several years, he adds. "It's been known for a long time that new ways to detect neutrons would be desirable."

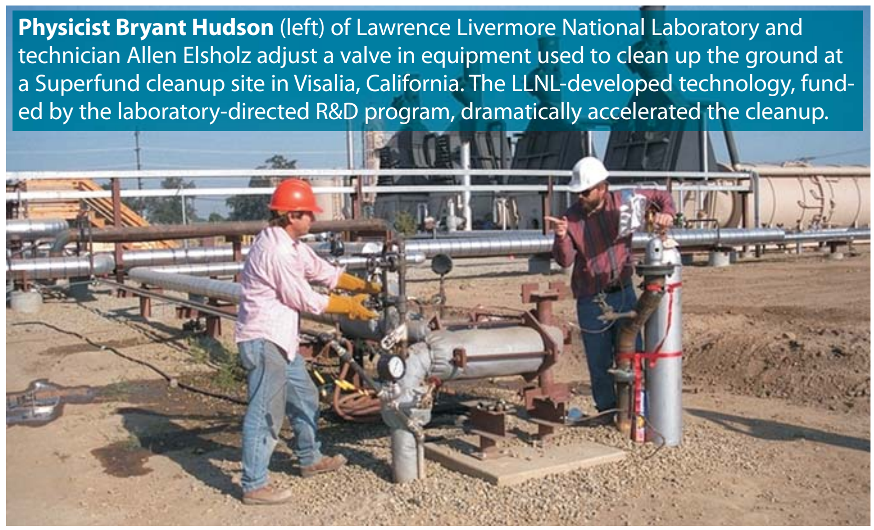
The interagency panel is also looking at ways to up tritium production. "We can try to increase the efficiency with which ^{3}He is extracted—that could lead to a 50% increase," says Steven Fetter, OSTP assistant director at large. Similar to the US situation, the Russian supply of ^{3}He seems to have been stanched, and so far nothing has come of the ideas of getting small amounts from tritium stored at the now-defunct reactors in Chalk River, Ontario, and from French and Chinese sources. Increasing the number of US reactors that produce tritium, an action being considered by the Obama administration, is too far off to be of near-term help.

"The government has been flat-footed here," says an expert who requested anonymity. Helium-3 fell through the cracks, he adds, "because NNSA produces ^{3}He as a byproduct. The [DOE] isotope program acts as a broker. Nobody had the responsibility, and now nobody wants it." But, he adds, "I am optimistic that within six months we'll be able to identify [a technology] that would be acceptable. If we don't run into obstacles—we might have a technical solution that may not be politically acceptable—we could have a solution ready to implement within a year."

Toni Feder

As weapons work slows, DOE labs keep busy with research

The laboratory-directed R&D program is a bright spot in a bleak outlook for nuclear weapons R&D.



Physicist Bryant Hudson (left) of Lawrence Livermore National Laboratory and technician Allen Elsholz adjust a valve in equipment used to clean up the ground at a Superfund cleanup site in Visalia, California. The LLNL-developed technology, funded by the laboratory-directed R&D program, dramatically accelerated the cleanup.

LAWRENCE LIVERMORE NATIONAL LABORATORY

Within the next several weeks, a four-acre site in Visalia, California, that had been brimming with creosote and other chemicals is expected to be formally removed from the Environmental Protection Agency's Superfund national priorities list, the rogues' gallery of the nation's most polluted sites. For 80 years Southern California Edison, the site's owner, had used its facility there to treat utility poles. Back in 1997, SCE had already been remediating the subsurface for 20 years with conventional processing, and it was looking at another 30–60 years to finish the job.

Then along came a technology invented by two geophysicists at Lawrence Livermore National Laboratory (LLNL) to clean up a decades-old gasoline spill on the lab grounds. Known as dynamic underground stripping, the new process dramatically accelerated the pace of contaminant removal from 10 pounds a week using conventional means to an astounding 46 000 pounds per week. The key was heat, in the form of steam injected through wells; vaporized creosote could then be vacuumed from adjacent wells. The Visalia cleanup was finished in about a year.

Fast forward to this year, when Sandia National Laboratories (SNL) announced that it is seeking an industrial partner to help advance its design for a small nuclear power plant. The lab's team leader, Thomas Sanders, touts the "right-sized reactor" that will produce between 100 MW and 300 MW of thermal power—compared with the 1000 MW or more that is typical of today's US commercial reactors. Offering features such as a 20-year refueling cycle and built-in alarm sensors to alert authorities to any fuel tampering, the reactor should be well-suited for the growing number of developing nations that aspire to nuclear energy. But it should also greatly reduce the potential for proliferation, Sanders and his team say. For around $250 million each, as many as 50 units a year could be manufactured in the US and then shipped and assembled onsite, they say.

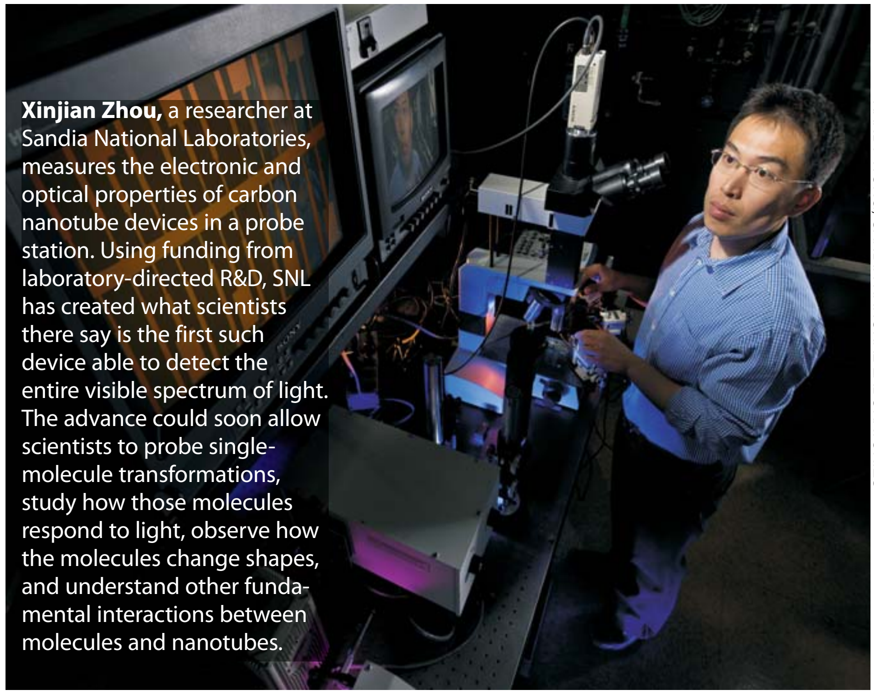
What the two disparate LLNL and SNL technologies have in common is their origin: The laboratory-directed R&D program, which allows the labs to choose how to spend a significant fraction—currently 8%—of their R&D budgets. Each of the US Department of Energy's (DOE's) multiprogram laboratories—weapons and civilian alike—have LDRD programs. But the three weapons labs, which also include Los Alamos National Laboratory (LANL), are especially reliant on the LDRD program to maintain proficiencies in basic research that lab and DOE officials say are vital to ensure a reliable and safe nuclear weapons stockpile and anti-proliferation programs.

"The LDRD enables us to conduct high-risk, potentially high-value research in areas that are foundational to national security," says J. Stephen Rottler, SNL's vice president for science, technology, and engineering.

"In a future with no nuclear testing, the nuclear deterrent relies on the scientific credibility and the agility of the staffs of the labs more than on the stockpile itself," says Duncan McBranch, principal associate director of science, technology, and engineering at LANL.

Declining budget at the NNSA

As recently as the 1990s, funding for high-risk research was built in to the labs' annual budgets from DOE's weapons programs. "In past decades, the size of the nuclear weapons budget allowed for a healthy amount of high-risk, long-term research at the weapons Laboratories, much of it growing out of, but diverging from, the core weapons-related capabilities," notes an external study of the weapons labs issued by the Henry L. Stimson Center in March of this year (see PHYSICS TODAY, April 2009, page 26). But nearly two decades without new weapons systems on the drawing board has taken its toll on the



RANDY WONG, SANDIA NATIONAL LABORATORIES

Xinjian Zhou, a researcher at Sandia National Laboratories, measures the electronic and optical properties of carbon nanotube devices in a probe station. Using funding from laboratory-directed R&D, SNL has created what scientists there say is the first such device able to detect the entire visible spectrum of light. The advance could soon allow scientists to probe single-molecule transformations, study how those molecules respond to light, observe how the molecules change shapes, and understand other fundamental interactions between molecules and nanotubes.

budget of the National Nuclear Security Administration (NNSA), the semi-autonomous agency in DOE that pays for the bulk of the labs' operations. Today, LDRD is the only major source of funding for high-risk, long-term research, Rottler told an audience at an August conference on the LDRD.

DOE officials are equally enthusiastic about the program. "LDRD has shaped the character of our labs more than anything except for the Manhattan Project," says David Crandall, the NNSA's chief scientist. He calls the LDRD funds an "extremely precious resource."

In early August, Energy Secretary Steven Chu asked for help from President Obama's scientific advisory council to rebuild basic research at the weapons labs. Until 2008, he told them, the three labs had been "on a 10-year glide path" that would have ended with a 50% cut to their NNSA-funded programs and a corresponding reduction in their LDRD. Although that spiral was arrested in its eighth year, no increases have materialized since. Today, just 51% of SNL's \$2.2 billion annual funding is from the NNSA, notes Rottler, down from the 75% share the NNSA provided just a decade ago. Most of the balance comes from other DOE programs and federal agencies such as the Department of Defense (DOD) and the Department of Homeland Security (DHS). The LDRD program ensures that those agencies help maintain the basic research capabilities of the labs.

A "critical funding source"

Jamileh Soudah, director of institutional and joint programs at the NNSA, says the agency has never made an explicit decision to exclude high-risk research monies. But, she adds, "In an era of declining budgets, the pressure of mission deliverables for both weapons and nonproliferation programs means that LDRD has become a critical source of funding for the labs to support their underlying research capability and explore new mission solutions."

On the bright side for the labs, the share of their overall budgets that they can devote to LDRD is the highest it's been since the program was first authorized by Congress in 1991. Since fiscal year 2006, the labs have tacked on an 8% LDRD surcharge to the rates they charge the NNSA, other DOE program offices, and other sponsors for the R&D they perform. Before that, the levy had been steady at 6%, except for 2000, when it dipped to 4%, reflecting lawmakers' concerns about alleged espionage. The threat of congressional meddling remains; in the bill that would provide FY 2010 funding for DOE, House appropriators have urged the NNSA "to devote a substantial proportion of their LDRD to countering threats not deterrable by threat of nuclear retaliation, and to seeking means to render deterrable those threats presently considered nondeterrable." Such instructions, of course, are contradictory to the intent of the LDRD program.

The \$166 million LDRD program at SNL for FY 2010 will finance more than 400 projects, says Rottler. The LANL program totaled \$127 million in FY 2009, says McBranch. LLNL, which has the smallest program of the three labs, is providing \$85 million for LDRD in FY 2010, down from \$91.5 million in FY 2008. Its program backs about 200 projects ranging in size from \$50 000 to \$2 million. Although the labs' annual solicitations for LDRD proposals are typically oversubscribed to the tune of 10 proposals for every project funded, lab managers and DOE officials alike agree that the program is currently about the right size. But Soudah cautions that the program can't be expected to fully sustain the necessary capabilities and infrastructure the labs need.

Recruiting new scientists

The LDRD program also is considered crucial to providing a challenging scientific environment that will lure young scientists and engineers into the labs. Chu himself has warned that low budgets have created "a bit of a bind" for the labs as they try to recruit new talent.

In FY 2008 more than half of the three labs' postdocs—89 of 119 postdocs at LLNL, 212 of 342 at LANL, and 93 of 168 at SNL—were brought in to work on LDRD projects, and 71% of the postdocs hired full-time were supported by the program, says Soudah. Further measures of the LDRD's merit are its 35% share of all the patents issued to the labs and its claim to 25% of the labs' peer-reviewed publications. One very large project at LLNL has produced 50 articles, including four covers, and yielded one patent, two patent applications, and two more applications in the works.

Of *R&D Magazine*'s coveted R&D 100 awards received by the three labs, LDRD projects capture a remarkable 60%. One prize winner, developed at LANL, is a magnetic resonance imaging technology that operates with far weaker magnetic fields (1 μT–100 mT) than does conventional MRI. At such ultralow fields, protons resonate at a frequency that overlaps with the most interesting and unexplored areas of molecular dynamics and biological processes, explains Petr Volegov, a principal investigator on the project. LANL has initiated a follow-on LDRD project to image the structure of the brain and to package the technology with functional, real-time measurements of the cognition process, Volegov says. Besides reducing the expense and increasing the portability of medical MRIs, the low-field system could operate in the presence of shrapnel and other metal, an important consideration for emergency-room and battlefield use. The lab has produced a working prototype and is holding preliminary discussions with several companies on commercializing the technology.

McBranch says that LANL's MRI technology found its way into an application that couldn't have been foreseen at the project's outset: A prototype system deployed at the airport in Albuquerque, New Mexico, to screen carry-on luggage has been able to discriminate potentially dangerous liquids from benign ones. The lab boasts that its "MagViz" system could make current travel restrictions on liquids obsolete.

Modeling a cleanup

Roger Aines, one of the inventors of the LLNL process used to clean up the Visalia pole yard, credits the LDRD with financing the development of models predicting how the toxic pollutants move through the ground. A second LDRD project at the lab provided the basic chemistry that produced the process that cleansed groundwater at the site. The cleanup processes have been used at several DOE and DOD cleanup sites. The largest application is under way at DOE's Savannah River site, where the contaminant is the industrial solvent trichloroethylene.

The largest-ever LDRD undertaking at LLNL involved 50 staffers and cost $7 million a year for three years. Completed this past March, the transformational materials initiative was a collection of projects linked by the common theme of reducing the cost and improving the efficiency of nuclear stockpile maintenance, says Robert Maxwell, the principal investigator. In one effort, researchers studied the feasibility of recycling the high explosives that are removed from nuclear weapons during dismantlement for reuse in conventional munitions or in future nuclear warheads. Another group developed diagnostic devices that could be retrofitted onto warheads so that lab experts might be alerted immediately when a deployed weapon required servicing.

Some of those diagnostics could have applications outside the stockpile, Maxwell explains. A microelectromechanical stress detector is now being tested in animals with funding provided by DOD. It may improve the understanding of how shock waves from blasts are transmitted or diffused by helmets and other battlefield personal armor (see also page 20). "You put these sensors between the personal protective equipment . . . and the body," Maxwell says. "Then you expose the animal to shock and look at how well the shock is transmitted or diffused. It helps you understand how the shock is transmitted to the various parts of the human body." He adds that DHS is evaluating a gas-detection sensor developed by the project for potential use in homeland security applications.

Energy and security overlap

McBranch says that LANL tries to select LDRD projects that address multiple missions. Thus, while $87 million of its $127 million LDRD program for this year will be relevant to homeland security issues, $71 million of the total expenditure also is relevant to energy challenges. Improvements to the nation's electric grid should make it more resilient to a terrorist attack or to natural disasters, he notes. Actinide materials chemistry addresses both nuclear energy and nonproliferation, and materials science and nanotechnology find uses in both national security and renewable energy applications.

One LANL group is attempting to bring network theory to bear in solving what McBranch describes as a general applied mathematics problem: the distributed grid that will be required to accommodate the big growth that's expected in wind and solar power generation. That effort will incorporate usage data supplied by an electric co-op in Taos, New Mexico, that has recently installed more than 12 000 "smart meters" and 10 MW of photovoltaic capacity. Another LDRD project at LANL, McBranch says, aims to engineer intelligent and adaptive wind systems by improving the understanding of how turbulence, twisting forces, and other stresses can accelerate wear on turbine bearings and affect efficiency.

David Kramer

Mostly recovered, the LHC readies for restart

The LHC will run at reduced energy until its superconducting magnets are retrained and the connections between them fixed.

Just nine days after it was first turned on in September 2008, the Large Hadron Collider at CERN was brought to a standstill when an improperly soldered splice connecting two superconducting cables failed (see PHYSICS TODAY, November 2008, page 24). When it starts back up in November, the plan is to test and debug both the LHC and its experiments for a while at 3.5 TeV per proton beam, then to ramp up to perhaps 5 TeV, hopefully sometime in 2010. Some lingering problems still need to be solved to make it safe to go to the design goal of 7 TeV, or 14-TeV center-of-mass collision energy.

"The first job is to rediscover the standard model," says LHC project leader Lyn Evans. "Produce the top quark, measure its mass, and use the data to calibrate all the physics we know from the Tevatron," which produces 2-TeV collisions at Fermilab near Chicago. Adds Tejinder Virdee, spokesman for the LHC's Compact Muon Solenoid experiment, "It's important to get going."

CERN

The busbars (below) in the Large Hadron Collider's connectors (left) must all be made to have sufficiently low resistance, and about a third of the magnets have to be retrained before the machine's design collision energy can be reached.