using only the data in the region of the spectrum shaded blue is on the left. This image represents emission from uranium and shows only the large uranium plate. On the right is the image obtained using data in the region of the spectrum shaded pink. These data are characteristic of plutonium and reveal the rectangular figure behind the uranium inside the container.

Safeguarding Weapons

When nuclear arms and their components are secured and stored, the primary concern is to verify that no material is removed from a storage area. In addition to armed guards, an inventory control system that constantly must have confidence that the SNM in the other’s storage vessels is associated with nuclear weapons components but must be able to develop that confidence without performing an inspection that is sufficiently detailed to raise classification issues. This ability, or confidence, is called transparency.

In a recent joint U.S.–Russian demonstration at LLNL, we obtained data with a conventional, nonimaging gamma-ray detector and with GRIS. The data were collected from a radioactive source hidden inside a typical weapons component storage container. Both detectors possessed similar energy resolutions and could identify the type of material present. However, in a single measurement, the non-imaging detector could not verify the quantity of SNM present or the likelihood that the material was a weapons component. Such information could only be obtained from the nonimaging detector by scanning it across the storage vessel in small steps. Although this generated a crude image of the object that allowed identification, it also required most of a morning to complete. By comparison, the inspection with GRIS took half an hour—a time which could be easily reduced to a few minutes. The GRIS images taken from two directions 90 degrees apart (Figure 4) clearly show that a disk of plutonium and not a weapons component is in the storage container.

Related applications that take advantage of GRIS’s ability to “see” behind shielding occur in nuclear waste disposal and in the characterization of nuclear weapons. Figure 5 illustrates such an application. Here, we placed a rectangular shape made from plutonium rods inside a storage drum. To simulate shielding, we placed a depleted uranium plate about 3 mm thick outside the drum. The uranium serves as shielding, as a source of confusing radiation, and as a different radioactive isotope.

Figure 5 demonstrates gamma-ray imaging and energy discrimination in applications for arms control transparency, contaminated waste identification, and weapons forensics. That the plutonium source is distributed inside a storage drum can be clearly seen, even through 3 mm of depleted uranium. The image on the left is generated from 100-keV gamma radiation of the depleted uranium; the image on the right is generated from the plutonium energy band at about 400 keV. With the appropriate energy selection, the plutonium can be seen through the uranium.
Astronomers have worked on the problem of imaging gamma rays for about 30 years. Although cosmic sources of gamma rays are extremely bright, they are also exceedingly far away, so the problem is how to image dim sources in a relatively large background. In principle, a pinhole camera could be used, but only a small fraction of the available radiation would reach the film or detector. In the late 1960s, it was recognized that one could improve the pinhole camera by punching more holes in the blocking sheet. Each hole projects its own image on the detector, and the different images overlap. If the hole pattern is known, one can mathematically recreate a faithful reproduction of the scene.

Although initial attempts showed that the technique worked, they also showed that the pattern had to be selected carefully, or false sources would appear in the image. The research on pattern effects was largely completed in the 1970s when a class of patterns called uniformly redundant arrays was created. These patterns possess a unique property: the information present in the shadow pattern from any one source in the image is not affected by the presence of gamma-ray sources in other parts of the image.

In the schematic of the imager (see the illustration below), we assume that radiation is coming from a very distant source. The light rays from this source are parallel, so a shadow of the mask is projected on the detector much the way it would be projected by the sun. Each pixel (the smallest picture element) in the image is represented by parallel gamma rays incident from one direction that project a detector-sized portion of the mask pattern onto the detector. The pattern is selected such that each projection is unique and independent of all other projections.

The image is recreated by a cross-correlation technique: the complete detector pattern is summed against each unique mask position by adding counts to the sum if the mask is open at this position and subtracting them if it is closed. Physically, counts are added if they could have come from that direction and subtracted if they could not. If no source is present, any detector-sized portion of the mask pattern has the same fraction of open and closed area relative to all other portions of the mask that of the same size, so the sum is zero (except for statistical fluctuations).

If a source exists at the particular location being summed, then every time there is an opening there will be counts, and the sum will recreate the true flux (amount of signal per unit time) from the source.

The advantage of this technique is that half the detector area is exposed to each of the sources in the field of view. The rest is behind closed mask elements. Compare this with a pinhole camera, in which the open area is only one pixel’s worth. For a point source, the signal-to-noise ratio increases as the square root of N, where N is the number of open holes. For our system, N is approximately 200, meaning a 14-times-greater signal strength and significantly reduced data-acquisition time.

Unfortunately, because all the counts in the detector are used at each image location, the more sources there are in the field of view, the less one gains from this technique. It reverts to one with the same sensitivity as a pinhole camera if the whole field of view glows at the same intensity.

The resolution of a coded-aperture camera is just what it would be for a pinhole camera. For each pixel, the angular offset in incoming radiation is the basic hole size divided by the focal length (detector-to-mask spacing). To obtain the resolution at the source, one must multiply this angle by the distance to the source.

**Position-Sensitive Detector**

Converting the signal to a visual image requires a position-sensitive detector. Moreover, the position resolution must be comparable to the mask hole size; otherwise the pattern washes out. Because typical position-sensitive detectors (known as Anger cameras) for gamma rays of energies from 20 kiloelectron volts to greater than 1 melectron volt have position resolutions of the order of 1 cm, an imager must be quite large to have a reasonable number of pixels across the detector. An imager made with such a detector must also have a long focal length to achieve even modest position resolutions at the source.

Our development of a gamma-ray detector with a position resolution of about 1 mm allowed the full exploitation of the coded-aperture technique in a compact system. In the schematic of the detector at the left, a position-sensitive photomultiplier tube is combined with a thin cesium–iodide crystal. When a gamma ray hits the crystal, it causes a brief flash of light, which is converted to an electronic signal by the photomultiplier tube. The tube is unique in that it allows the position of the light flash to be determined from its four output signals. The amount of light is proportional to the energy of the gamma ray and is also measured by the photomultiplier tube. The 6- x 5-cm active area of the detector yields about 40 pixels across its face, allowing for a mask pattern about 20 x 20 pixels (ideally, one oversamples by a factor of two.)
Gas at elevated temperatures. Separation takes advantage of the fact that the gas, composed of the lighter uranium-235 isotope, diffuses at a slightly higher rate than the gas containing heavier uranium-238. The UF$_6$ is enriched in heated equipment and piping contained within insulated housings.

Occasionally, because of leakage of wet air or environmental changes in the housing, solid UF$_6$ deposits develop. Such deposits routinely occur in an operational plant and must be located and identified. This task is not trivial. Many facilities— including those going through decontamination and decommissioning— contain highly enriched uranium, which could cause a criticality accident if a deposit of uranium-235 becomes too large.

Current characterization of the uranium deposits in these plants is performed primarily using sodium-iodide-based radiation detectors. These are carried through the plant, and readings are taken at fixed intervals to map the radiation fields. If a “hot” region is found, workers must enter the plant to locate and identify the deposit. Such a task is time-consuming, expensive, and potentially hazardous. GRIS avoids these problems by generating images from outside the shielding that definitively locate the hot material.

Our first use of GRIS in this environment was at the idled K-25 plant. GRIS was mounted on a cart to look up some 4 m at the pipe galleries overhead. Each gallery, enclosed in heat shielding, contains pipes ranging in size from a few centimeters to more than a meter in diameter. The building had been entirely scanned by K-25 personnel walking under and on top of the galleries using an uncollimated radiation detector; the results from this survey were used to select sites of interest for application of the GRIS imager. The first image was a gamma-ray and video image of a deposit near the 12-m-wide pipe gallery. We selected this pipe because the lack of heat shielding allowed us to verify that the gamma-ray and video images identified the hot pipe.

A second exposure was taken of a more representative location where an isolated deposit of material was known to exist. After an initial wide-field image was taken to see the complete deposit, we moved the imager under the hot spot and zoomed in on this region. Figure 7 shows a deposit in a 1.2-m-diameter pipe, where an expansion joint exists. The deposit is probably uranium oxide, formed when a leak developed in the expansion joint. The images from the next location, although they are nearly featureless, clearly demonstrate the power of the technique. We took GRIS to a location where we expected to find a series of radioactive pipes running the length of the area covered in the image. Two exposures were needed to cover the full width of the 12-m-wide pipe gallery. The resulting images (Figure 8) revealed only a few hot spots, not the contamination expected from the standard analysis.

Although we have not fielded such an application, the implementation is straightforward. The gamma-ray imager is installed so that it can “see” all sources, and a baseline image is taken. Then, the imager is set on a timer to take that image over and over again. A mathematical comparison of each successive image to the original can be used to sound an alarm should something be moved; we developed suitable algorithms to do this in the course of analyzing the Peacekeeper data. The advantages of using an imager in this case are that it can be set up very quickly, personnel need not leave the room, and visible light is not required.

Figure 6. Video (right) and composite gamma-ray/video overlay (left) of a contaminated pipe at the K-25 gaseous diffusion plant at Oak Ridge. The gamma-ray image clearly shows which of the pipes overhead is contaminated.

Figure 7. Overlay of gamma-ray intensity as a function of position for wide-field (left) and zoom views (right). The gamma-ray image on the right, which is overlaid on a video image, was taken after the imager was moved under the hot spot initially identified from the image on the left. The radiation is emitted by a uranium deposit inside a 1.2-m-diameter steel pipe hidden behind heat shielding.
areas of particularly intense radiation. In a similar application, GRIS could be used to find "lost" radioactive sources. Intense radioactive sources are sometimes used for materials characterization in construction and maintenance. If these sources are lost from their holders, they present a significant radiation hazard.

Finally, nuclear medicine could potentially benefit from application of a gamma-ray imager with capabilities similar to those of GRIS. The gamma emissions of several well-known radionuclides used in medicine fall within the range of energies GRIS exploits.

Spectrometry and the Stars

In addition to the programmatic imaging work described so far, we have collaborated with the University of California at Berkeley and at Santa Barbara to combine our unique detectors with a novel implementation of coded-aperture imaging to build the world’s highest angular-resolution, gamma-ray telescope (Figure 11). Constructed with Laboratory Directed Research and Development funding, GRATIS (gamma-ray arc-minute telescope imaging spectrometer) comprises 36 individual imagers specifically tailored to work in the astronomical energy band from 20 to 200 keV. Our high-position-resolution detectors combined with a 4-m focal length allow GRATIS to achieve an unprecedented angular resolution of 2 arc-minutes (arc-min). By providing each of the 36 detectors with its own one-dimensional coded-aperture mask (Figure 12), we provide better overall performance at lower manufacturing cost than a more conventional telescope of similar size. Every one of these

Other Applications

Other GRIS applications are being considered. For example, a private company working for the nuclear power industry is studying the feasibility of using the gamma-ray/video overlay imagery to direct workers away from areas of particularly intense radiation. In a similar application, GRIS could be used to find "lost" radioactive sources. Intense radioactive sources are sometimes used for materials characterization in construction and maintenance. If these sources are lost from their holders, they present a significant radiation hazard.

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Figure 8. A powerful example of the advantages of gamma-ray imaging, this image shows little contamination within the heat shield. Instead, the image shows that the contamination is in a nearby area.

Figure 9. These images were obtained at the Portsmouth diffusion plant. The overlaid engineering drawing shows that only small pipes used for process monitoring are contaminated, and thus the deposit does not pose a criticality hazard.

Figure 10. Overhead view of process equipment at the Portsmouth, Ohio, facility overlaid on engineering drawings of the area. The gamma-ray image clearly localizes the deposit to one length of pipe. The cylindrical diffusers are spaced about 2 m apart.
telescopes produces a one-dimensional picture of the sky; the images are combined mathematically to give a full two-dimensional image.

GRATIS provided a special challenge because viewing radiation from the cosmos requires that the telescope be above all but the most tenuous portions of the atmosphere. Thus, GRATIS is hung from a helium balloon, and the pointing system is operated by remote control. To keep a source in the center of the field of view requires that the pointing system be stable to 1 arc-min. To reconstruct the images properly requires that we know where the telescope is pointing to an even higher accuracy, which is obtained by using a coaligned star camera and a gyroscope system that allow us to reconstruct the pointing after the flight to approximately 20 arc-seconds.

GRATIS was first flown successfully in spring 1994 from Palestine, Texas. During its 11-hour flight, we observed three scientific targets: Cygnus X-1, Cygnus X-3, and Her X-1; we are in the process of analyzing the data. Meanwhile, GRATIS is on the ground in Alice Springs, Australia, ready for its next flight this fall, when we will observe the center of our galaxy.

Continuing Development

Our ongoing efforts in gamma-ray imaging include improvements in the detectors and in image-generation techniques. We are building a new detector that takes advantage of the rotated one-dimensional imaging used in GRATIS to extend the useful energy range of this work and to significantly lower the cost per unit area of detector. Called the Gamma-Ray Bar Imaging Telescope (Figure 13), GRABIT achieves these advances by separating the energy- and position-resolving functions of the detector.

A series of scintillator bars is mounted on a nonimaging photomultiplier tube. Most of the scintillation light from a gamma-ray event is collected by this tube, the signal from which is used to determine the energy of the gamma ray. To determine where the gamma ray hits, we pick off a small fraction of the light with a fiber-optic bundle and transmit it to an imaging device such as the photomultiplier tube used in GRIS. By observing which fiber end glows and knowing its arrangement on the imager, we can determine which bar is hit by the gamma ray.

To understand how this feature improves the system performance, note that the GRIS detectors determine an event’s position by finding the center of the light footprint at the input to the photomultiplier tube. However, as one makes the crystal thicker, the average event size will increase because the light spreads out more before it reaches the tube, thus decreasing the ability to find the flash location. By dividing the crystal into bars, we remove this problem: the position resolution is limited only by the width of the bar. The costs are lower because the unit area of nonimaging tubes is only about one-tenth that of imaging tubes. By reading out a bar with a fiber optic, we effectively increase the expensive imager area some 40 times. We are currently assembling a laboratory prototype of this detector system.

Our previous imaging work clearly demonstrates the advantage of generating images using different parts of the energy spectrum. Unfortunately, the energy resolution of the cesium iodide currently used is only about 10%, not enough to distinguish commercial (reactor-grade) plutonium from weapons-grade plutonium. Higher energy resolution makes this distinction possible because it separates the different gamma-ray energy lines of the various plutonium isotopes.

Another advantage of improved energy resolution is the ability to obtain information from a strong source that lies behind a significant thickness of other material. In such a case, the overlying material acts much like the diffuser in front of a light, scattering the radiation and blurring the image. However, unlike visible light, the scattered radiation at these higher energies is also shifted to a lower energy. By restricting the image to photons, which are in a known spectral line from the source, one can remove this type of blurring. With these advantages in mind, we plan to develop position-sensitive, solid-state detectors such as germanium- or zinc-doped cadmium telluride, both of which provide much better energy resolution.

Because it was developed for gamma-ray astronomy, the coded-aperture imaging technique as it has been applied by others assumes that the source is very far away. In the close imaging work we have described, this assumption does not hold. We have applied several techniques to compensate for this difference and are continuing to make improvements to the imaging techniques.

We are investigating the application of more advanced imaging algorithms to the coded-aperture data. These techniques rely on iterative approaches, based on Bayesian logic, that seek the...
Expenditures for health care reached about 14% of the U.S. gross domestic product, or a staggering $1 trillion. Many experts agree that the annual bill for healthcare will grow even larger in the next few years. To reverse this trend, technology-driven cost reductions are needed.

In some industrial fields, such as electronics, technological innovation is part of an effective strategy to reduce costs without decreasing quality. For example, Lawrence Livermore National Laboratory (LLNL) is marshaling its world-class technology base to help the nation to contain escalating costs for health care.

Over the last decade, a broad spectrum of Livermore research projects has explored new or improved health care technologies that can potentially reduce health care costs. For example, LLNL is working on projects related to repetitive strain injury as well as in specialties such as ophthalmology, dentistry, and prosthesis design and manufacture.

To coordinate these activities, we established the Center for Healthcare Technologies at LLNL. Its goals are to:

- Continue to pursue the high-quality science and technology efforts that are already directed toward improved health care.
- Become better known in the health care community.
- Propose LLNL initiatives in health care that are more integrated than others.
- Promote a national focus for federal activities in health care technology.

The Center has an external advisory committee of senior health-care professionals and an internal coordinating and advisory committee. Perhaps most importantly, the Center represents a single point of contact through which interested organizations outside the Laboratory can gain access to the LLNL individuals or groups that are most appropriate for addressing specific health-care needs.

Our current strategy entails three phases of activities, which we have launched in parallel.

In Phase I, we are delivering results on current projects and gaining recognition for our accomplishments in health-care technologies. More than two dozen projects at the Laboratory are ongoing, and one of our most recent and exciting initiatives—the prevention of hemorrhaging in stroke-damaged blood vessels.

During our first year, we contacted more than 80 medical, industrial, and governmental organizations. We are identifying and coordinating projects that extend LLNL core competencies into new markets and help to meet future DOE Defense Program requirements and providing cost-effective medical technology at the same time.

In Phase II, we are initiating and participating in larger health-care projects through multidisciplinary teams of collaborators. For example:

- Digital Mammography Systems is a proposed new medical technology project aimed at reducing costs and improving the accuracy of mammography.
- Testbed'95 is an example of an initiative that helps to meet future DOE Defense Program requirements and provides cost-effective medical technology.

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The very best surgeons possess exceptional skill and dexterity, but most have not had access to what sounds like the best of high technology tools—a medical laser. Medical lasers have been used successfully in some procedures such as repairing detached retinas, breaking up kidney stones, and removing port wine stain birth marks. However, their remarkable ability to simultaneously cut and cauterize has not caused them to eclipse steel or electrosurgical tools because they have lacked predictable precision with body tissue and have been too large and expensive to be a practical part of medical offices and operating rooms.

Recent advances by Livermore researchers are changing the capabilities of surgical lasers so that they may fulfill their promise to become the “blade of choice,” especially in dentistry and are particularly well-suited to precision microsurgery on corneas, delicate ear bones, and the brain.

Limitations of Earlier Lasers for Surgery

Since their advent about 30 years ago, lasers have been observed to induce damage in transparent solids, such as defect-free dielectrics (electrical insulating materials used during laser beam amplification and as mirrors to direct beams). For pulses longer than a few picoseconds, the generally accepted theory of bulk damage to these materials is that the incident radiation heats electrons (those in an atom’s conduction band, to be exact), and these electrons transfer thermal energy to other electrons and atoms in the lattice. In other words, the dielectric material is damaged by the melting, boiling, and thermal shock that result.

Similarly, a fundamental limitation of past surgical laser systems was the heat caused by the beams—either a continuous beam or one made up of multiple, 1000-ps pulses, or “bursts.” As a result, laser surgery was soon found to be unexpectedly complicated. Lasers affect irradiated tissue through absorption of the light energy, and the absorption is determined largely by the properties of the material being irradiated, such as its color. Consequently, a surgeon might be cutting tissue quite effectively with the laser at the proper specific energy when the beam suddenly hits a different kind of tissue. If the tissue has different absorption properties, the cutting rate and heat generation can suddenly increase or decrease dramatically—by orders of magnitude. Surgeons have had to worry about how much energy the beam deposited and the degree to which the irradiated tissue absorbed or reflected the light. They might irradiate tissue with no apparent effect, only to discover that the light was being reflected or transmitted and absorbed by other tissues and causing undesired burning at these sites.

Indeed, this collateral damage has been a real concern with conventional laser-surgery pulsed systems. For example, laser cutting can significantly heat material some distance from the target—such as in the case of desiccation of the material or, if there is water below the surface, explosive vaporization resulting in torn tissue.

There has been a clear need for a tool better than the scalpel, but one that does not require continuous adjustment or present the possibility of catastrophic mishap. Ultrashort pulses provide the answer.

Ultrashort Pulses Provide the Answer

Recently, however, laser technology has cleared some hurdles. By applying chirped-pulse amplification to solid-state lasers, Livermore researchers have built systems producing picosecond pulses. In a concept paper, we proposed development of minimally invasive medical technology, an area in which the medical industry has great interest and which is now being considered as a government focus area.

Our Phase III activities seek to establish a national strategy for health care technology programs. The focus is on reducing costs without reducing access or quality of service. We have proposed a government organization operating under the National Institutes of Health (NIH). We envision this new agency as a forward-looking, expert organization that pursues the best technical solutions from the best sources combined with the medical expertise of the NIH. We have presented our concepts to the largest health care, medical research, and industrial organizations in the U.S., to Congressional staff members, and to members of the Clinton Administration. Science and Technology Review will report on developments and feature important technological advances as they occur.

For further information contact: Patrick Fitch or any member of the Center for Healthcare Technologies (510) 424-4856 (healthcare@llnl.gov).
terawatt ($10^{12}$ W) pulses with ultrashort durations—well under a picosecond. (Chirped-pulse amplification is described in some detail in the article on multilayer dielectric gratings in the September 1995 issue of Science and Technology Review.) According to theory, subpicosecond durations are far too short for appreciable electron energy to be transferred to surrounding material. As a result, less energy is absorbed by the tissue, so material should be able to be removed by subpicosecond pulses with essentially no collateral damage. Theory also predicts that the energy absorption mechanism for ultrashort pulses makes material removal by laser much less sensitive to tissue type than is the case with longer pulses.

To confirm the theoretical promise of ultrashort pulses, we performed a series of experiments on various materials. These extensive experiments, with materials such as fused silica and calcium fluoride, yielded results that agreed well with theory. We then produced “phantom tissues”—materials whose properties mimic the densities and effective atomic numbers of living tissue. We mixed gelatin and water to make collagen gels (collagen is a fibrous protein found in all multicellular animals), and we mixed aqueous solutions of cupric chloride in different concentrations to produce a range of light-absorption properties. We then performed ablation measurements—measurements of how much material was removed by being “blown off,” or ablated. We used a chirped-pulse amplification laser to obtain pulses of continuously adjustable duration from 0.3 ps to 1000 ps, with a laser spot size of 0.5 mm in diameter (about the size of a period). After irradiating the sample, we inspected it for formation of an ablation crater. The smallest craters we could observe were approximately 1 micrometer in diameter, 500 times smaller than the area the laser had ablated. We determined the ablation threshold for a given pulse width. Then, to determine the ablation efficiency, we measured ablated crater depth and diameter after 10 to 100 laser pulses, recording the energy of each pulse. Now we could predict how the laser was “cutting.”

The figures below show typical craters produced by 1000-ps pulses and by pulses of less than 1 ps in a clear collagen gel (a and b) and in tooth enamel (c and d). Much more thermal damage appears with the longer pulses (a and c). For ultrashort pulses, collateral damage is practically absent, and a clean, smooth crater is produced (b and d).

Ablation thresholds for collagen gels follow the trends that we predicted. The ablation threshold for clear gels, which are similar to corneas, in the 1000-ps pulse width range (75 joules/cm$^2$) is about 1000 times higher than the ablation threshold for black gel (0.074 joules/cm$^2$). In the subpicosecond pulse width range, this difference decreases to only a factor of six. Thus, the ablation thresholds for transparent and nontransparent tissues converge at shorter pulse widths.

Short pulses cause highly localized, shallow energy deposits, and each one removes only a thin layer of material (less than 1 micrometer). Varying the number of pulses controls how much material is removed. High repetition rates (greater than 100 Hz) achieve high energy removal rates (greater than 1 mm during 10 seconds). This method of tissue ablation has several advantages:

- It is efficient. With decreasing pulse width, the energy density needed to ablate material decreases.
- Minimal collateral damage occurs because ablation is efficient with the short pulse and because the ablated tissue carries away a large fraction of the deposited energy from the laser.
- The ablation threshold and ablation rate vary only slightly as tissue type and state change.
- Ablation depth can be controlled with extreme precision because a small amount of tissue is ablated per pulse and because the number of pulses can be controlled.

With ultrashort laser pulses, the absorption threshold and ablation rate (depth of material removed per pulse) are relatively insensitive to factors such as laser wavelength and tissue state (e.g., structure, hydration, and oxygenation). Because an ultrashort laser pulse (0.005 ps to more than 20 ps) is medically useful by virtue of its duration rather than its wavelength, a variety of lasers operating over a wide range of wavelengths can be used, such as lasers based on dyes, excimers, or solid-state materials. However, solid-state infrared lasers such as those used at the Laboratory offer the advantages of safety and convenience. Our experimental results are still preliminary; further research is needed to understand what happens to the energy after it is deposited by the laser. How the energy couples to the atoms of the tissue, how the tissue is ablated, how the stress wave is generated, how the stress wave propagates into the tissue, and how the collateral damage occurs all warrant further investigation.

**Practical for Surgery**

Ultrashort-pulse lasers have an important niche in surgery. The precision ablation of these lasers allows microsurgeons to perform intricate operations, such as drilling holes through small middle ear bones, for which they use microdrills. Likewise in brain surgery, which also puts a premium on accuracy and control and on minimizing thermal collateral damage, a system with a high pulse-repetition rate could allow a surgeon enough speed and control to virtually “sculpt” the tissue.

An added benefit of lasers to surgery is the fact that the pulses can be transmitted by fiber optics. Laser energy can be delivered to many remote locations within the body through fiber-carrying catheters. In the future, instead of making large incisions to gain access to certain organs or cavities, surgeons will use more endoscopic and laparoscopic techniques. Fiber-delivered lasers are already being used to break up kidney stones, for example, and are performing better than ultrasound for this purpose.

Ultrashort-pulse laser systems also have great potential in dentistry to replace the dentist’s drill for cavity and root-canal work. The drill produces pain chiefly by heat—the drill produces pain chiefly by heat. The ultrashort-pulse lasers produce minimal heat and vibration and virtually no collateral damage to surrounding enamel.

The Laboratory is not alone in developing ultrashort-pulse laser systems. However, the critical step, once their medical utility has been conclusively proven, will be to make them practical—and affordable—for surgeons and dentists.
Powering Future Vehicles with the Refuelable Zinc/Air Battery

Developed at Lawrence Livermore National Laboratory, the zinc/air battery weighs only one-sixth as much as standard lead/acid batteries and occupies one-third the space, yet costs less per mile to operate. Further, because the battery is easily refuelable, it promises trouble-free, nearly 24-hour-a-day operation for numerous kinds of electric vehicles, from forklifts to delivery vans and possibly, one day, personal automobiles. The test of a Santa Barbara Municipal Transit bus with a hybrid of zinc/air and lead/acid batteries capped a short development period for the zinc/air battery. The test run indicated the zinc/air battery’s potential savings in vehicle weight from 5.7 to 4.0 metric tons, in battery weight from 2.0 to 0.3 metric tons, in battery volume from 0.79 to 0.25 m³, and in electricity cost from 5.6 cents per mile to 4.7 cents per mile. The power, however, remains the same.

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Gamma-Ray Imaging Spectrometry

At Lawrence Livermore National Laboratory, we have developed an instrument that can help locate and identify special nuclear material (SNM) and other radioactive materials. Recent advances in position-sensitive detector technology, coupled with advances from gamma-ray astronomy, have allowed researchers to build the gamma-ray imaging spectrometer (GRIS), capable of collecting the radiation and generating an image of its source. Such images of invisible radiation can be combined with visible-light images to clearly show the location of the materials. The gamma-ray energy information from different parts of the image can uniquely identify the type of material present. Although GRIS was developed to control the SNM associated with nuclear weapons, we have tested the instrument in several of a myriad of applications in other areas, including environmental cleanup, astronomy, medicine, the nuclear power industry, and any other enterprise where radioactive sources are used.

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