REMOTE SENSING

Nonproliferation Boom Gives A Lift to the National Labs

Last December, as international arms-control negotiators were locked in a diplomatic struggle with North Korea over its nascent nuclear weapons program, the intelligence community's eyes were on a U.S. military satellite orbiting far above the Korean peninsula. The satellite, in turn, was watching a 5-megawatt experimental nuclear reactor near the North Korean capital of Pyongyang. As long as the satellite continued to detect heat from the reactor, U.S. officials could be relatively confident that the facility was making electricity and North Korea wasn't building a bomb: It would need to shut down the reactor before it could extract waste fuel and process it to make plutonium for a nuclear weapon. But if the satellite detected any significant cooling—the first sign of a shutdown—U.S. officials were authorized to start making whatever threats it took to keep North Korea from bomb-building.

The satellite is an early example of a Cold War technology now being put to use for global peacekeeping. And if a major Department of Energy (DOE) research program launched over the past 2 years is successful, it may be joined by many others keeping similar vigils—an entirely new generation of remote-sensing satellites, all alert for the signs of some nation trying to assemble a nuclear arsenal. The program has its roots in the intelligence programs that have for decades relied on satellites to watch for signs of nuclear tests. But the satellite concepts now being explored by scientists at DOE's national labs are an attempt to spot proliferation at a much earlier stage, perhaps as early as the point when a country first starts to stockpile nuclear material.

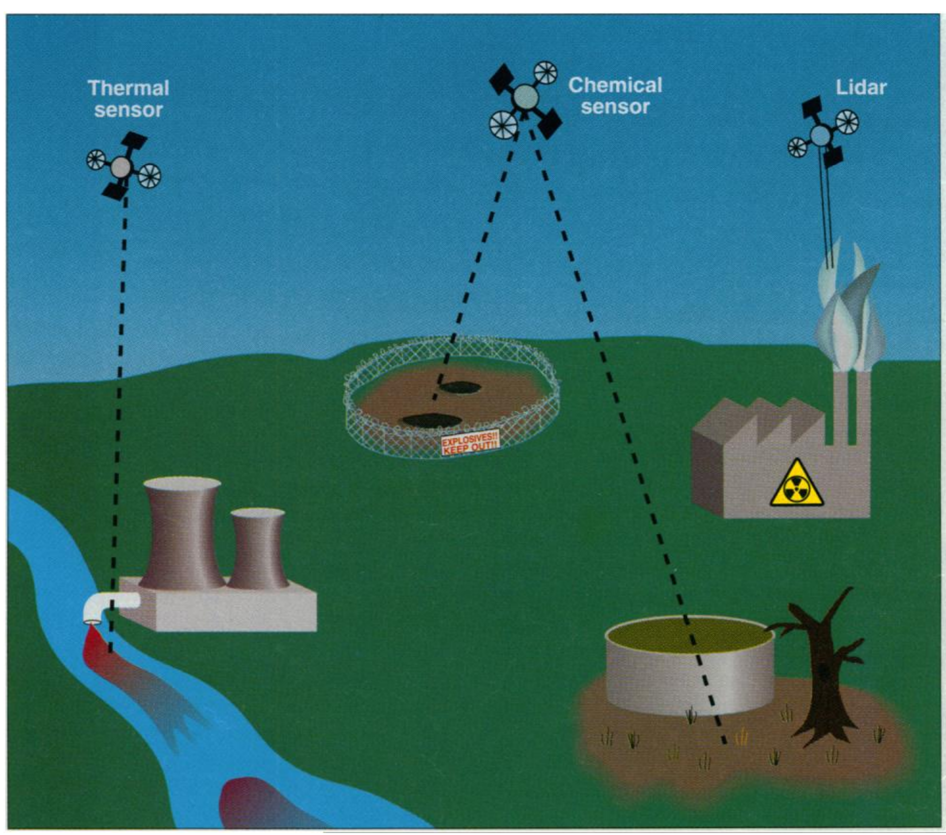
It's a welcome mission for the national laboratories, now suffering from cutbacks in weapons programs. And it's motivated by new geopolitical realities in the aftermath of the Cold War. As more nations seek to join the nuclear club, says Los Alamos National Laboratory division director Donald Cobb, "you want to spot proliferation as early as possible." Indeed, with many would-be nuclear powers, experts say, those early signs could be the only warnings; new members of the club might be content with crude weapons that would require no testing.

The new early warning technologies go far beyond cameras and simple sensors. In one part of the program, which is expected to cost a total of $100 million annually by next year, researchers are developing multispectral sensors that could spot anything from chemical residue released during plutonium reprocessing to the thermal signature of a nuclear reactor in a weapons material production cycle—even before the nuclear material is removed. Meanwhile, other researchers are looking at the possibility of detecting even more subtle warning signs, such as the electromagnetic signals emitted by isotope-separating centrifuges and the characteristic vegetation damage near tanks storing waste from weapons production.

Participants concede that it's an enormous technical challenge. Indeed, several promising approaches have already lost their luster, including the use of high-powered lasers to probe the atmosphere around suspect facilities for gases emitted by the weapons production process. But as remote-sensing technology advances across the board, driven by the needs of global change research as well as military intelligence, some network of space-based nonproliferation satellites appears increasing likely. "I'm skeptical," says David Albright, a nonproliferation analyst with the nonprofit Institute for Science and International Security. "But these people can do amazing things when they get $100 million a year."

The program began to gain momentum in 1991, with the discovery that Iraq was much closer to building a nuclear weapon than most experts had believed. "We were pretty surprised," says James Tape, program manager for nonproliferation and arms control at Los Alamos. "The lessons learned from Iraq got everyone's attention and got a lot of people asking, 'What more can we do?'" The next year, then-President George Bush proposed a major new nonproliferation initiative at DOE.

A welcome task. Iraq, and now North Korea, have also made the nonproliferation program "a high priority for the [current] Administration," says Frank von Hippel, an arms-control policy official in the White House Office of Science and Technology Policy. One sign came last July, when President Bill Clinton visited Los Alamos and promised in a speech to shift more of the scientific expertise at the weapons laboratories into proliferation detection. That's good news to the laboratories and their congressional supporters, says von Hippel, and the fact that many of the remote sensing technologies could also serve for environmental monitoring could be another political selling point.



High hopes. Proliferation-detecting satellites could sense thermal emissions from a plutonium-producing reactor, chemical residues from explosives testing, or dying vegetation at a waste storage site. Active laser sensors might also probe gaseous emissions for telltale compounds *(right)*.

The researchers, meanwhile, face a double challenge. To go beyond obvious signs of proliferation, such as the flash of a nuclear test, or indirect clues such as the thermal evidence that a reactor has stopped running, requires the ability to detect subtle chemical and thermal signatures. In addition, the data gathered by satellite sensors have to be quantitative, so that on-board electronics can filter the information to identify possible proliferation signals and send a list of suspicious sites to intelligence experts on the ground. Not surprisingly, the details of which signatures the researchers are focusing on and how they will achieve the needed sensitivity are secret. "The real concern is that if you tip your hand, there may be counter-measures that make your job harder," says Robert Scarlett, who manages the proliferation detection program at Los Alamos. But interviews with more than a dozen lab and DOE officials reveal the broad outlines of an ambitious program, in which the national laboratories are playing complementary roles.

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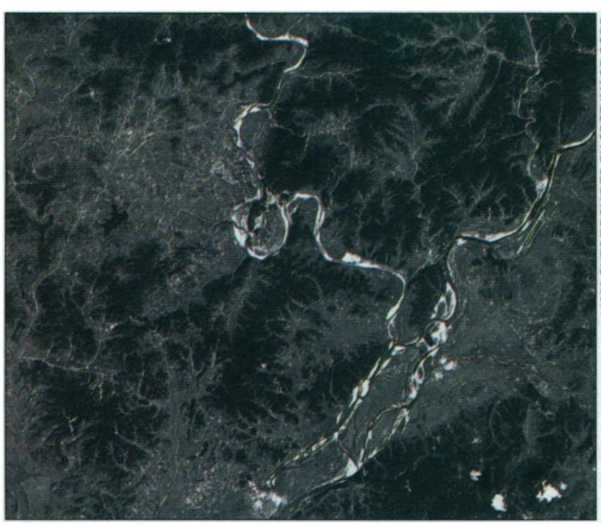
—David Albright

Much of the effort at Los Alamos and Sandia National Laboratory is devoted to "passive" sensors—mostly multispectral analyzers. In 1992, when then-President Bush proposed shifting $168 million of the DOE budget into new non-proliferation programs, the two labs jointly proposed a "Space Proliferation Detection Initiative." The goal was to develop a fleet of proliferation-sensing satellites, mostly carrying passive sensors. Only half the promised money finally materialized, but a somewhat pared-down version of the initiative is now under way, and satellites carrying the program's offspring will be launched within 2 years.

First to fly will be a technology derived from previous programs to spot nuclear tests. In 1995, DOE plans to launch a satellite—known as FORTÉ, for Fast Orbital Recording of Transient Events—that is designed to use on-board neural network electronics to distinguish between the electromagnetic signature of lightning and that of a nuclear explosion. Lightning has been the source of false alarms in the past, says DOE program manager Max Koontz.

The new generation of proliferation-sensing satellites will debut in 1996 with the launch of an experimental spacecraft known as the Multi-Spectral Thermal Imager (MTI). The $70 million satellite will carry an 18-band multispectral sensor, which can detect infrared radiation with wavelengths from .04 to 12 microns. By analyzing these emissions, the instrument should be able to detect heat fluctuations from reactor cooling towers and waste water, even through clouds. In an initial test, researchers on the ground will directly measure heat output at DOE's Savannah River weapons production facility, which has several nuclear reactors that can produce weapons materials; at the same time, the satellite will measure the same thermal emissions from space. Comparing the "ground truth" with the space readings will allow the researchers to gauge the sensitivity of space detection and calibrate the sensors.

Later, the Sandia and Los Alamos groups hope to design and fly other multispectral sensors that will attempt to use techniques similar to those of their brethren in environmental remote sensing to detect vegetation changes around nuclear material processing plants. Uranium enrichment and plutonium reprocessing yield large amounts of chemical waste, including organic compounds, acids, and fluorine. Lab scientists say that satellites could spot characteristic "kill zones" around waste holding tanks, where chemicals associated with nuclear processing have contaminated the soil or groundwater and killed vegetation.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Don't look now. A satellite view of a North Korean reactor *(center)* suspected of producing weapons plutonium.

Passive sensors, however, can't sniff out the traces of airborne gases released during plutonium production or uranium refining. Those chemical clues of a weapons program might be even harder to hide than the longer-lasting signs evident to passive sensors. But to detect them, a satellite would have to carry active sensing technology, probably based on lasers. In theory, a laser sensor can tease out the composition of a gas by measuring the wavelengths of laser light scattered, absorbed, or absorbed and reemitted through fluorescence. One strategy is to send out two pulses with slightly different wavelengths, one of which corresponds to a known absorption resonance of a chemical that might be released in the production of nuclear material, and compare the reflected signals. A drop in reflectivity at the resonant frequency reveals the presence of the chemical.

The technology is not all new. A laser sensing technique based on this principle and known as Light Detection and Ranging (LIDAR) has already been developed at Los Alamos; it has been used to measure pollution in Mexico City and to detect the exhaust plume of a SCUD-like missile. And Lawrence Livermore National Laboratory, which in the 1980s was the center of the exotic Star Wars laser program to shoot down enemy missiles, hopes to put some of that expertise to work in proliferation sensing. Livermore "has done some really great work in high-powered diode lasers, and we thought that might contribute to our [proliferation-sensing] capability," says Koontz.

The labs are facing a formidable challenge, however. Laser sensing has not been demonstrated for distances more than a few miles—even less than that, for the more sensitive measurements in which gases absorb and then reemit light to reveal their nature. So early last year, before DOE invested heavily in laser-based proliferation sensing projects, it asked JASON—an independent panel of civilian scientists that advises defense agencies—to assess the promise of space-based lasers as a sensing tool. The JASON panel was pessimistic. Indeed, Stanford University physicist Sidney Drell, who headed the JASON panel, says the chemical signatures likely to be found near a weapons facility are probably too faint to detect from space.

Because few data exist on just how strong such chemical signatures actually are, the JASON panel recommended that DOE do more research on the characteristics of those signatures before sinking money into high-tech gadgets for spotting them from space. "When you're working on this, you have to know what kinds of signals are realistic, what are the unique characteristics, how strong are they? I think we are at a stage where gaining more understanding of that problem is important," Drell says.

In its 16 November report, the JASON panel concluded "that there was very little likelihood that we would ever get to a place where we could use [laser sensing] for satellite applications," says Koontz. These findings "certainly change things," he says. "It would be foolish to say otherwise.... All the technical evidence now indicates that the probability of success in that area is very, very small." But he says DOE will continue investing in laser sensing, if only for ground and aircraft-based proliferation detection.

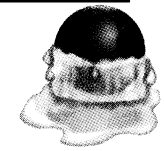
Other clues. While researchers at the other national laboratories struggle with remote-sensing technology, researchers at DOE's Pacific Northwest Laboratory in Richland, Washington, are compiling a list of proliferation signals for these sensors to detect. "We looked at the entire cycle from [uranium] mining to [weapons] testing, and we looked at what was observable at every step," says Thomas Fox, senior director for national security at the lab. "It started as a simple exercise, talking to some bomb guys, and before we knew it, we had 65 pages" of potential candidates, from characteristic chemicals to telltale means of transportation. Nearby Hanford nuclear reservation, where much of the nation's nuclear waste is stored, has "all the signatures of a proliferant" and has been an ideal testing ground, Fox says. (Indeed, DOE has recently disclosed a secret test that was a forerunner of the current program. As early as in 1949, the government conducted a secret "Green Run" test at Hanford in which large amounts of radioactive isotopes were released into the atmosphere so researchers could test ground-based instruments designed to measure emissions from Russian nuclear production facilities.)

Even the optimists in the program expect that it will be more than a decade before any of the new proliferation-sensing technologies are actually in use. "The further we get into this, the harder we realize it is," says David Dye, program leader of Livermore's Intelligence and National Security Technologies program. But the labs see that as a challenge, not grounds for discouragement. "If people said, 'Hey, this is a piece of cake,' you wouldn't see the national labs involved," says Stanley Fraley, who heads the policy and analysis department at Sandia.

Eventually, says Koontz, "I'm confident that there will be a mechanism to detect proliferation from space. It's a highly complex technical task, but it's the kind of challenge that the laboratories can eventually meet." With a half-dozen nations threatening to join the nuclear fraternity, there are plenty of reasons to find better ways to spot the early signs of proliferation. No one expects satellites to replace ground-based sensing and actual inspections entirely (see policy forum on seismic monitoring of a nuclear test ban, p. 634). But as nations like North Korea and Iraq continue to resist on-site observation, Washington policy makers are finding the prospect of space detection—despite its technical complexity—hard to resist.

–Christopher Anderson

PLUTONIUM DISPOSAL



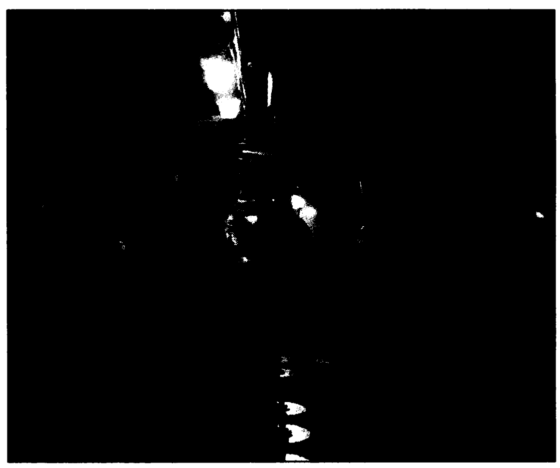
No Easy Way to Shackle The Nuclear Demon

For science, the end of the Cold War has brought a shift in priorities, new access to previously secret data and technologies—and, for a few scientists, the peculiar challenge of undoing some of their predecessors' handiwork. When the United States and Russia agreed in 1991 to dismantle between them some 30,000 nuclear warheads, they bequeathed to the world 100 tons of weapons-grade plutonium, an element that didn't exist on the planet before it was made in the laboratory in 1940. Figuring out how to keep this plutonium out of the environment and, more important, out of the hands of countries and terrorist groups bent on acquiring nuclear arms is one of the thorniest challenges facing scientists and policy makers in the post-Cold War era, and weighing possible solutions has grown into what IBM physicist Richard Garwin has called "a lively minor industry."

That industry has already churned out thousands of pages of product, in the form of reports by the Department of Energy, the Office of Technology Assessment (OTA) and, most recently, the National Academy of Sciences (NAS), which released its report on 24 January. The options surveyed in the reports include storing the plutonium indefinitely, converting it into high-level radioactive waste by running it through nuclear reactors, and launching it into space or simply burying it. One reason the possibilities—and the reports analyzing them—are proliferating is the technical challenge. Because it takes about 10 pounds of plutonium to fashion a nuclear bomb as powerful as those that demolished Nagasaki and Hiroshima, scientists have to find a way to dispose of plutonium so secure, says Garwin, a member of the NAS panel, "that not one part in 10,000 is lost...to those [for whom] even that small amount is worth millions or even hundreds of millions of dollars."

Every solution proposed so far has its drawbacks, not all of them technical. "This is a political problem as well as a technical one," says University of California, Berkeley, physicist John Holdren, chairman of the NAS Committee on International Security and Arms Control, within which the plutonium study was conducted. Any solution has to take into account the existing policies restricting civilian uses of the material. It has to set an example for the Russians and convince Russia and other nuclear powers that the United States isn't reserving the option of retrieving its plutonium and reassembling its bombs. And as a multibillion-dollar project at a time of shrinking defense budgets, it has to withstand powerful political pressures at home (see box).

The problem these scientists are grappling with is growing rapidly: The Department of Energy's Pantex facility near Amarillo, Texas, is dismantling nearly 2000 warheads a year. Each scrapped nuclear weapon yields electronic controls, conventional explosives, enriched uranium, and tritium—a short-lived radioactive isotope of hydrogen. It also yields a plutonium "pit," a sphere of plutonium about the size of a grapefruit. A pit is a curiously benign object. Plutonium is extremely toxic, but only when it is inhaled, and it is not so radioactive that it can't be safely handled in a theft attempt. And although it takes exquisite engineering to turn a plutonium pit into a hydrogen bomb, plutonium can be fashioned relatively easily into a fission bomb.


DOE

Unleashing the demon. Plutonium pit production 5 years ago at the Department of Energy's Rocky Flats plant.

For now, the pits are safeguarded at Pantex in bunkers built to withstand the crash of any aircraft short of the heaviest transport planes. Russia also claims to be accumulating as many as 2000 pits each year, although experts say that it's still unclear exactly how and where the pits are being stored. Those growing stockpiles, especially in Russia, pose a nightmarish security concern, says Wolfgang Panofsky, former director of the Stanford Linear Accelerator Center and chairman of the NAS plutonium study group. And that adds to the urgency of working out some way to dispose of the pits permanently.