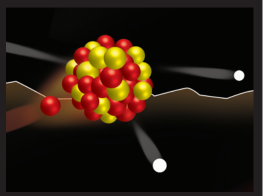
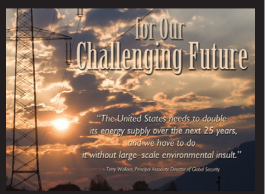
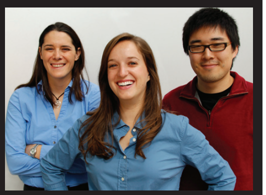
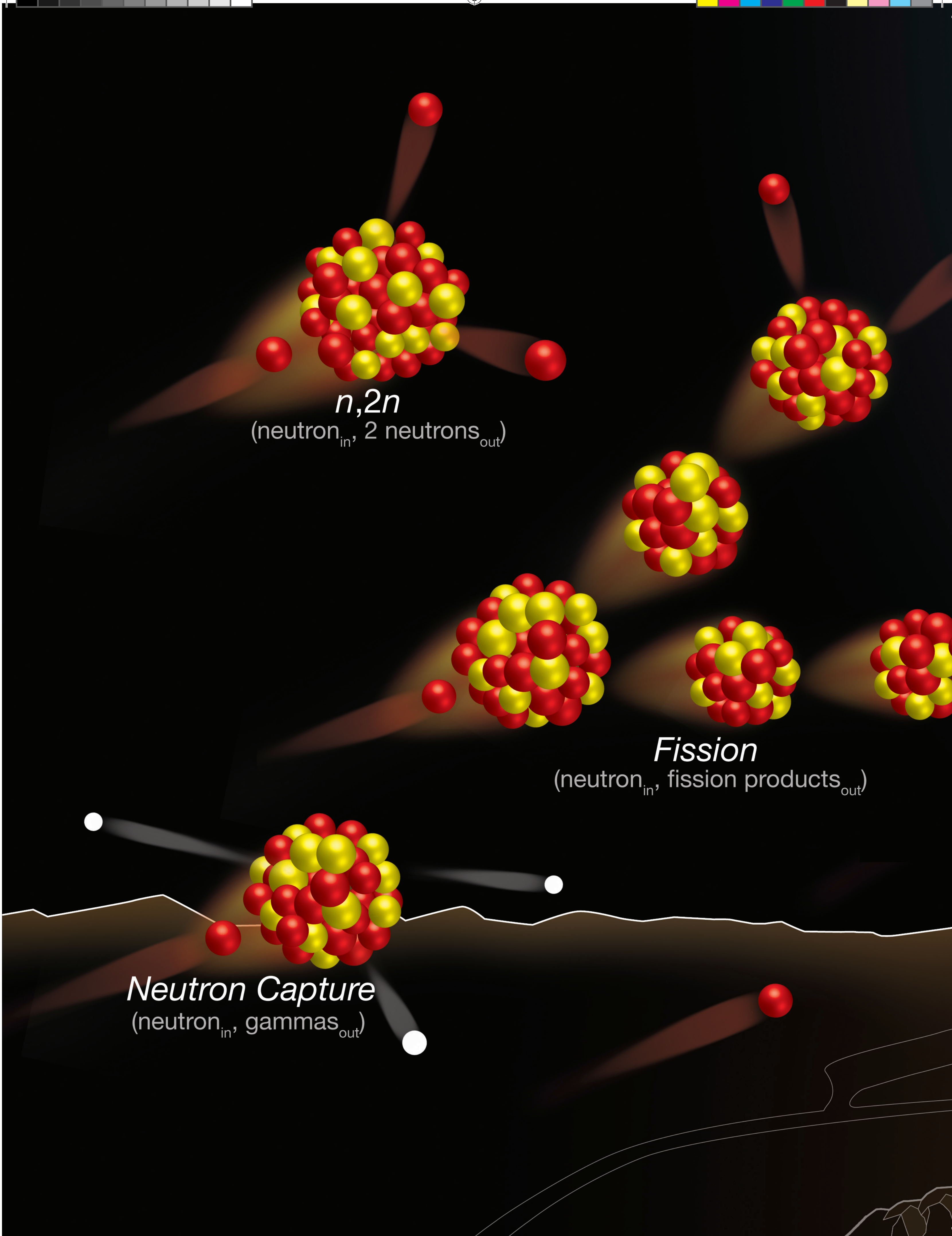
National Security Science earned a Distinguished Technical Communication award in 2012.

STC Society for Technical Communication





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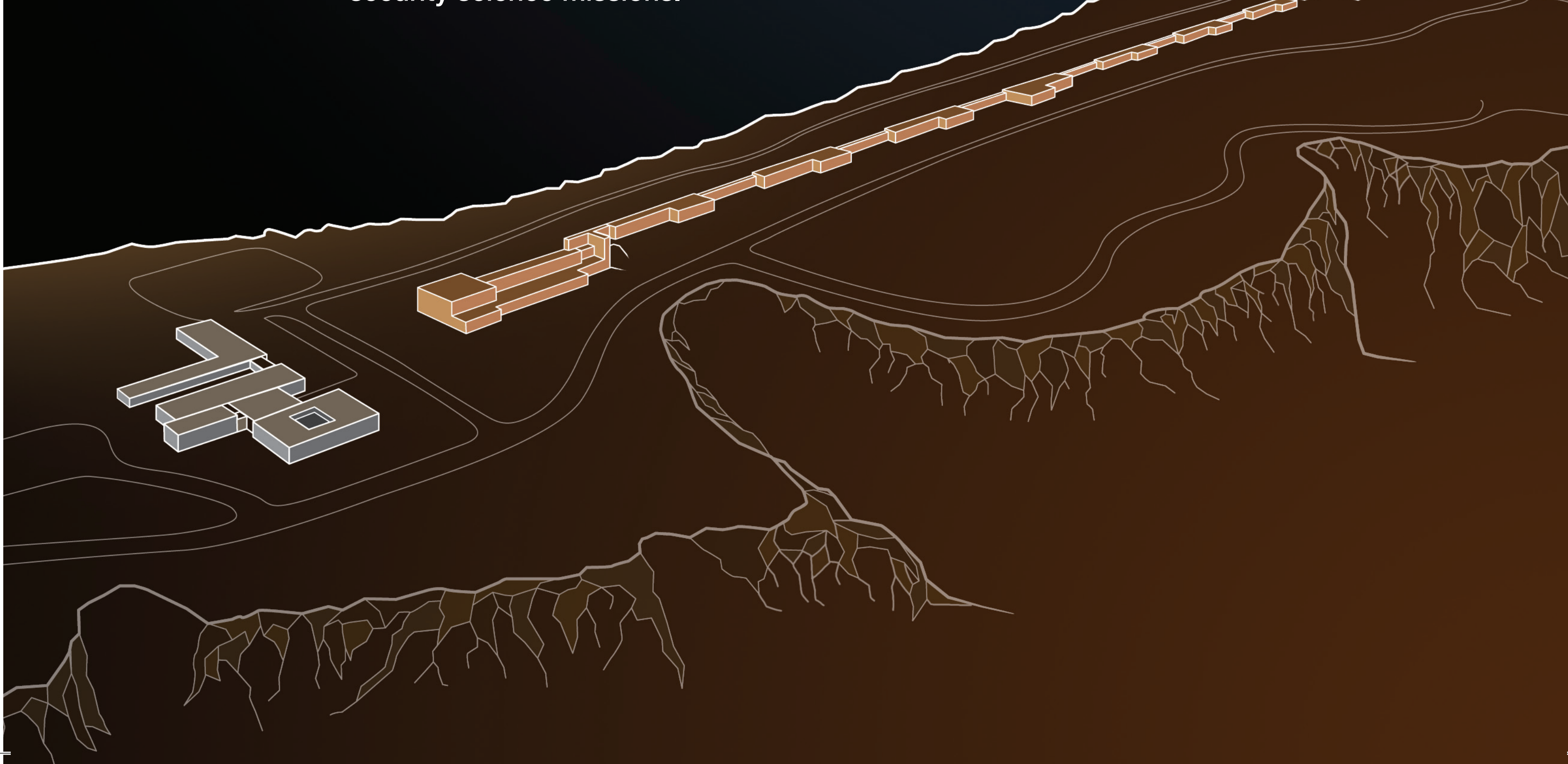
LANSCE

Mission-Critical for National Security

The Los Alamos Neutron Science Center (LANSCE) is a premier accelerator-based, multidisciplinary research facility providing the scientific community with intense proton and neutron sources for both civilian and national security research. It remains at the forefront of national security work because its very intense proton beam and delivery modes can be tailored to meet changing scientific and programmatic needs. In addition, LANSCE scientists apply their creative talents for technological innovation to developing suites of powerful precision instruments that exploit the accelerator's unique capabilities.

LANSCE is a mission-critical facility for the National Nuclear Security Administration (NNSA) and the Department of Energy (DOE). In 2011, the NNSA renewed the memorandum of understanding that affirms the governance and the importance of LANSCE to the weapons program and other national security science missions.



Aerial view of LANSCE, looking east to west. Additional facilities at Los Alamos National Laboratory are visible to the west.

1 Lujan Center: Creates neutrons used in the materials, engineering, chemistry, nanotechnology, biological, medical, and geological sciences. Neutron scattering is used to research, for example, high explosives for the weapons program.

2 Weapons Neutron Research: Provides nuclear data crucial to the Stockpile Stewardship Program as well as for other basic, applied, and defense-related research.

3 Proton Radiography: Uses 800-MeV protons for imaging dynamic experiments in support of national and international weapons science and the Stockpile Stewardship Program.

4 Isotope Production Facility: Produces radioactive isotopes for medicine and research that are in short supply. For example, enough strontium-82 is produced to aid 20,000 heart patients each month.

5 Ultracold Neutrons: Generates the most intense, ultracold neutrons in the world. Cold neutrons are needed for experiments on the fundamental laws of physics and aid in the quest for new particles.

6 Materials Test Station: Tests materials and fuels for use in advanced fast reactors. MTS is under development.

7 Linear Accelerator: Supports all of these facilities.

The Accelerator

The LANSCE accelerator is a half-mile-long, 800-mega-electronvolt (800 MeV), high-intensity linear accelerator (linac) that accelerates a pulsed beam of protons to 84 percent of the speed of light. These hurtling proton pulses can be customized and delivered simultaneously to five unique research facilities: Weapons Neutron Research (WNR), the Lujan Neutron Scattering Center (Lujan Center), Proton Radiography (pRad), Ultracold Neutrons, and the Isotope Production Facility. A sixth facility, the Materials Test Station, is being developed. The linac's proton beam is the source of neutrons, which are generated through a process called spallation. The accelerated protons are aimed at a tungsten metal target. When the protons smash into the neutron-rich nuclei of the tungsten's atoms, the impact shatters (spalls) the nuclei, releasing copious neutrons. The neutrons are used in a wide range of applications. Because they are neutral in charge, they can pass through materials, revealing their properties, structures, and functions in ways protons (with a positive charge) and electrons (with a negative charge) cannot. Researchers at LANSCE use neutrons to study biological as well as nonbiological materials.

Continued on page 6

LANSCE: Button-to-Boom

Supporting the Stockpile Stewardship Program

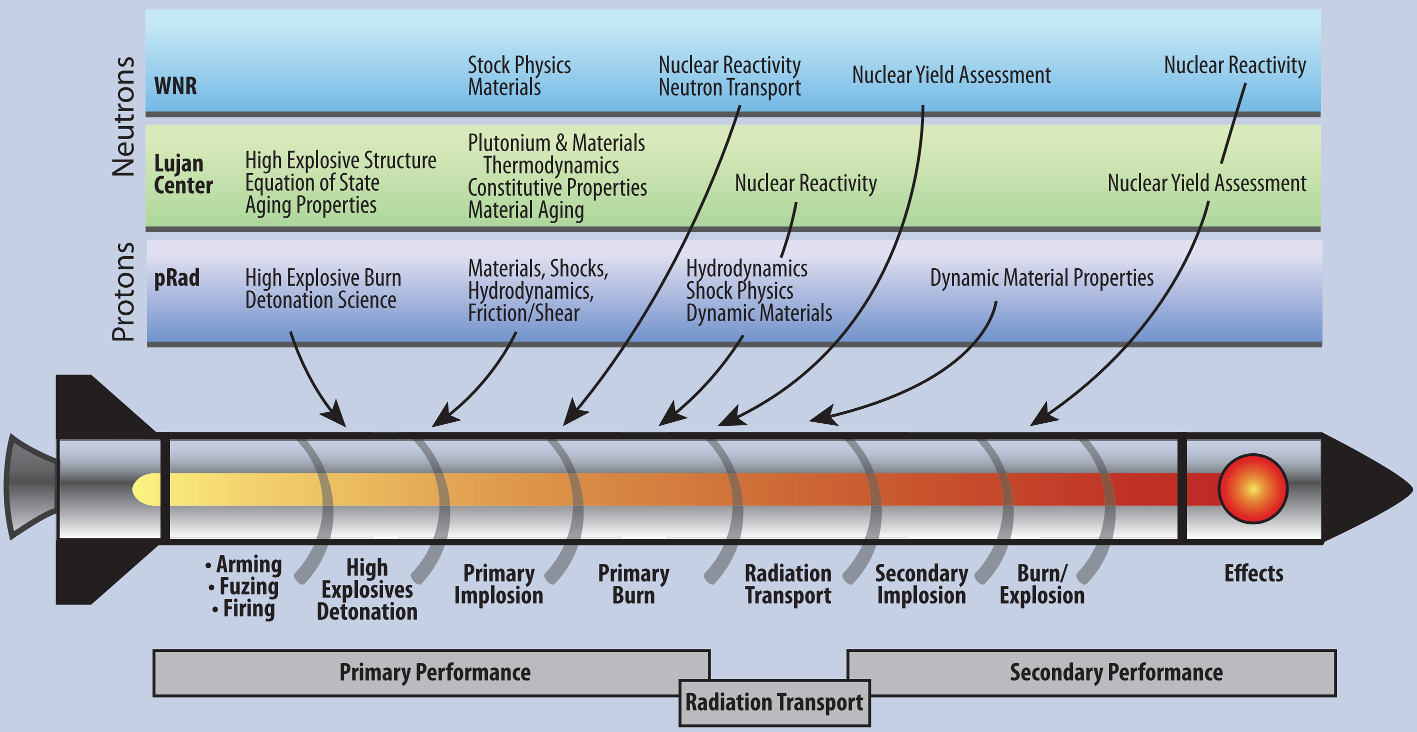
Since 1992, the United States has observed a moratorium on nuclear testing that has led to fundamental changes in the way the Weapons Program assesses whether the U.S. stockpile is safe, secure, and effective. When nuclear tests were conducted, the pedigree of a particular nuclear explosive package was evaluated experimentally with underground tests. The overall confidence in the continued performance of devices in the stockpile relied heavily on the expert judgment of designers with significant underground-test experience. In the absence of testing, a new assessment methodology was required, namely, science-based prediction of weapon performance; the Stockpile Stewardship Program (SSP) was born.

The SSP is based on the scientific capability to quantitatively assess the performance of a nuclear explosive package. This includes the performance margin and associated uncertainties, that is, how close the system is to the point at which it might fail to perform as specified. This capability is firmly rooted in the scientific ability to obtain the experimental data needed to accurately model weapon performance across a broad range of physical conditions.

LANSCE facilities are used to meet this scientific grand challenge with research that explores many aspects of weapons science and behavior: from button-to-boom.

For example, LANSCE research has produced high-explosive data underpinning the certification that the B61 gravity bomb's nuclear warhead will meet specific performance requirements. LANSCE generated nuclear data critical to revising the baseline performance of the W88 primary. LANSCE also generated materials data validating the reuse of components in the W76 Lifetime Extension Program. These weapons systems were originally designed by LANL in concert with other national laboratories.

In the future, our science-based predictive capabilities must continue to improve to ensure the accuracy of our stockpile assessments as weapons age and their components are refurbished or replaced. These capabilities remain crucial to stockpile assessments. LANSCE is poised to meet these future challenges with enhancements to its capabilities and its continued engagement with the best of the scientific community.



The Stockpile Stewardship Program is a science-based predictive capability. From button-to-boom, LANSCE uniquely addresses the SSP requirements.

The Science

Because neutrons not only split (fission) the atom but also are released when the atom splits, they are the drivers of the fission chain reaction in both nuclear reactors and nuclear weapons. The blizzard of neutrons inside these devices causes nuclear transformations of everything it strikes, transmuting one element into another and creating radioactive isotopes seen nowhere else. It turns out that the energy range of neutrons available at LANSCE, coupled with LANSCE's unique experimental capabilities, is ideal for studying the effects of this nuclear alchemy on materials used to build and fuel nuclear reactors. Neutrons are also ideal for studying the nuclear and materials physics that determines nuclear weapon performance.

In fact, neutrons are an essential tool for refining our understanding of nuclear weapons, from the nuclear reactions that produce the energy to the analysis of weapons debris that determines the nuclear yield. Thus, the LANSCE neutrons are especially important while there is a moratorium on all nuclear weapons tests that involve nuclear detonation. LANSCE scientists are also using those neutrons to explore fundamental nuclear physics and reveal information, for example, about the origins of the universe.

In fact, neutrons are an essential tool for refining our understanding of nuclear weapons, from the nuclear reactions that produce the energy to the analysis of weapons debris that determines the nuclear yield.

Accelerated protons are important in and of themselves. At LANSCE they are used, for example, in proton radiography, a technique invented at Los Alamos and further refined in collaboration with other national laboratories. Proton radiography provides high-resolution, high-speed, multisnap-shot imaging of hydrodynamic (liquid-like) properties and processes in materials under extreme stresses (like imploding devices). Proton radiography is also important for imaging high-explosive detonation, a process that must be more precisely characterized to better predict the button-to-boom processes—from high-explosive detonation to nuclear yield. (See sidebar "LANSCE: Button-to-Boom.") Research at pRad is crucial to the Stockpile Stewardship Program.

The Facilities

LANSCE's linac and research facilities are vital to the continued success of the Laboratory's national security science mission and the NNSA's weapons programs. LANSCE conducts research on, for example, materials under extreme temperatures and pressures, the probability that a nuclear reaction will occur under certain circumstances (called nuclear cross sections), and on the high explosives used to initiate weapons detonations. LANSCE is the only linac-based U.S. facility equipped to conduct classified research on stockpile materials and components. LANSCE supports all NNSA laboratories and the United Kingdom's Atomic Weapons Establishment in meeting their nuclear weapons science missions.

National User Facilities

LANSCE has three DOE-designated National User Facilities: WNR, the Lujan Center, and pRad. These facilities are available to researchers from U.S. universities, industry, and other government laboratories, as well as to scientists from around the world. This large and active user program makes LANSCE one of the Laboratory's most important portals to the academic community. LANSCE attracts and retains many of the Laboratory's brightest early-career scientists.

A World-Class Science Facility

Los Alamos National Laboratory considers LANSCE its "signature" science facility. DOE designates LANSCE a world-class facility because of the accelerator's record of reliable operation: scheduled beam time was delivered an average of 88 percent of the time in 2011.

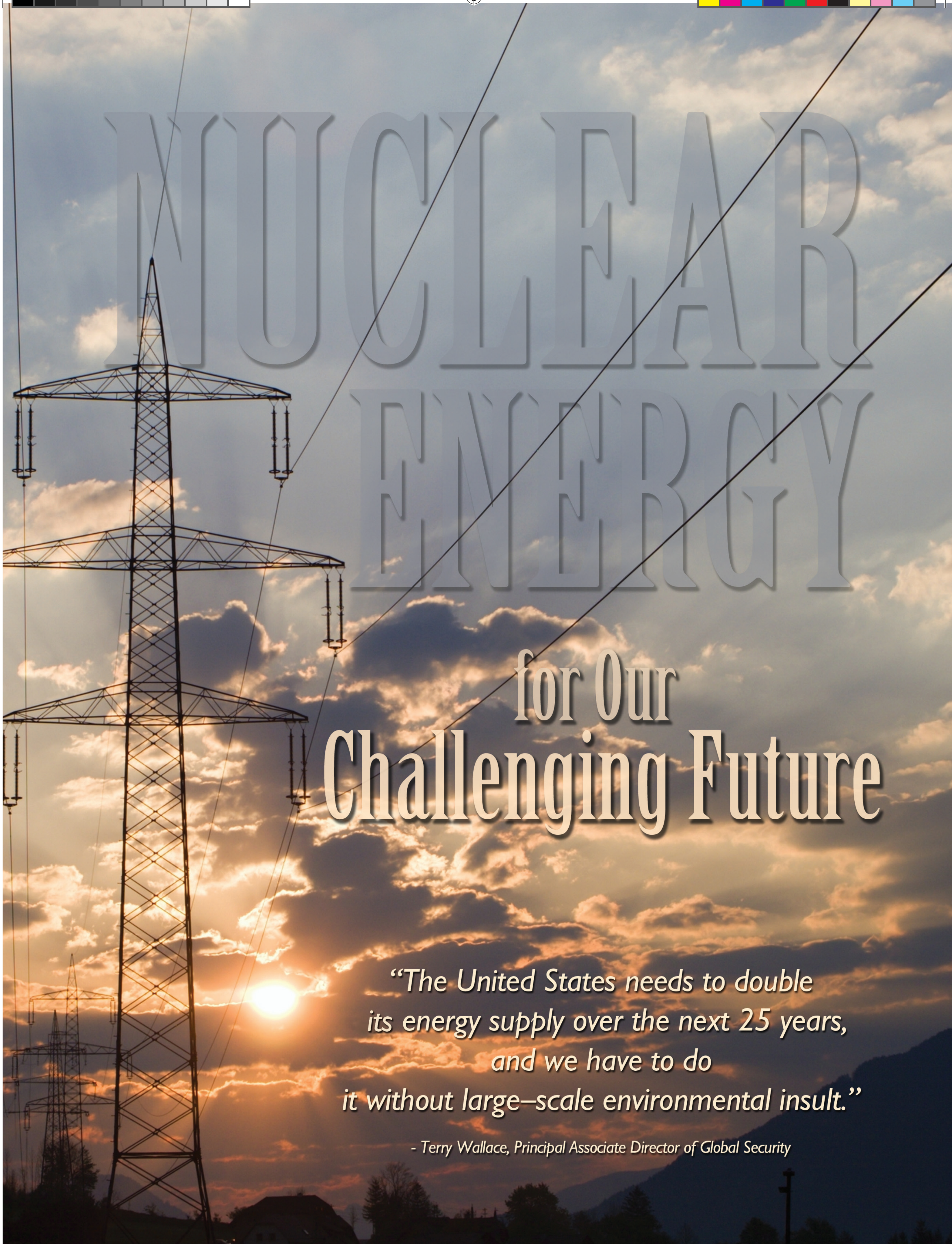
So that it can continue to operate reliably and to its original specifications, under the auspices of the NNSA, LANSCE is currently undergoing a substantial reboot. Key accelerator and infrastructure components are being upgraded, redesigned, and replaced. This investment promises that LANSCE will continue the national security science work needed to ensure the nation's nuclear deterrent, its energy security, and to solve the many other challenges the government brings to the Laboratory. LANSCE will remain a leader on the frontier of national security science for many decades to come.

The following three articles present a sample of the diversity of LANSCE's national security science and its impact on the nation. ✦

–Kurt Schoenberg
Deputy Associate Director
for Experimental Physical Sciences
and LANSCE User Facility Director

–Alex Lacerda
LANSCE Deputy Division Leader

For more information visit lansce.lanl.gov



NUCLEAR ENERGY for Our Challenging Future

"The United States needs to double its energy supply over the next 25 years, and we have to do it without large–scale environmental insult."

- Terry Wallace, Principal Associate Director of Global Security

The U.S. Energy Information Administration's *International Energy Outlook 2011* predicts a 53 percent growth of global energy consumption between 2008 and 2035, with fossil fuels, primarily coal and oil, representing up to 78 percent of the increase.

Fossil fuels are a finite resource, and their use pollutes the Earth and reportedly changes the climate to our detriment. With the world's population surpassing 7 billion people and hungry for ever more energy, the United States, along with the rest of the world, needs to explore multiple cleaner energy sources, including solar, wind, and nuclear power.

For its own national security, the United States needs to rely more on domestic energy sources. Nuclear power could be an important part of a homegrown energy portfolio for generating the nation's electricity. Solar power and wind-generated power can contribute, but only nuclear power can reliably and cleanly provide large quantities of electricity.

But nuclear power creates radioactive nuclear waste, which needs long-term deep geological storage and which must be kept secure against the diversion of its fissile materials to weapons work (proliferation). So the Department of Energy's Fuel Cycle Research and Development program is looking for ways to expand nuclear energy use while reducing waste production and proliferation risks. Fast reactors, coupled with a new closed-fuel cycle, may be the answer. The Los Alamos Neutron Science Center (LANSCE) will be central to U.S. decision making about whether fast reactors are the answer the nation wants when addressing questions about the energy future.

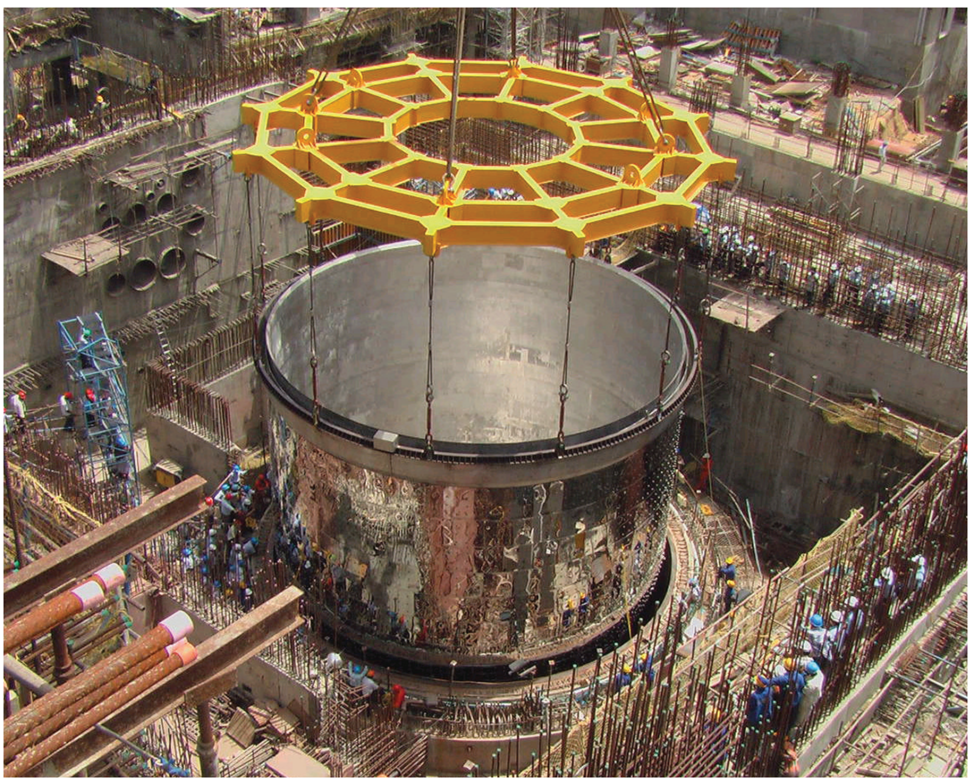
What a Little Neutron Can Do

A fast reactor is actually a fast-*neutron* reactor, "fast" being the energy of the reactor's neutrons. Fast reactors use neutrons with a high kinetic energy—1 million electronvolts. Thermal reactors (most of today's power reactors) use 0.025-electronvolt "slow" neutrons.

Neutrons initiate fission in a reactor's fuel, and they maintain it—a neutron splits an atom's nucleus, releasing energy, new radioactive isotopes ("fission products"), and additional neutrons, which strike more nuclei, causing new fissions and releasing more neutrons in a self-sustaining process: a neutron chain reaction.

Neutron energy determines how a reactor consumes its fuel. Thermal reactor fuel is a combination of two uranium isotopes—U-235 (5 percent) and U-238 (95 percent)—and the thermal reactor uses that fuel very inefficiently: its slow neutrons can fission only the U-235, not the U-238. When a slow neutron strikes a U-238 nucleus, rather than splitting the nucleus, the neutron gets captured inside the nucleus ("neutron capture"), changing U-238 into U-239 and beginning the transmutation (change) of one element into another. First, U-239 decays into neptunium, which then decays into plutonium, but the neutrons do not stop there. Rather, some slow neutrons get captured by the newly made plutonium, which then transmutes through decay into americium. Further, neutron capture followed by decay transmutes some americium into curium. All these transmutation products have higher atomic numbers than uranium and are therefore called "transuranics."

The fission products also can capture slow neutrons, and every neutron captured is a neutron removed from the fission chain reaction. Thus, the fission products and transuranics eventually "poison" a thermal reactor; that is, when too many have built up in the fuel, the chain reaction can no longer be sustained. At that point the fuel is called "spent"



India's Prototype Fast Breeder Reactor (PFBR) is pictured here under construction at Kalpakkam. India expects to commission the reactor this year. As a "breeder," this fast reactor will produce more fissile material than it consumes. India will use the surplus material in fuel for additional breeders, whose construction is scheduled to begin in 2017. –International Atomic Energy Agency and must be replaced. Unfortunately, that happens well before all the U-235 has been consumed.

Fast neutrons can do much more. Their high energy lets them fission all uranium isotopes, including U-238, and even the transuranics that build up in the spent fuel from thermal reactors. For that reason, much of the thinking about fast reactors links them to the reprocessing of spent fuel for recovering of fissionable materials, which is what the closed fuel cycle is all about. Whether the United States eventually uses fast reactors for nuclear energy depends largely on a U.S. shift to the closed fuel cycle.

"If you use an open fuel cycle, you don't use about 99 percent of the energy available in uranium. Does it make sense to restrict nuclear power to a system that does not fully use the energy resource, does not tap all the energy that's available in the system?"

–Eric Pitcher, LANSCE Division Office

Open or Closed?

The United States currently uses the "open" fuel cycle, wherein the fuel is put through a thermal reactor once and then discarded, with most of its uranium unused.

Says Eric Pitcher, of the LANSCE Division Office, "If you use an open fuel cycle, you don't use about 99 percent of the energy available in uranium. Does it make sense to restrict nuclear power to a system that does not fully use the energy resource, does not tap all the energy that's available in the system?"

The open cycle also generates a lot of waste that, because it contains the transuranics, is very long lived. Many of the transuranics have exceedingly long half-lives. Plutonium-239 (Pu-239) has a half-life of 24,000 years, while Pu-242's half-life is more than 300,000 years. Americium-243 has a half-life of 7,000 years, and neptunium-237 lasts almost forever, with its half-life of 2 million years. With such things as part of the mix, spent fuel must be stored indefinitely in a deep geologic repository. To compound the problem, no such repository exists yet; for now, the spent fuel stays in interim storage.

"All the nuclear materials that have come out of our reactors are still stored where the reactors operate," say Pitcher. "A couple of reactors have lived out their useful lives and been closed down, and all that's left is a large green field and a building that stores the spent nuclear fuel. There's nothing else left. No reactor, nothing."

There are different approaches to a closed fuel cycle. The ultimate closed cycle would be one in which only fast reactors were used. In such a scenario almost all of the fuel would be consumed, leaving mostly the fission products. (The fission products will always be waste.) But the possibility of that great a commercial use of fast reactors is far in the future.

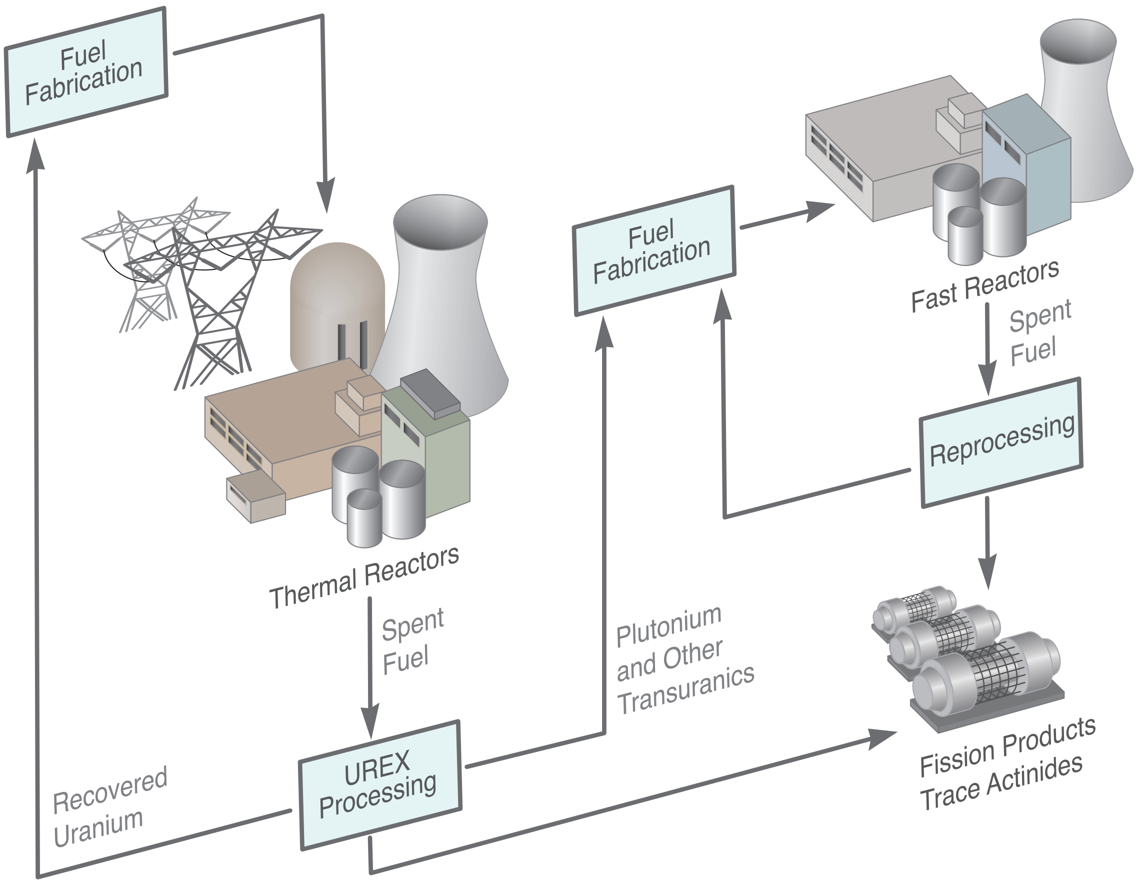
The most common closed cycle—used in Great Britain, France, Japan, and Russia—involves extracting the spent fuel's plutonium and mixing it with uranium to form a new, mixed-oxide fuel, or MOX. The use of MOX reduces the volume of waste destined for geological storage, but the waste still contains the long-lived "minor" actinides (the elements with atomic numbers 89 to 103, excluding uranium and plutonium). So the MOX process results in what is really only a partly closed cycle.

In a fully closed cycle, the uranium would be separated and recycled into new fuel for thermal reactors and the plutonium and other transuranics recycled together into fuel for fast reactors. There would still be waste—the short-lived fission products and traces of long-lived actinides created by transmutation inside the fast reactor.

"But the volume of those wastes would be much smaller than the volume of waste we have now," says Pitcher, "and that would greatly reduce the number of geologic burial sites you'd need for a large fleet of reactors supplying electricity."

The fully closed fuel cycle would also reduce the risk of proliferation—the diversion of plutonium to weapons production. The plutonium would be burned (fissioned in a reactor) instead of sitting in storage, currently onsite dry-cask storage (steel containers, surrounded by concrete) and because it would never be separated from the other transuranics, so there would be no pure plutonium stream. The MOX process does include a pure plutonium stream. Concerns about the proliferation risk of that stream are a major reason the MOX process has not been used in the United States.

Workers at the Fukushima power plant struggle with the damage wrought by the 2011 tsunami. The highly radioactive spent fuel from the plant's reactors threatened to add to the disaster when water was lost from the cooling pools where it was stored. –Eco Watch



In a fully closed fuel cycle, a chemical process—UREX, still being developed—would separate the uranium into one stream and the plutonium into another, with the other transuranics. The uranium would be reprocessed (for example, enriched in U-235) and turned into new fuel for thermal reactors. The plutonium and other transuranics (including the minor actinides) would become fuel for fast reactors. In both cases, the fuel would be used, reprocessed, and reused more than once in a continuous recycling strategy until all that is left for disposal as waste are the fission products and a trace of actinides created by the fast reactors from the minor actinides in a process called "transmutation."

An additional risk is inherent in the first step of storage—placing the spent fuel rods in cooling pools before moving them to dry-cask storage. The cooling pools can be vulnerable in a disaster such as the March 2011 tsunami that damaged the Fukushima nuclear reactors in Japan. During that event, water was lost from the cooling pools, raising fears that the spent fuel rods would overheat enough to release large amounts of radioactive material.

Says Pitcher, "The pools might have had a lot less spent fuel if Rokkosho [Japan's new reprocessing plant, still coming on line] had been up and running." Rokkosho is a MOX plant, so it represents only a partly closed fuel cycle, but the point is still a good one. Rods that were cool enough could already have been out of the pools and into reprocessing.

Materials Test Station

Pitcher is the project manager for the proposed Materials Test Station (MTS), a new fast-neutron irradiation facility planned for construction at LANSCE. MTS will help researchers answer questions about a fast-reactor nuclear power future for the United States.

Today fast reactors exist only in Japan, Russia, India, and China, although they have been operated and eventually closed down in the United States, Great Britain, Germany, and France. They are not as widespread as proponents predicted in the 1970s, partly because uranium has remained abundant and cost effective but also because fast reactors are difficult to operate and expensive to construct. The operational challenges include reliability and safety—many of the fast reactors that are now closed were undergoing repairs for more time than they were operating and were finally permanently closed down because of accidents.

To date, fast reactors have used either uranium or MOX fuel. If they are to be used to transmute nuclear waste, as they would in the fully closed fuel cycle, scientists need to experiment with different types of fuel with different combinations of isotopes to find the ones that will burn as needed in a fast reactor. And they must create new alloys for structural materials that can withstand the extremely high heat and intense neutron radiation inside a fast reactor.

Despite the difficulties, research into better, more advanced designs for fast reactors is continuing because of fast reactors'

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efficiency and potential impact on the waste problem. In fact, the United States is leading an international collaborative effort—the 13-nation Generation IV International Forum—that is pursuing six new reactor designs, three of which are fast reactors.

In support of such new designs, all the questions about fast reactors must be answered. The role of MTS will be to help solve the puzzles about fuel and alloy for structural reactor materials. Experiments run by Los Alamos researchers are already revealing the properties of new fuels and alloys. "But," says Pitcher, "the success of those materials cannot be judged until they have been irradiated and tested in an environment mimicking the extreme conditions found in a fast-neutron reactor." MTS will provide that environment and thereby fill a huge gap: the United States currently has no fast-neutron facility where new fuels and materials can be tested.

This lack of a domestic facility means that, without MTS, researchers would be forced to travel to fast reactors abroad, enduring all the difficult logistics and costs inherent in conducting irradiation research: government-to-government negotiations, extensive and complicated export licensing requirements, transportation requirements, and other costly challenges.

As an example, negotiations for use of the French fast reactor Phenix (now closed) to test a small sample of fuel began in 2002 but were not completed until 2007; testing was completed in 2009, at a cost of almost \$8.5 million. Today the samples are still awaiting shipment back to the United States for post-irradiation analysis. (They are expected back this year.)

Left in temporary storage above ground, containers of high-level radioactive waste must be checked periodically for leaks and for the internal buildup of gases that might rupture the container. This problem persists because of the absence of a permanent underground repository. Los Alamos scientists have developed a new laser process that penetrates such containers (for sampling) and then reseals them with a unique laser alloying technique that prevents cracks, permits the final seal to be certified, and allows the container to be resampled repeatedly.

Radioactive waste is categorized and managed in terms of its radioactive content and thermal characteristics. Wastes categorized as "high-level"—including spent nuclear fuel and byproducts of fuel reprocessing activities—must be immobilized and transported for isolation in engineered vaults or underground repositories. The wastes pose long-term hazards to people and the environment. Scientific approaches for solidifying and immobilizing high-level wastes include vitrification in borosilicate glass.
–World Nuclear Transport Institute

A Cost-Effective Solution

Filling the fast-neutron facility gap without MTS could be very expensive. Building a new experimental fast reactor would cost more than \$1 billion. Modifying a linear accelerator and building a new experimental facility and beam line would cost over \$160 million. In contrast, building MTS at LANSCE will cost less than \$100 million because MTS can take advantage of LANSCE's 800-million-electronvolt linear proton accelerator for the production of fast neutrons. And an experimental hall and beam line already exist at the accelerator's end, ready for MTS. Having the basic structures already in place makes MTS the most cost-effective and quickest solution—clearly the preferred alternative.

Pitcher is excited about the part MTS can play. "MTS will be an important facility for researchers, and it will be important for informing decision makers who are considering options for new nuclear energy systems and fuel cycles. We'll be able to show the performance specifications you'd get with the reprocessing option, the waste streams that would come from the reprocessing step, the volume and composition of the waste stream and, therefore, the size and number of repositories you'd need to build, if you wanted a future scenario where 30 percent of U.S. electricity was produced by nuclear power. And we can offer assessments of technology that could then be deployed under such a scenario."

He concludes, "Those who are passionate about the future of nuclear power believe that it depends strongly on the deployment of fast reactors and the use of reprocessing. I really believe in the need for MTS. It will help our government make those decisions and move nuclear power forward in this country."

–Eileen Patterson

The INVISIBLE NEUTRON THREAT

A neutron produced by a cosmic ray and traveling at nearly the speed of light strikes a military C-141B Starlifter carrying over 100 troops at 37,000 feet over the Sea of Japan. Immediately the pilot notices something is wrong. Very wrong. The plane is suddenly banking to the right and is in danger of going out of control. What is happening?

Is a single subatomic particle capable of causing such a big problem? The answer is yes: a microchip in a plane's flight controller can malfunction and produce an erroneous command after being struck by a neutron. These neutrons, like ghosts, can pass through materials without being noticed. At aircraft cruising altitudes, about 2,000 of them per second penetrate each square yard of the aircraft's surface, passing through the passengers, seats, and onboard electronics and exiting on the other side. What happens when a high-energy neutron collides head-on with a silicon atom's nucleus in a transistor of the onboard electronics?

Neutron Threat

For over 20 years the military, the commercial aerospace industry, and the computer industry have known that high-energy neutrons streaming through our atmosphere can cause computer errors known as single-event upsets (SEUs). These are "soft" errors—no permanent damage is done—but a single digit in computer memory suddenly changes, or a logic circuit produces an erroneous result that may hang up (or crash) an application. The neutron's head-on collision with a nucleus is what does the mischief. It produces a burst of electric charge that causes a single transistor—the basic building block of the integrated circuits patterned on the surface of a microchip—to flip from the OFF state to the ON state.

The rate at which SEUs occur in a microchip is proportional to the number of neutrons reaching the microchip per second, called the neutron radiation intensity. In the atmosphere, the neutron intensity keeps increasing with altitude up to 60,000 feet and then levels out, and the rate of SEUs follows along. At 30,000 feet, for example, both the neutron intensity and the SEU rate are 300 times higher than they are at sea level. Unfortunately, neutrons are so penetrating that there is no practical way to shield critical equipment on an aircraft. So, the military and the aerospace industry have developed mitigation strategies.

If an SEU occurs in a flight controller on a manned aircraft, the pilot can override the flight controller, or better, the circuits in the controller can automatically correct the error through triple modular redundancy (TMR). In TMR, the signal in one electronic circuit is compared with the results from two other identical circuits. The error-affected circuit is then overridden—in short, outvoted by the other two circuits—before the wrong signal ever leaves the controller. TMR has worked very well for flight controllers and other critical devices that depend on microchips. However, TMR mitigation is very expensive in terms of dollars, time, weight added to the aircraft, and space required, so until recently TMR was considered uneconomical for the less-critical functions like imaging and data processing devices.

The SEU rate per microchip depends on three things multiplied together: the neutron intensity, the intrinsic sensitivity of each transistor to neutron-induced SEUs, and the number of transistors on the microchip. Suppose the SEU rate for a particular microchip with particular transistors, used at a certain altitude, is 1 every 1000 hours, and there are 100 microchips in use. Then at that altitude, 1 of those 100 microchips will suffer an SEU once every 10 hours. In other words, the higher the altitude, the greater the neutron sensitivity of the transistor, and the larger the number of microchips in use, the higher the SEU rate.

On October 7, 2008, an Airbus A330-303 operated by Qantas Airways was en route from Perth to Singapore. At 37,000 feet, one of the plane's three air data inertial reference units had a failure, causing incorrect data to be sent to the plane's flight control systems. This caused the plane to suddenly and severely pitch down, throwing unrestrained occupants to the plane's ceiling. At least 110 of the 303 passengers and 9 of the 12 crew members were injured. The injuries of 12 of the occupants were serious, and another 39 occupants required treatment at a hospital. An SEU was the only potential cause for the malfunctions not ruled out. All potential causes were found to be "unlikely," or "very unlikely," except for an SEU. However, the Australian Transport Safety Board (ATSB) found it had "insufficient evidence to estimate the likelihood" that an SEU was the cause. –ATSB Transport Safety Report Aviation Occurance Investigation AO-2008-070 Final

How Big Is the Neutron Threat?

Today the military has increasing concerns about the neutron threat because the number of airborne microchip-based devices is increasing rapidly. For example, in the Iraq and Afghanistan wars, awesome arrays of microchip-based off-the-shelf computers and imaging devices have been deployed on surveillance and other military aircraft to deliver critical battlefield information. Some are flown over the North Pole at up to 60,000 feet and give the U.S. military a view of the entire northern hemisphere. The neutron intensity there is about 2,000 times that at sea level.

The evolution of the digital world is due to a single driver: the shrinking size of individual transistors

Other lower-altitude aircraft are giving soldiers real-time imagery of the streets and neighborhoods they are about to enter. The military counts on having the information processed onboard and quickly downloaded to soldiers on the ground. However, the SEU rate per microchip at sea level in the latest off-the-shelf devices has grown rapidly in the last 5 years as the transistor size has decreased and the number of transistors on each chip has increased. Is the SEU risk now too high? Is mitigation worth the cost? And how can these risks be measured before the equipment is deployed?

The military is not alone in facing this problem. The same microchips used in avionics are appearing everywhere in our digital world, for example, in ground-level civilian systems for banking, transportation, medicine, communication, entertainment, and more. They are critical in insulin monitors and GPS-enabled emergency response systems, in antilock brakes, and smart stoplights, smart phones, increasingly realistic video games, advanced audio systems, and the supercomputers that forecast the weather and predict the performance of our nuclear weapons. (See sidebar "Supercomputer Testing at the ICE House.")

Will Moore's Law Come to an End?

The evolution of the digital world is due to a single driver: the shrinking size of individual transistors. Each time the area of the transistor is cut in half, the industry doubles the number of transistors per microchip, and the chip performance (number of operations per second) doubles. For the last 40 years, transistor area has halved and chip performance has doubled every 2 years, a rate of increase known as Moore's Law. Because smaller transistor size reduces fabrication costs and allows transistors to operate at lower voltages, the increased performance comes at little extra cost, enabling more microchips to be used in an ever-greater number of products. It is no wonder Moore's Law is hailed as an engine of growth for our economy.

Yet, Moore's Law may to come to an end due in large part to the neutron threat. The drive toward smaller transistors is now leading to an increased sensitivity to SEUs per transistor, particularly in transistors with subcomponents that are 65 nanometers (billionths of a meter) or less wide. At those dimensions, billions of transistors can be patterned on a chip, but the critical electric charge needed to flip a transistor becomes very low. Now because much smaller bursts of charge from neutrons hitting silicon nuclei can cause an SEU, the SEU rate increases sharply.

Heather Quinn of Los Alamos' Intelligence and Space Research Division is a reliability expert for electronic data systems aboard satellites and aircraft. Quinn, who has been measuring the rate of SEUs since she came to LANL in 2004, warns that the more our society goes toward automation and the more that advanced microchips with billions of transistors per microchip are used, the greater the neutron problem will become.

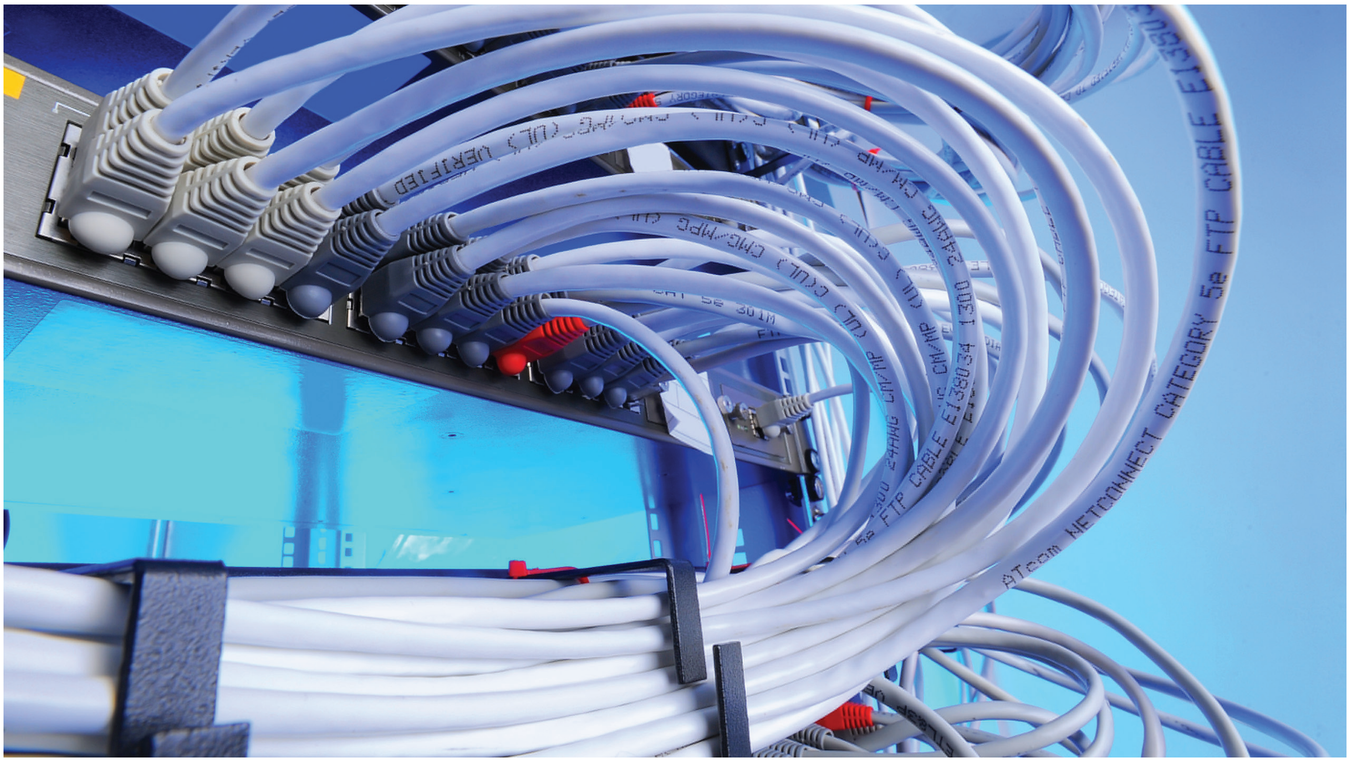
One hour of exposure in WNR's neutron beam should produce the same number of SEUs as 100 years of exposure at normal cruising altitudes. It would be neutron testing on steroids.

LANSCE: Dealing with the Neutron Threat

Today it's widely recognized that neutron radiation is a major factor limiting the reliability of advanced electronics. Chipmakers and users have been learning the hard way that they need to measure neutron-induced effects in advance to avoid dangerous, costly failures. Boeing was among the first to see the problem. In the early 1990s, Boeing was concerned about the electronics going into their new 777 commercial airliner and needed a rapid way to test for neutron-induced failures. But how and where could they quantify the risk?

Boeing's Eugene Normand knew that the neutron beams at LANSCE's Weapons Neutron Research (WNR) facility, the

Many companies (including these) have visited Los Alamos National Laboratory to use the services of the ICE House.



Routers run the digital world, sending information from one computer network to another across cities, regions, nations, and continents. An office building can contain thousands of them. Their sheer numbers make them a target for neutron-induced SEUs.

most intense high-energy neutron source in the world, have the same energy spectrum (numbers of neutrons at different energies) as the neutron radiation in the atmosphere. Normand contacted Steve Wender, director of WNR, and proposed that Boeing be allowed to place its electronics in WNR's neutron beam to replicate exposure to the neutron energy spectrum in the atmosphere. That way Boeing could research neutron-induced electronic upsets and the relative rates at which they would occur aboard the new aircraft. By using WNR, Boeing could assess the atmospheric neutron risk at a single facility instead of traveling to different single-energy neutron sources and then filling in data for the other neutron energies with theoretical guesswork.

Called the Irradiation of Chips and Electronics (ICE) House, the facility is now a mecca for the global electronics and avionics industries—from chip producers to consumer product companies.

Wender pointed out that, in addition, the WNR neutron beam intensity is a million times greater than the neutron intensity at about 30,000 feet. That meant that one hour of exposure in WNR's neutron beam should produce the same number of SEUs as 100 years of exposure at normal cruising altitudes. It would be neutron testing on steroids.

Wender began working with a team from Boeing, Honeywell, and LSI (the semiconductor storage and networking giant) to develop one of WNR's neutron beam lines as the first one-stop shop for predicting the SEU rates from atmospheric neutron radiation. That beam line was gradually transformed into the world's best user facility for determining the risks of neutron SEUs.

The ICE House

Called the Irradiation of Chips and Electronics (ICE) House, the facility is now a mecca for the global electronics and avionics industries from chip producers to consumer product companies.

On the military front, the Department of Defense (DoD) has asked Quinn to place electronic components planned for DoD aircraft in the neutron beam at the ICE House and test for neutron-induced SEU rates. While military airplanes have an overall lifetime of 20 to 30 years, their electronics get refreshed every 5 to 10 years. DoD wants to increase the flexibility and range of functions on each microchip, which today means deploying electronics with transistor components as small as 28 nanometers. It also means greater use of field-programmable gate arrays (FPGAs): chips that can be reprogrammed remotely with an uploaded bit stream of new program instructions. These FPGAs give DoD the option to alter the mission focus of an aircraft in midair if, for example, a new threat suddenly emerges.

Quinn not only tests components at the ICE House, but also tests possible mitigation strategies. Susceptibility to neutron-induced "latch-up" (in which the part suddenly draws a large current and could potentially burn out) are considered unacceptable, and those parts are immediately screened. But parts susceptible to "soft" (nondestructive) errors, such as SEUs, can often be helped. Quinn will recommend a redesign or the use of error-correcting software or built-in redundancy (like TMR), depending on the test results.

The Joint Electron Devices Engineering Council, representing about 300 manufacturers and users of electronics, states in its published standard for testing memory units that WNR "is the preferred facility" for accelerated neutron-induced SEU testing.

Growing Demand for the ICE House

Among the five neutron sources in the world that attempt to reproduce the effects of atmospheric neutrons, the ICE House is the only one in the United States and, according to a recent article published in the Institute of Electrical and Electronics Engineers (IEEE) *Transactions on Nuclear Science*, ICE House test results most closely match what can be expected in the field.

Beyond aircraft manufacturers and DoD, more industries are using the ICE House to test their new products. Automotive standards require that a car's computer system be tested for neutron radiation effects once it has more than a specific amount of microchip-based memory. The Joint Electron Devices Engineering Council, representing about 300 manufacturers and users of electronics, states in its published standard for testing memory units that WNR "is the preferred facility" for accelerated neutron-induced SEU testing.

Chipmakers such as Intel are developing new transistor designs that are small but hold enough charge to be resistant to the effects of neutrons while operating at low voltages. To test these new designs, they are requesting significant amounts of beam time at the ICE House.

"The ICE House is the only facility providing users from the military, industry, and academia with easy, economical access to neutrons that mimic the environment," says Wender. "And we are rapidly becoming oversubscribed."

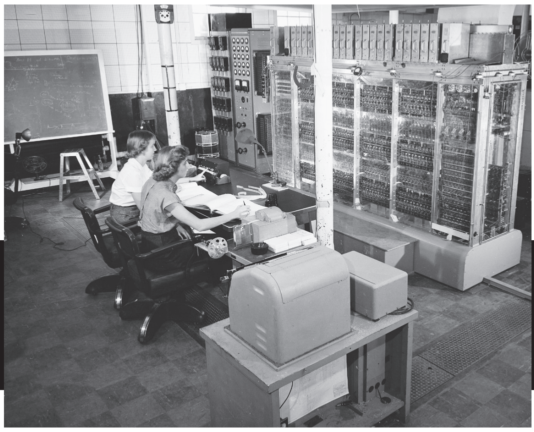
Adding On to Meet Demand

To meet increased demand, LANL's management organization, LANS, LLC, has capitalized the construction of a second beam line for the ICE House. It should be completed in 2012 and will come none too soon. The high-tech industry hopes to keep Moore's Law going for at least another decade, during which time the subcomponents of transistors will downsize from 45 nanometers to 4.5 nanometers, making the transistors all the more susceptible to neutron-induced threats.

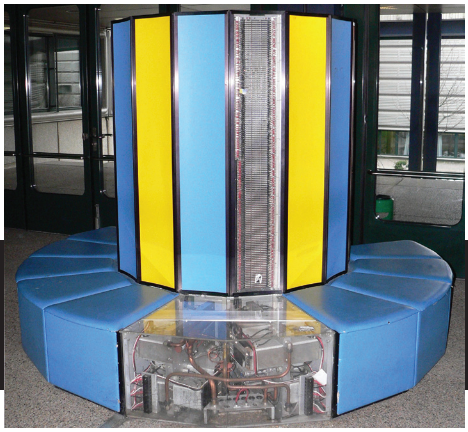
To make systems more tolerant of neutron-induced errors and device variations, researchers are envisioning more-powerful mitigation strategies that involve every layer of the system—from the software applications and operating systems to the individual circuit components. "This is not a problem that we expect to go away anytime soon, and solving it must have a high priority," states IBM Fellow Carl J. Anderson in a recent study of cross-layer reliability sponsored by the National Science Foundation and edited by Quinn, Nick Carter of Intel, and André DeHon of the University of Pennsylvania.

Those solutions to the neutron threat will have to be vetted. Undoubtedly LANSCE's ICE House, with its controlled and quantified neutron-radiation environment, will continue to be an invaluable resource to help researchers design, test, and certify the highly complex electronic automation systems we use now and envision for our future.

–Necia Grant Cooper



1952: LANL's MANIAC was the first digital electronic computer to perform large-scale hydrodynamic calculations relevant to nuclear weapons. Made of vacuum tubes, not semiconductor transistors, MANIAC was not susceptible to neutron-induced SEUs.



1976: LANL's Cray-1 (similar to the Cray-1 shown here) was the first supercomputer with a transistor-based memory and the site of the first recorded SEU on the ground. Error-correcting codes were introduced to alleviate the SEU problem in memory.

Supercomputer Testing at the ICE House

On the ground as in the air, the rate of SEUs is proportional to the number of transistors in a computing system. Thus, the supercomputers used for nuclear weapons simulations and other national security challenges, which contain thousands of microchips each containing many millions of transistors, are big targets for SEUs—even though the neutron flux on the ground is hundreds of times lower than at aircraft cruising altitudes.

Cray-1 Supercomputer

Case in point: During 1976, LANL was given a 6-month free trial of the Cray-1 computer, one of the first "supercomputers" (at 80 megaflops, or 80 million operations per second) and the first Cray design to use integrated circuits. LANL kept close track of its reliability and discovered 152 bit flips in the memory units in the 6-month trial period (900 hours of running time), or one every 6 hours. The cause was unknown, but LANL became a key player in monitoring computer errors and advising on error-correcting codes to solve the problem.

Much later (2010), measurements at the ICE House strongly suggested that the cause of those early Cray-1 bit flips were SEUs induced by atmospheric neutrons. Thus, in retrospect, they became the first recorded SEUs on Earth. (SEUs had first been detected in satellites.)

Q Supercomputer

In 2002, a similar situation occurred early in the deployment of LANL's Q supercomputer, which in June 2003 became the world's second fastest supercomputer at nearly 14 teraflops (or 14 trillion operations per second). An unexpectedly high number of crashes were traced to bit flips in a memory unit supporting the processors. Neutron involvement was suspected, in part because LANL is at a 7,200-foot elevation, with a neutron intensity that is several times higher than at sea level. Bit-flip rates measured during ICE House tests and analyzed by LANL statistician Sarah Michalak and colleagues were consistent with the rate of errors observed in Q in the field. Mitigation strategies were developed, allowing scientists to successfully use the Q for state-of-the-art scientific calculations and simulations that help ensure the safety and reliability of the nation's nuclear weapons stockpile.

Roadrunner

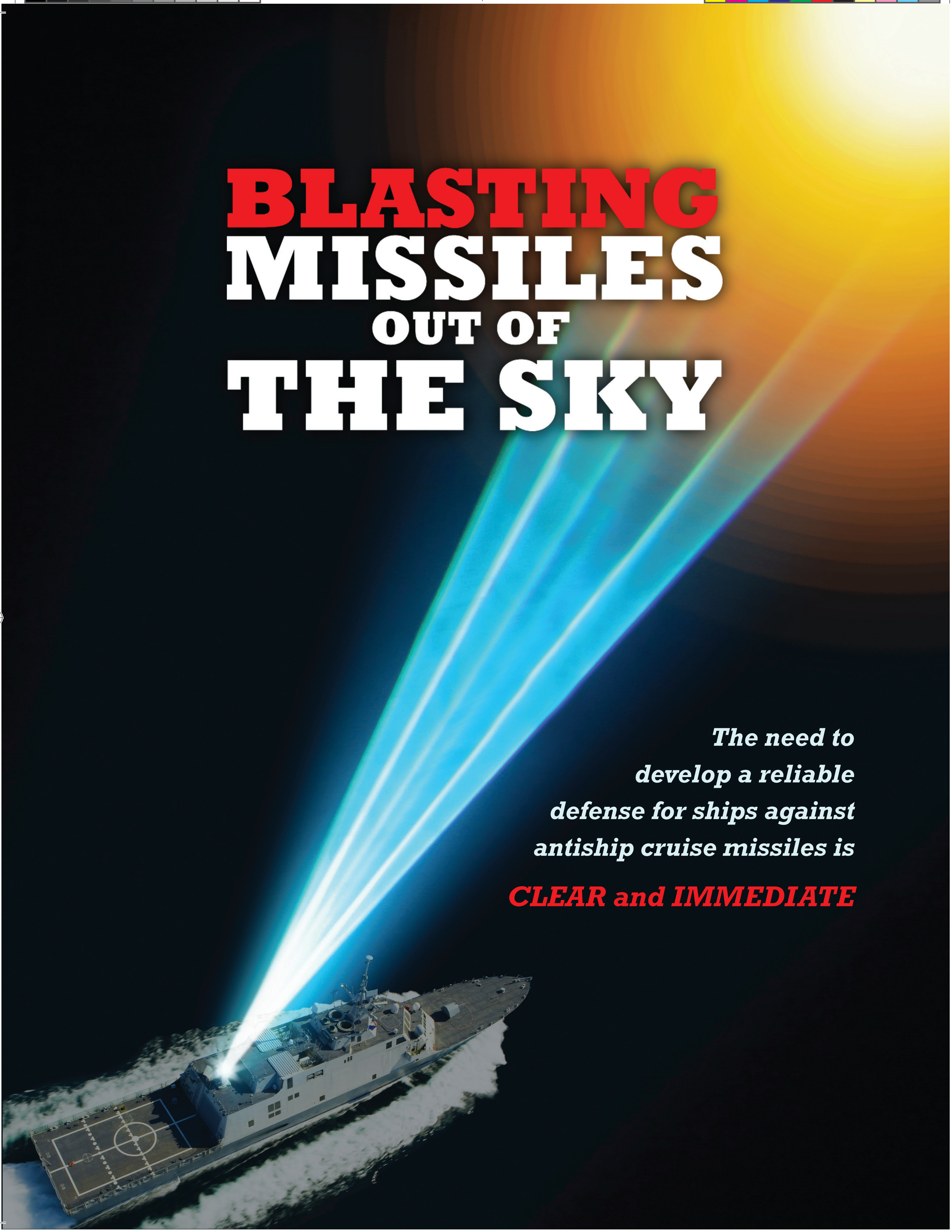
In LANL's Roadrunner, the first petaflop supercomputer (1000 trillion operations per second), much of the hardware has built-in protection from SEUs. However, the protection is not perfect. There are still two concerns: vulnerability to SEU-induced crashes, which can cause a calculation to crash, and silent data corruption, in which an undetected error causes the system to deliver computationally incorrect results. These latter errors are termed "silent" since an undetected error cannot produce an error message that would alert a user. Michalak supervised ICE House testing of the Triblade compute-servers used for computation in Roadrunner. Based on the results, the Roadrunner platform is predicted to experience one-neutron-induced crash roughly every 130 hours of operation and one-neutron-induced silent data corruption roughly every 1,100 hours.

SEU Mitigation

The impact of silent data corruption on large simulations will most likely be small, especially because extensive numbers of calculations are used to verify and validate the codes that affect decision making. A LANL team led by Nathan DeBardeleben is investigating silent data corruption by purposely inserting SEU-type errors and tracing how applications respond to these anomalies. The results will guide the development of software that is more resilient to SEUs and other types of errors.

The effects of crashes are typically mitigated by a practice called checkpoint-restart. At various "checkpoints" during a calculation, the state of the computer is stored, and anytime a crash occurs the calculation is halted, data from the most recent checkpoint is loaded, and the calculation is restarted. To reduce the time needed to store checkpoint data, Gary Grider is leading a LANL effort to develop a technique using flash memory to store checkpoint data very rapidly during the calculation and then slowly transfer that data to the parallel file system while the calculation proceeds independently. This technique should be deployed in supercomputers in the next few years.

2002-2003: When first deployed at Los Alamos, the Q supercomputer exhibited an unexpectedly high number of crashes. These were traced to bit flips in a memory unit supporting the processors, and the results of subsequent testing at the ICE House were consistent with the hypothesis that the bit flips were caused by neutrons. Successful mitigation strategies allowed the Q machine to support state-of-the-art calculations for the nuclear weapons program.



BLASTING MISSILES OUT OF THE SKY

The need to develop a reliable defense for ships against antiship cruise missiles is

CLEAR and IMMEDIATE

“One of Los Alamos’ core capabilities is accelerators. And it is not just about operating advanced accelerators, like those at LANSCE—it’s about our people thinking about the future uses of accelerators. For example, we can think about potential accelerator-based weapons of the future. How about powering a free-electron laser so that it can blast missiles or other threats out of the sky? Well, such power requires an accelerator. Our understanding of accelerators makes such innovations possible.”

–Terry Wallace, Principal Associate Director of Global Security

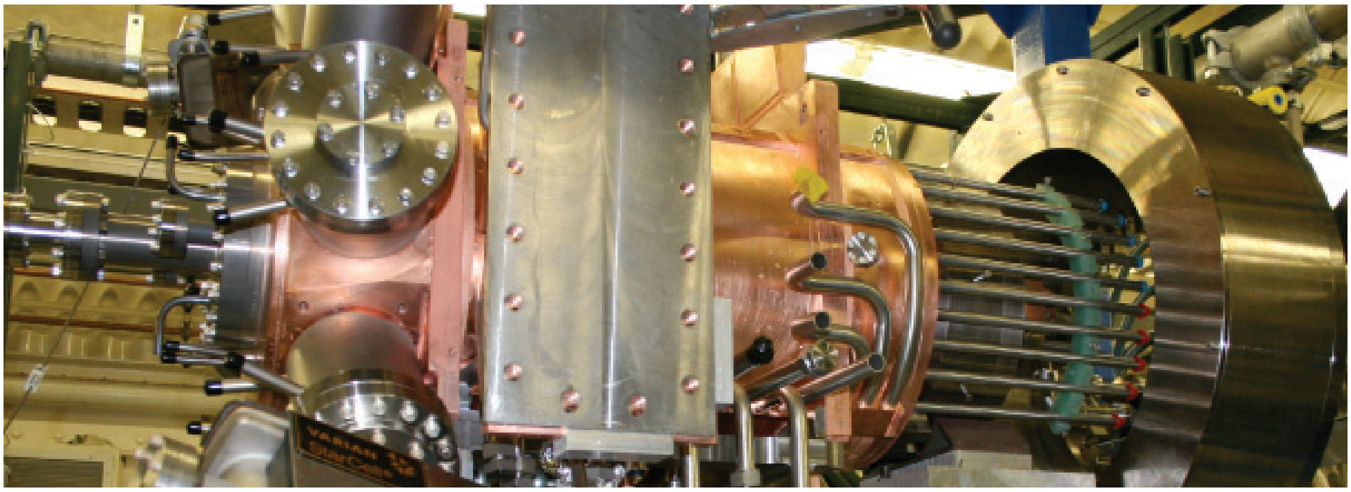
Ships in the United States Navy are armed with a variety of weapons, including 5-inch guns, vertical-launch missiles, advanced antisubmarine torpedoes, and cruise missiles like the Tomahawk. To defend against antiship cruise missiles, ships use a layered defense strategy that consists of surface-to-air missiles for medium-range defense and radar-guided Gatling guns (large-caliber machine guns firing over 100 rounds per second) that are used as a close-in weapon system to counter any threats that have penetrated the ship’s outer defenses.

But antiship cruise missiles are becoming increasingly sophisticated. They are extremely fast—up to 5 times the speed of sound—and agile. Destroying cruise missiles before they hit a ship is a daunting challenge; a ship detecting a cruise missile traveling at Mach 5 (5 times the speed of sound) would have only a few seconds to destroy the missile before it destroyed the ship. Some cruise missiles also have computerized “smart” systems that, once locked onto a target, make the missiles difficult—if not impossible—to shake off. At present, no ship can outrun or outmaneuver a supersonic antiship cruise missile if the missile is locked onto it. The need to develop a reliable defense for ships (which can cost hundreds of millions of dollars) against antiship cruise missiles (which can cost less than $1 million) is clear and immediate.

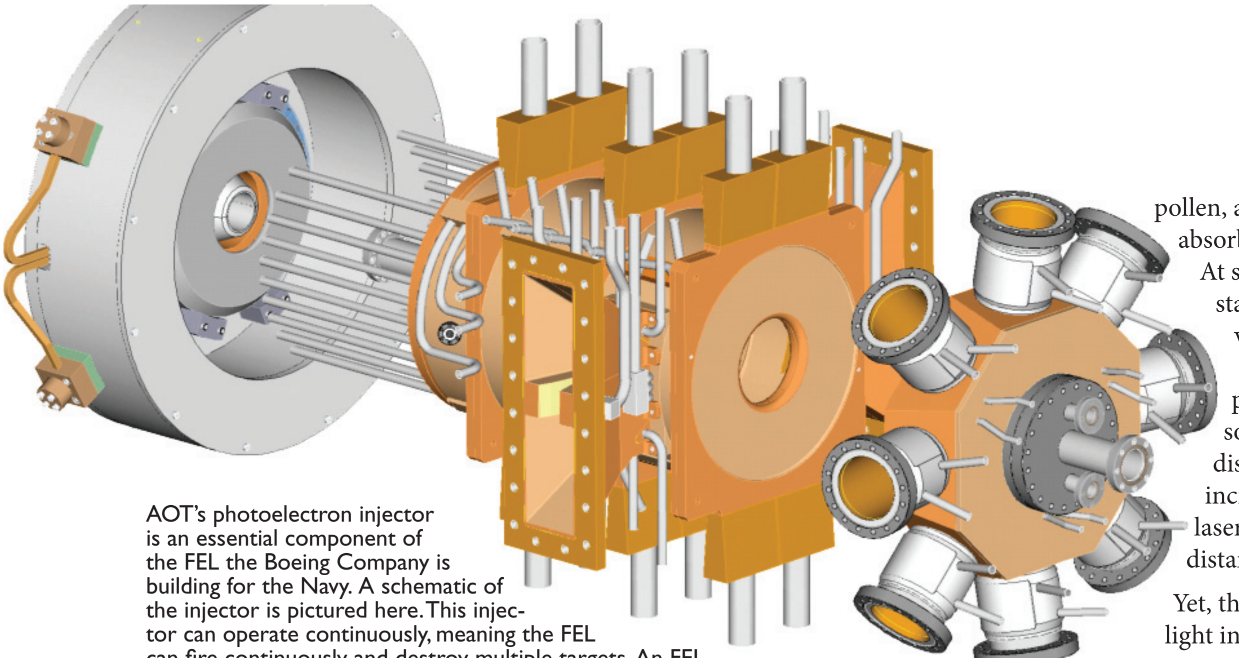
Free-Electron Laser

In collaboration with the Office of Naval Research (ONR), Boeing Company, other national laboratories, and industrial and academic partners, Los Alamos National Laboratory and its Accelerator Operations Technology (AOT) Division, at the Los Alamos Neutron Science Center, are developing a potentially effective countermeasure against antiship cruise missiles and other threats by using free-electron lasers (FELs). Because an FEL’s photons—the concentrated particles of light composing the laser beam—have the potential to be powerful enough to destroy cruise (and ballistic) missiles many miles away, FELs are called the Holy Grail of military lasers.

Researchers at AOT recently built and successfully tested an advanced injector—a key FEL component—that produced a beam of electrons powerful enough for a megawatt-class (one million watts) antimissile FEL weapon. In an FEL, the electrons are produced in an electron injector and injected into a particle accelerator, which kicks them up to fantastically high energy levels. “We accelerate the electrons through a series of radio frequency (RF) cavities, known as RF accelerators, to almost the speed of light. The resultant energy of the electrons ranges from tens of millions to hundreds of millions of electronvolts,” says Dinh Nguyen, who co-leads the Laboratory’s FEL research team. These electrons are used to create the high-powered photons that



AOT’s photoelectron injector in its laboratory at LANSCE. This first-of-a-kind injector has the potential to generate electron beams with the requisite brightness and average current to drive high-power megawatt FELs. Because the laser power of an FEL is not amplified with a solid, liquid, or gas, there is no waste heat that is generated or absorbed, meaning that there are no large heat-management issues to mitigate onboard a ship.



AOT's photoelectron injector is an essential component of the FEL the Boeing Company is building for the Navy. A schematic of the injector is pictured here. This injector can operate continuously, meaning the FEL can fire continuously and destroy multiple targets. An FEL can theoretically be increased in power from 10 kilowatts to 1 megawatt without increasing the size of the system. The FEL's power can also potentially be scaled up from 1 to many megawatts. –Dinh Nguyen

make up the precise and concentrated beam of light of the FEL. "Our injector increased the electron beam current by a factor of 10 over what was previously demonstrated. A megawatt FEL is no longer theoretical."

This is "a major leap forward for the [FEL] program," says Quentin Saulter, the ONR's FEL program manager.

Game Changing

"You need megawatts of laser power to destroy a cruise missile," says Nguyen. "The laser kills with heat. Extreme heat destroys the missile's mechanics and electronic guidance systems, making it aerodynamically unstable so it tumbles wildly out of control. Extreme heat can also ignite the missile's fuel, causing it to explode. But there's not much time to heat up a missile. You need a tremendous amount of heat, like that from a megawatt laser, and a beam several feet in diameter to cook something like a missile that quickly." He adds, "Imagine being able to use a 'super blowtorch' to destroy something that's miles away…"

Unlike other weapons, an FEL can fire continuously. "It's like having a gun that never runs out of ammunition," says Nguyen. There would be no reloading between shots. In the laboratory, FELs have operated continuously and reliably 24 hours a day—for months. FEL technology allows destruction of multiple targets at the speed of light, all day and all night.

> *No wonder the FEL is described by the ONR as "game changing."*

The FEL is an ideal countermeasure for ships because its beam can be optimized for varying atmospheric conditions at sea. For example, substances in the atmosphere—particularly water vapor, but also smoke, salt particles, dust, pollen, and other pollutants—absorb and scatter light.

At sea, absorption by substantial amounts of water vapor is a particular problem for lasers. The problem of light absorption increases as the distance the light travels increases, reducing a laser's effectiveness against distant targets.

Yet, there are wavelengths of light in the electromagnetic spectrum where light absorption by water vapor is markedly less, creating a window in the vapor for the light to pass through. These windows change along with atmospheric changes. Current non-FEL missile-defense laser technology is hampered because these lasers have fixed wavelengths; if a beam's wavelength matches that of the water vapor, there is no window: the laser is absorbed. Because these conventional lasers operate at only specific, fixed wavelengths, they cannot be adjusted to compensate for atmospheric changes.

FELs overcome these problems because they can be operated at different wavelengths. Indeed, FELs have the widest frequency range of any type of laser. This means FELs' wavelengths are tunable—they can be changed, in essence, by the turn of a dial. If an FEL's operators know the wavelengths that will become attenuated in the atmosphere, they can adjust the FEL's wavelength to a different wavelength. By finding the window, the FEL's beam of light travels longer distances.

In addition, the power of the FEL can also be adjusted, meaning the beam can be dialed in for "graduated lethality" as missions change. A less powerful beam can be used for purposes such as communications, a more powerful beam for countering the enemy's optical systems, and an even more powerful beam for destroying small ships or aircraft.

The development of FELs could lead to significant changes in naval tactics, ship design, and the overall types of ship-based weapons—together these would mean a radical technological shift for the Navy. No wonder the FEL is described by the ONR as "game changing."

Energy Efficient and Cost Effective

FELs would not be as big a drain on a ship's electrical energy as other types of lasers are, a boon because ships need that energy for propulsion and the operation of other weapons systems. This energy saving is because conventional lasers rely on a solid (such as glass or a crystal) or a gas as the "gain medium." The gain medium is the material lasers use to amplify their power. The FEL is unique because it uses a completely different technology to produce its beam of light. It uses accelerated unbound electrons ("free" electrons) as its gain medium. The electrons are created by a photocathode inside an injector—a photoelectron injector—and are then injected into the particle accelerator. "The photoelectron injector was invented at Los Alamos," explains Nguyen. "Electrons make a high-gain medium, which makes a powerful FEL possible. Using this technology, it becomes feasible to amplify 1 watt to 1 megawatt!" These waves of electrons, traveling at the speed of light inside the accelerator undulate between a series of alternating magnets, which causes the electrons to emit the powerful beams of photons.

The Navy estimates the "cost per shot" of a laser at less than a dollar: missiles used for ship defense cost $800 thousand up to $15 million dollars each.

After a small fraction of the electrons' energy is converted into laser energy, the electron beam is recycled through the accelerator. The electrons are decelerated, and the energy they release is deposited inside the accelerator (called energy recovery); these electrons are then "dumped." A new beam of electrons is injected into the accelerator and accelerated, using largely the deposited energy from the previous beam. The new beam passes through the alternating magnets to create another powerful beam of photons; it too is then recycled back through the accelerator, and the energy recovery process starts again. Once it is running, the FEL is like a battery: an energy storage system that needs only a bit of recharging to stay full. Operating in this energy recovery mode significantly increases the FEL's efficiency.

The Navy estimates the "cost per shot" of a laser at less than a dollar: missiles used for ship defense cost $800 thousand up to $15 million dollars each. Compared with conventional antimissile weapons systems in deployment, the FEL would be the most efficient and the most cost-effective.

Winning Tomorrow's Battles

Because of LANL scientists' expertise and innovations in accelerator science, and because of their access to a high-powered accelerator and its infrastructure, the members of the FEL team provide the science and technology behind the FEL program's injectors, accelerators, and amplifiers. Their contribution to the final engineering design of the prototype FEL system is expected this spring. The next phase for the Boeing-led FEL program's collaborators is to build and assemble a full-power prototype. The prototype will be assembled and tested at LANL.

"We are winning the battles of the future in the laboratories of today," says ONR's Saulter. "If we do the investments now, if we do the science, if we do the engineering, then our future is secure."

–Octavio Ramos Jr.

To see the Office of Naval Research's video regarding FEL development, go to Youtube: *http://www.youtube.com/watch?v=fWdGkb7r1iA)*

The Air Force class in Advanced ICBM Operations in November 2011 is shown gathered in front of the National Security Sciences Building at LANL. The course was redesigned with input by captains McKnight (front row, left) and Valdivia (front row, center). Dr. Christopher T. Yeaw (center row, left) is the chief scientist for the Air Force Global Strike Command (Barksdale Air Force Base, LA). The command is responsible for organizing, training, equipping, and maintaining all ICBM and nuclear-capable bomber forces. Yeaw is responsible for organizing, training, equipping, maintaining, and preparing the Global Strike Command's activities in the sciences and technology. Jon Ventura (center row, right) is an advisor to the course and is LANL's point of contact for the program.

LANL and the Air Force: Partners in Excellence

Two serious incidents alerted the Department of Defense to the Air Force's need to drastically improve its handling of nuclear weapons and nuclear weapons-related materiel. In 2006, four non-nuclear nose cone assemblies and their associated electrical components for an intercontinental ballistic missile (ICBM) were mistakenly shipped to Taiwan. In 2007, an Air Force B-52 bomber, based at Minot Air Force Base (AFB) in North Dakota, unwittingly flew to Barksdale AFB in Louisiana with six cruise missiles onboard armed with nuclear warheads.

The ensuing investigations revealed a serious erosion of focus, expertise, mission readiness, resources, and discipline in the Air Force's nuclear weapons enterprise. In June 2008, Secretary of Defense Robert Gates appointed the Task Force on Nuclear Weapons Management, headed by former Secretary of Defense James Schlesinger, to recommend necessary improvements and the measures needed to reinvigorate the Air Force's nuclear weapons enterprise. This would, in addition, restore and reinforce international confidence in the United States' ability to manage its nuclear deterrent.

In September 2008, the Task Force frankly reported on the issues and challenges confronting the Air Force's management of its nuclear responsibilities. One of the Task Force's many recommendations was "that Air Force personnel connected to the nuclear mission be required to take a professional military education course on national, defense, and Air Force concepts for deterrence and defense."

Course in Advanced ICBM Operations

To help meet this recommendation, the Air Force charged the Twentieth Air Force at F. E. Warren AFB in Wyoming—one of three U.S. AFBs that maintain and operate the nation's Minuteman III ICBMs—to redesign the Air Force's Advanced ICBM Operations Course.

"This redesigned course would take our missileers [missile combat crew members] beyond their operational and tactical training and get them trained to think at the strategic level," says Captain Michael Valdivia, one of the instructors the Twentieth Air Force tasked to lead the course redesign. "They need to experience the entire nuclear weapons enterprise—from weapons theory, science, and production to the mechanics of how the weapons work. They also need to understand the U.S. policy of deterrence and how it works. And they need to understand how, in the absence of nuclear testing, the nation's nuclear stockpile—the weapons they're responsible for launching—is kept safe, secure, and effective. In other words, they need to know how and why the nation's Stockpile Stewardship Program [SSP] is successful."

Training Nuclear Professionals

In March 2011, Valdivia and Captain Thomas McKnight (who assists Valdivia) contacted Lieutenant Colonel Michael Port at Los Alamos National Laboratory. Port was on an Air Force fellowship at the Laboratory to gain a working knowledge of nuclear weapons architecture and of the Department of Energy's weapons-complex operations. The captains asked Port if he would inquire if Los Alamos would support a series of trainings for the redesigned course on nuclear weapons–based deterrence and stewardship that would be offered to junior officers (lieutenants and captains).

Los Alamos is a natural choice for providing the Air Force with this specialized education and training for two reasons. The Laboratory is the design agency for the Air Force's B61 nuclear gravity bomb and W78 nuclear warhead systems. In addition, one of the Laboratory's core missions is to use its unique scientific and technological capabilities in support of the SSP.

"To do their jobs better, our missileers need to understand and appreciate more about the business they're in," says Captain McKnight. "We are taking the sharp edge of the sword and giving it an appreciation of the whole blade, hilt and all, how it is wielded and maintained, who forged it, and why its existence is crucial to national security."

LANL's Principal Associate Director for Weapons Programs Bret Knapp readily agreed to the request. "We're the perfect partners for the Air Force. We have the resources they need to help their officers broaden their perspectives and become nuclear professionals."

Since March 2011, LANL has hosted 5 different daylong classes with approximately 20 officers per class. (Three additional classes are scheduled for 2012.) The classes involve a series of briefings on the science and technology the Laboratory uses for weapons design and the SSP. Tours are given of key LANL facilities, such as the Laboratory's Technical Area 55, with its plutonium science and

The staff at Malmstrom AFB explained key aspects of Minuteman ICBM missile maintenance to LANL staff members. A tour offered to LANL staff members gave them a chance to experience the tight, underground working environment of an ICBM launch silo. Here, Staff Sergeant Joshua Beatty explains the ins-and-outs of entry to a missile launch silo. Malmstrom AFB operates and maintains 150 Minuteman III ICBM launch silos that are spread throughout the 13,800 square-mile missile complex.

manufacturing facilities; the Los Alamos Neutron Science Center (which includes, for example, proton radiography, whereby a high-energy proton beam images the properties and behavior of materials driven by high explosives); the Laboratory's explosives research facilities; the Sigma Complex (which includes prototype fabrication and materials research for the weapons program, threat reduction, and homeland security work); and the Dual-Axis Radiographic Hydrodynamic Test facility (where multiple x-rays produce multiple-view radiographs of the detonation of full-scale mockups of nuclear weapons without their nuclear components).

By the end of the day, the officers have a first-hand understanding of and deeper appreciation for the science behind the nuclear weapons enterprise.

"The officers get to see the most amazing science and engineering. Their training at LANL is the best part of the two-week course," says Valdivia, "It's the capstone."

"It really gets the officers reblued [motivated]," says McKnight. "When they get back to their base, they've got the big picture—they 'get' the nuclear enterprise and how they, as nuclear professionals, fit into it. They also pass their excitement and knowledge on to their peers. They tell them, 'You've got to take this course!'"

It's a Two-Way Street

The designer and the user can learn from each other. LANL recognizes the value of learning from the experiences and perspectives of the officers and enlisted personnel in the Air Force—the professionals who use LANL's designs. LANL's staff members need to see their designs deployed in the field,

Staff Sergeant Joshua Beatty describes to LANL staff members how the 125-ton concrete door (on the left) that seals a Minuteman missile silo normally operates. During a missile launch sequence, this massive door, which is mounted on rails, is instantly blown with explosives down the rails to over 100 yards away from the silo, thereby ensuring a safe and successful ICBM launch.

meet the users, and learn the challenges users face in maintaining and operating the nation's nuclear deterrent and in keeping it safe.

In November, with the support of Air Force's Global Strike Command, the Laboratory sent 10 staff members from key weapons directorates to tour the Malmstrom AFB in Montana. Malmstrom (like F. E. Warren and Minot) also maintains and operates the Minuteman III.

During the three-day visit, LANL staff members witnessed a number of training activities, including crew preparations for manning Minuteman missiles in the field, nuclear warhead maintenance activities, missile handling and transport, and security protocols. Malmstrom's officers and enlisted personnel answered questions, offered suggestions that might enhance weapons systems sustainability, and raised questions of their own, for example, about the science of weapons reliability, aging, and other challenges in stockpile stewardship.

"They were clearly engaged and interested," says Brian Lansrud-Lopez of LANL's Experimental Theoretical Design Division, Air Force Systems Group. "We received several penetrating questions that were illuminating and that gave us a better appreciation for the Air Force personnel's perspectives and their curiosity about the science of weapons design and stewardship. This kind of interaction is essential to fostering institutional respect and personal trust across the nuclear weapons enterprise.

"I was enormously impressed with the discipline and professionalism that are clearly visible in all aspects of nuclear weapons activities at Malmstrom. I witnessed the dedication and enthusiasm that everyone brought to their maintenance, operation, and security duties," Lansrud-Lopez continues. "They gave me tremendous confidence in our deterrence and earned my respect."

The Malmstrom tour gave LANL staff the information and perspectives they need to do their jobs better and a real appreciation for the jobs and challenges faced by the men and women of the Air Force. "This field experience adds a level of gravity to my job—as a weapons physicist—that no number of successful computational simulations could produce," says Lansrud-Lopez.

Additional visits to other Air Force bases are planned for 2012.

–Clay Dillingham

Will South Korea Develop a Nuclear Capability?

The Alliance is Changing

NATO's Evolution in the Post–Cold War World

Assessing Current Multilateral Nuclear Approaches for Nonproliferation

National Security Office

INTERNS

Explore the National Security Environment

Los Alamos National Laboratory is home to the National Security Office, where interns learn about and gain experience in the national security science and policy realms that dovetail with the Laboratory's national security mission.

The National Security Office (NSO) at Los Alamos National Laboratory (LANL) supports the Laboratory director and other senior management in meeting LANL's national security mission by providing advice, strategic planning, guidance, and more. NSO provides the interface needed between national and international security policies and the scientific and technical capabilities used to address those policies.

For example, working with LANL's national security and science programs, the NSO monitors and studies global scientific, technical, and policy environments. NSO also maintains relationships with U.S. national security policy makers in the Departments of Defense, Energy, and State; the U.S. intelligence community; other national laboratories; and important academic and nongovernmental institutions.

To help provide the expert analysts needed for national security in the future, the NSO, directed by Bryan L. Fearey, provides internships for undergraduate and graduate students. NSO interns learn about and gain experience in the national security science and policy realms that dovetail with the Laboratory's national security mission.

The following three articles provide examples of the kinds of research and real-world experiences undertaken by NSO's interns.

Ariana Rowberry

The Alliance Is Changing: NATO's Evolution in the Post–Cold War World

While working with the Los Alamos NSO for the past two years, I conducted research on the evolution of the North Atlantic Treaty Organization (NATO). Formed in 1949, NATO served as a transatlantic military alliance, providing collective defense against the threat posed by the Soviet Union and the Warsaw Pact. With the end of the Cold War in 1991, NATO's traditional role effectively ended. No longer did a unifying threat exist for NATO. Recognizing that the risk of an attack on NATO territory after the Cold War was at a historical low, the alliance adapted to the new global security environment. This adaptation resulted in NATO's focusing its resources outside of the European periphery through engagement in out-of-area missions.

For the past 20 years, involvement in out-of-area missions has increasingly been NATO's paradigm. NATO has conducted four large out-of-area missions to date: Operation Deliberate Force in Bosnia-Herzegovina in 1995; Operation Allied Force in Kosovo in 1999; the mission through the International Security Assistance Force in Afghanistan in 2003; and most

Uruzgan, Afghanistan—An International Security Assistance Force soldier provides security in a village while children swarm around him in hopes of getting a small treat.
—Mass Communication Specialist 1st Class John Collins, U.S. Navy

recently, Operation Unified Protector in Libya beginning in 2010. Each operation has provided NATO with the opportunity to adapt to a new security environment and evolve as an alliance.

Although out-of-area missions have provided NATO with purpose beyond the Cold War, these missions have paradoxically placed the alliance in a vulnerable position.

There have been six Strategic Concepts produced throughout NATO's history, three of these after the end of the Cold War: in 1991, 1999, and 2010. A Strategic Concept outlines NATO's enduring purpose and fundamental security tasks. The North Atlantic Council, the principal political decision-making body within NATO, adopts a new Strategic Concept when the security environment has changed substantially enough to warrant a reexamination of NATO's mission. The post–Cold War Strategic Concepts reveal an increased emphasis on crisis management and prevention. The 2010 Strategic Concept globalizes NATO's definition of collective security and affirms its commitment to "analyze the international environment to anticipate crises and, where appropriate, take active steps to prevent them from becoming larger conflicts."

Although out-of-area missions have provided NATO with purpose beyond the Cold War, these missions have paradoxically placed the alliance in a vulnerable position. Out-of-area missions have unveiled a political stratification within the alliance. During the Cold War, member states easily rallied around one clear adversary: the Soviet Union. Today, the security environment is more diverse, and the world order is multipolar, meaning there are multiple states that hold economic and political power. The way one NATO member state perceives a potential threat may not match the way another member perceives it. These incongruent perceptions have made engagement in out-of-area missions contentious within the alliance, resulting in problems with acting collectively.

NATO provides the public good of globalized security through its engagement in out-of-area missions, meaning that the security provides benefits for all member states. However, each member state has a contrary incentive to preserve its resources and not contribute to out-of-area missions, with the assumption that other member states, who may place a higher value on conducting these missions, will contribute more. A member state is more likely to contribute to NATO missions when its negative externality is large, that is, when the member state does not have to pay the full cost of its participation. Conversely, member states are less likely to contribute when their negative externality is small.

Each member state has a contrary incentive to preserve its resources and not contribute to out-of-area missions, with the assumption that other member states, who may place a higher value on conducting these missions, will contribute more.

U.S. Marines are briefed in the well deck of the amphibious transport dock ship *USS Mesa Verde*, as the Bataan Amphibious Ready Group deploys to support U.S. and international efforts off the coast of Libya in the Mediterranean Sea in support of Operation Unified Protector. -U.S. Navy photo by Seaman Josue Escobosa/Released

While it is logical and fair that member states with great economic power, such as the United States and the United Kingdom, contribute a higher amount to out-of-area missions, there are still examples where burden sharing, with a more equitable contribution of resources within NATO, should be improved within the alliance. For instance, the United States has, thus far, exhibited its willingness to absorb the majority of the cost for out-of-area missions because of its economic capabilities. When President Obama handed control of Operation Unified Protector in Libya from the United States to NATO, it was up to the European members to decide how to best resolve economic and other collective action problems. This transition signifies a new chapter in the alliance's future.

Last summer, while I was on a university study-abroad program, the NSO presented me with the opportunity to visit NATO Headquarters in Brussels, Belgium. There I had the privilege of interviewing several key NATO figures, including Diego Ruiz Palmer, head of planning, and Jamie Shea, the deputy assistant secretary general for emerging security challenges.

I concluded that NATO's ability for long-range commitments to current or future out-of-area missions is likely unsustainable.

After my visit, I concluded that NATO's ability for long-range commitments to current or future out-of-area missions is likely unsustainable. My conclusion comes from observing that, while the future security environment cannot be predicted, it is unlikely that NATO will have the resources for future operations that would allow it to pursue out-of-area missions at levels comparable to those in Afghanistan and Libya. This lack of resources is, in large part, due to the limitation of NATO's fiscal resources and its political will to expend them, which is a function of the complexities inherent in an alliance of 27 nations that no longer face a common adversary.

As NATO moves forward, it should consider undertaking internal reforms that increase transparency and dialogue between and among member states to reduce current political stratification. Externally, NATO should also seek, depending on the specific mission, to more effectively coordinate efforts with international and regional organizations such as the United Nations, the Organization for Security and Cooperation for Europe, and the Arab League. Furthermore, NATO should look to use its resources in a more economical manner, engaging in out-of-area missions that require fewer resources and are more widely agreed upon by NATO members. For example, the 2010 Strategic Concept outlines that NATO could have a role in addressing nontraditional security threats in the future, including cyberterrorism and energy insecurity.

With its unique membership and comparative advantage in conventional military forces, NATO is the only alliance of its kind in the world. NATO has demonstrated through its involvement in out-of-area missions that it is able to effectively engage in international crises. Because of its unique set of capabilities, it is in the security interest of both the United States and the international community to invest in NATO's mission.

Ariana Rowberry is a junior at the University of North Carolina-Chapel Hill, studying political science and peace, war, and defense.

Emily Cura Saunders

Will South Korea Develop a Nuclear Capability?

The United States offers security guarantees to several countries; in some instances these are formal and tested alliances such as NATO, in others they are more implicit understandings. As a graduate research assistant at the NSO, I focused on the topic of security guarantees, sharpening such a broad topic by looking at nuclear security guarantees in Northeast Asia.

Through two different legally binding treaties, the United States is obligated to come to the defense of both the Republic of Korea (ROK)—South Korea—and Japan, should they be attacked. These treaties include a concept known as extended deterrence. Through extended deterrence, the United States extends the benefits afforded by its nuclear deterrent to key allies. This has been a centerpiece of U.S. foreign and defense policy for decades. Therefore, the U.S. commitment to defend the ROK and Japan is underlined by a nuclear security guarantee. While neither treaty explicitly states that the United States would use nuclear weapons in the event of a crisis, it does not rule out this option. This unwritten aspect of U.S. defense commitment is seen as essential by both of these U.S. allies.

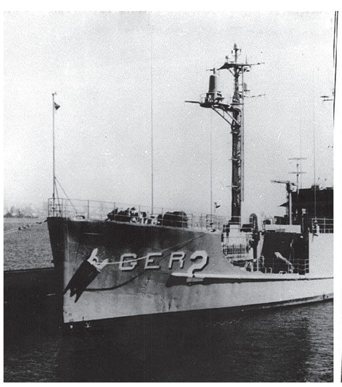
Extended deterrence extends U.S. nuclear capability to key allies. It has been a centerpiece of U.S. foreign and defense policy for decades. Therefore, the U.S. commitment to defend the ROK and Japan is underlined by a nuclear security guarantee.

There is much speculation that these nuclear security guarantees are part of what has kept the ROK and Japan from pursuing nuclear weapons programs of their own. In recent years, various U.S. administrations have reduced both the role and number of nuclear weapons in the U.S. defense posture. These reductions have made some countries covered by the U.S. nuclear security guarantees question the strength of the U.S. nuclear commitment. The question is this: Are there red lines that the United States nuclear posture cannot cross before states under the security guarantee believe it is in their best interest to develop an independent nuclear deterrent?

Two variables that could affect whether a country pursues nuclear-fuel-cycle technology (spent-fuel reprocessing and enrichment) in the hope of hedging an independent nuclear deterrent are the loss of confidence in the U.S. commitment to nuclear extended deterrence and extreme regional security threats. It is useful to turn to history to examine these variables and their effects on a country's proliferation activities in the form of nuclear-fuel-cycle expertise, nuclear weapons development, and policy rhetoric. The ROK is an interesting case study because it illustrates the complexity of U.S. extended deterrence commitments.

The ROK and the United States signed a Mutual Defense Treaty in 1953, right after the Korean War armistice. Just three years later, the United States reportedly introduced nuclear weapons on the Korean Peninsula. While there was no mention of nuclear weapons in the treaty, their physical presence would certainly demonstrate the U.S. commitment to its extended deterrence obligation. With nuclear weapons possibly on the peninsula and a major U.S. troop commitment, the assumption was that the ROK would not feel compelled to attempt an independent nuclear deterrent. Nevertheless, in the 1960s, the ROK began nuclear-fuel-related experiments. What were the circumstances in which the ROK felt it needed to begin these experiments?

As is the case today, in the 1960s the Democratic People's Republic of Korea (DPRK)—North Korea—often provoked the ROK. There were assassination attempts on the ROK president and several other terrorist acts such as capturing



USS Pueblo incident. The *USS Pueblo* was a Navy technical research ship gathering intelligence on North Korea. On January 20, 1968, North Korean military vessels fired on the ship in international waters (killing a crew member), then boarded, and captured it. Crew members (82) were held captive and tortured for 11 months, then released in December 1968. The *USS Pueblo* is still held by North Korea and is used as a tourist attraction. It remains in active commission and is the only U.S. naval vessel in captivity. –U. S. Navy

Secretary of State Hillary Rodham Clinton and Defense Secretary Robert Gates look toward North Korea from a guard post in South Korea's Camp Oulette in the demilitarized zone. –U.S. Army

the *USS Pueblo*, armed guerrilla infiltrations, and shooting down a U.S. EC-121 reconnaissance plane. The DPRK is pursuing similar provocations today.

Are there red lines that the United States nuclear posture cannot cross before states under the security guarantee believe it is in their best interest to develop an independent nuclear deterrent?

The regional security issues were further exacerbated by the fact that the ROK was quickly losing faith in the United States' capability to protect it. With a major war then going on in Vietnam, President Nixon created a doctrine calling for more military independence by Asian countries under U.S. protection. In 1970, Secretary of State William Rogers notified South Korea that the U.S. planned to withdraw approximately 20,000 troops. In August of that year, Vice President Spiro Agnew went further, indicating the United States would withdraw U.S. military forces completely over the next five years. The threat of these troop withdrawals confirmed the ROK's fear of abandonment. Such a drastic drawdown certainly triggered the ROK into looking into developing an independent nuclear deterrent.

With all of these factors bearing down on the Park Chung-hee administration, in 1970, President Park established the Agency for Defense Development and the Weapons Exploitation Committee. This committee was expected to produce or acquire nuclear weapons systems and military supplies. Three years later, ROK's nuclear weapons program was well underway, with nuclear research teams and efforts to obtain nuclear reprocessing plants, associated core designs, and additional nuclear technologies from France.

Smoke rises from South Korean Yeonpyeong Island after being hit by dozens of artillery shells fired by North Korea on November 23, 2010. This was one of the heaviest bombardments on South Korea since the Korean War armistice in 1953. –Reuters/Yonhap

It appears that the ROK attempted to develop nuclear-fuel-cycle technology, explore weapons development, and acquire military supplies at a time when the DPRK was particularly provocative and when the United States was preoccupied with a war in Vietnam. Could these factors again compound to inspire the ROK to attempt to develop nuclear-fuel-cycle technology today? If they did attempt this, they could do so in full compliance with the International Atomic Energy Agencies safeguards, but would this be viewed as an attempt at developing an independent nuclear deterrent by the United States or by the international community? How acceptable would these actions be to the United States, which provides the nuclear umbrella over the ROK? What could the United States do to curb potential proliferation activities, bolster the confidence of the ROK, and apply diplomatic pressure?

These are all worthwhile questions that I plan to examine in greater detail at LANL as part of my doctoral dissertation work. The Laboratory's NSO provides an exceptional opportunity to do this kind of research. For example, one of the most fruitful experiences I had at LANL occurred outside the walls of the Laboratory. My mentor, Bryan Fearey, director of NSO, brought me to the Pentagon in July. Over the course of seven meetings, I was able to speak to high-level officials about these very important questions. The knowledge and unique insights these policy makers shared with me is absolutely invaluable in terms of both my general curiosity and for my doctoral research.

Emily Cura Saunders is a Ph.D. student in political science at Claremont Graduate University's School of Politics and Economics where she studies public policy and comparative politics. She was recently honored as a selectee to the Center for Strategic and International Studies Project 2012 Nuclear Scholars Initiative.

Peter Hong

Assessing Current Multilateral Nuclear Approaches for Nonproliferation

While interning with the NSO, I studied the viability of and prospects for efforts to establish multilateral nuclear approaches (MNAs). MNAs broadly describe proposals to place parts of the nuclear fuel cycle under multilateral control to reduce the risks of proliferation of nuclear weapons. The proposals seek to achieve two key, linked goals: guarantee states a source of fuel and incentivize states to not pursue fuel enrichment or reprocessing capabilities.

While MNAs will not prevent nuclear proliferation by states determined to seek nuclear weapons, MNAs could help other states resolve energy security problems.

For example, supporters reason that multilateral control of the nuclear fuel enrichment process (part of the "front end" of the nuclear fuel cycle) may persuade states not to pursue their own indigenous uranium enrichment capability. This capability enables states to produce fuel for peaceful uses as well as for nuclear weapons.

MNAs can best achieve their assurance and nonproliferation goals if the widest possible group of states finds the MNAs credible.

While MNAs will not prevent nuclear proliferation by states determined to seek nuclear weapons, MNAs could help other states address concerns about energy security problems. Yet MNAs have gained little traction, partly due to mistrust between the advanced nuclear states sponsoring MNAs and the nuclear entrant states encouraged to adopt MNAs.

Current MNAs

Despite the lack of progress, MNA interest was spurred by a 2005 report from the International Atomic Energy Agency Expert Group (that included representatives from 26 countries) that examined the nuclear fuel cycle and suggested several multinational approaches to strengthen controls over sensitive nuclear materials and technologies. Its findings brought forth new MNA proposals. Renewed attention on MNAs is also in response to an expected growth in interest in nuclear energy (albeit tempered by the Fukushima disaster). These recent proposals range from creating multilateral fuel reserves (fuel banks) to establishing enrichment, reprocessing, disposal, and storage facilities under multilateral control. Demonstrating a credible and assured multilateral fuel supply could convince these states that domestic, self-controlled sensitive-fuel-cycle technology is not necessary for achieving their long-term energy security goals.

Significant Ambiguities

However, I discovered that many of these recent MNA proposals contain significant ambiguities that do not guarantee credible and assured fuel access to states. A lack of detailed criteria on the use of fuel reserves to limit fuel supply disruptions, on arrangements for fuel fabrication, and on ways to avoid negatively affecting the commercial nuclear fuel market are just a few of the major uncertainties in recent MNAs. Addressing these missing details is essential to convince states to rely on a multilateral fuel arrangement instead of on indigenous enrichment or reprocessing. In addition, none of the current MNAs propose solutions for managing spent nuclear fuel (the "back end" of the fuel cycle). Yet solutions to the back end may be important for MNA adoption. First, the back end ignites contentious debates within nearly all states working toward setting a national policy on spent fuel disposition. Second, no permanent commercial or multilateral spent-fuel alternative solution currently exists. Clearly, establishing a back-end solution in an MNA is extremely difficult.

Unique Opportunities

For students interested in nuclear nonproliferation and arms control policy, Washington, DC, is thought to be the only logical "policy" destination. As an undergraduate interested in nonproliferation policy, my research at the NSO challenges this notion. The NSO gave me an experience marked with unique resources, access to nonproliferation-policy experts resident at the Laboratory, and critical insights. This facilitated my research in nonproliferation initiatives and gave me a newfound, deeper understanding of MNAs. After spending time in Washington, I can conclude that few undergraduate policy experiences in Washington compare to the opportunities for growth I experienced at the Laboratory.

Peter Hong is a senior majoring in political science at Stanford University.

The Iranian nuclear power plant in Bushehr is the first civilian nuclear power plant built in the Middle East. Iran is striving to produce and enrich its own nuclear fuel, which could also be used to make a nuclear weapon. Recent MNAs include establishing nuclear fuel banks where nations could purchase, at the market price, reactor fuel for use in their power plants and not have to produce it themselves. Creating fuel banks is part of the global effort to stop the spread of nuclear arms to nations such as Iran and North Korea. –Reuters

Vice Chairman of the Joint Chiefs of Staff **Tours LANL**

Vice chairman of the Joint Chiefs of Staff Admiral Winnefeld (left) arrives at LANL by helicopter and is greeted by Principal Associate Director for Weapons Programs Bret Knapp.

Where does the vice chairman of the Joint Chiefs of Staff go when he wants to learn about the design and function of nuclear weapons and the science and engineering behind the nuclear weapons Stockpile Stewardship Program? The answer: Los Alamos National Laboratory.

Most Senior Military Officer to Visit LANL

Admiral James A. Winnefeld Jr. is the 9th vice chairman of the Joint Chiefs of Staff and the nation's second-highest-ranking military officer. As vice chairman, Winnefeld is the most senior military officer to visit the Laboratory.

Winnefeld is also the senior military officer on the Nuclear Weapons Council (NWC). The NWC provides both the Legislative and Executive branches of the government policy guidance and oversight of the nuclear stockpile management process to ensure high confidence in the safety, security, and reliability of U.S. nuclear weapons. To meet his new duties as vice chairman, Winnefeld asked to visit Los Alamos.

Classified Briefings

Winnefeld received a wide variety of classified briefings by the Laboratory's senior leadership, including Director Charlie McMillan and Principal Associate Directors Bret Knapp and Terry Wallace.

"Our task was to demonstrate that LANL's scientific and engineering capabilities will continue to provide the admiral, the Joint Chiefs of Staff, and the NWC with the information they need to keep the nation secure," McMillan said.

Laboratory Director McMillan and Admiral Winnefeld stand before the Laboratory's Army-Navy "E" Award flag in the Los Alamos Weapons Conference Center. The "E" Award was presented to Los Alamos in1945, in honor of its work on the Manhattan Project. During World War II, the "E" Award was presented to organizaions for excellence in the production of critical war equipment.

LANL's New Blue Room

The Blue Room is a classified room where models of weapons are on display for use in classified briefings by the Weapons Program. It incorporates modern visualization technologies to assist in briefing distinguished visitors on the Laboratory's contributions to the nuclear weapons enterprise.

In the Blue Room, the director briefed Winnefeld on the designs and functions

Dane Spearing (right) briefs Director McMillan (left) and Admiral Winnefeld (center) at TA-55, the Laboratory's plutonium science and pit manufacturing facilities.

of nuclear weapons. He also briefed the admiral on LANL's plutonium-pit manufacturing for the W88, a warhead designed by LANL for the U.S. Navy and deployed on Trident II submarines. McMillan then described to the admiral LANL's activities in support of the Life Extension Program (LEP) for the W76-1 (nuclear warhead) weapon system.

Principal Associate Director Knapp informed the admiral about LANL's support of the LEP for the B61-12 (gravity bomb) weapon system. This LEP received the NWC's approval to proceed to phase 6.3 on November 10.

Following these briefings, the admiral was given a tour of Technical Area 55 (TA-55), LANL's plutonium science and pit manufacturing facilities. At TA-55 he was further briefed on the W88 pit manufacturing process, and received other briefings on pit surveillance work and work on radioisotope thermoelectric generators (RTGs).

RTGs generate electrical power and heat from the radioactive decay of isotopes like plutonium-238. RTGs are commonly used as power sources in spacecraft, where low amounts of power and heat are needed for longer periods than batteries or other power sources can provide.

"It's an extreme honor to have had Admiral Winnefeld visit the Laboratory," McMillan said.