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."

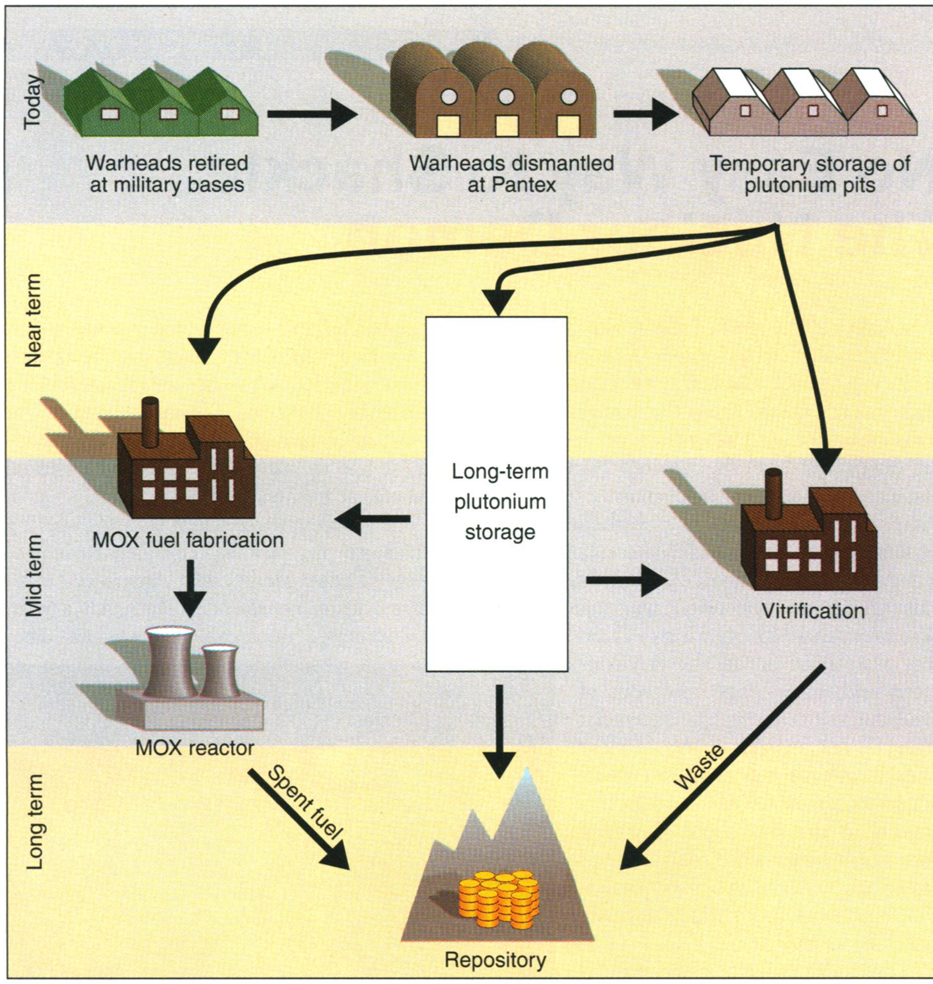
Every solution proposed so far has its drawbacks, not all of them technical. "This is a political problem as well as a technical one," says University of California, Berkeley, physicist John Holdren, chairman of the NAS Committee on International Security and Arms Control, within which the plutonium 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.



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Long roads to a resting place. Plutonium from warheads could be burned in reactors to make it highly radioactive, stored indefinitely, or mixed with high-level radioactive waste, then vitrified.

One thing everyone agrees on is that whatever solution is ultimately adopted, it "will be neither simple nor painless," as the OTA report put it. The NAS study, the most comprehensive to date, rejected unorthodox solutions that would eliminate the plutonium in a single stroke, such as a proposal to launch it into the sun. Before such a launch could be attempted, says Panofsky, the public would have to be convinced that "the risk generated by a launch-pad accident or some malfunction that would make the plutonium return to Earth is acceptable." Nor did the committee offer much support for an idea to bury the plutonium in kilometers-deep holes.

The simplest solution to the plutonium problem is to defer the search for a permanent answer and keep the plutonium safely stored until researchers develop an acceptable way to eradicate it completely. As the NAS scientists note, the plutonium will have to be stored for 10 to 20 years, in any case. And the cost of long-term storage, says Lawrence Livermore National Laboratory analyst William Sutcliffe, a consultant to the NAS committee, would be relatively small.

Indefinite storage, however, comes with serious disadvantages, says the NAS panel. For one, the stored plutonium remains a tempting target for theft, and its security depends on continued political stability in the nation controlling it—a serious concern in Russia. And indefinite storage on U.S. soil might not convince the world that the United States is serious about disarmament—that it's not just storing the plutonium away for the day when it will be put back in weapons. To the NAS panel, those political drawbacks make long-term storage an unsatisfactory option, says Panofsky.

Two other options, say the NAS and outside experts, deserve serious consideration: burning the material in nuclear reactors, and mixing it with highly radioactive nuclear wastes. Neither would be entirely satisfactory, but both could be made to work.

Power play. The reactor option, after all, is already planned for another part of the nuclear harvest, the enriched uranium being extracted from bombs. The weapons-grade uranium, explains Frank von Hippel of the White House Office of Science and Technology Policy, will be diluted with natural uranium, resulting in a difficult-to-separate mixture of isotopes that is usable for reactors but not for weapons. "What you're doing," says von Hippel, "is taking weapons-usable material and just by dilution producing non-weapons material that has economic value."

Plutonium can't be tamed quite so easily. All of its isotopes are suitable for bombs, which means it cannot be diluted to make it "proliferation resistant." On the other hand, once the plutonium has passed through a reactor core, a would-be bomb-maker would have great difficulty dealing with it, even though most of the plutonium would remain in the spent fuel. "It does not make it go away," says Holdren. "Rather it gets transformed into something that very closely resembles the 800 tons of reactor plutonium that already exists in spent fuel"—highly radioactive material that would be extremely difficult to steal and reprocess into usable plutonium. In the words of Jim Harding of the Washington State Energy Office, the process turns the plutonium "from the nastiest thing on the planet to the second nastiest thing on the planet." As high-level waste, it would still be a challenge to store, but it would pose little risk of proliferation.

Although a study of the plutonium problem conducted for the Department of Energy by reactor manufacturers called for a new generation of plutonium-burning reactors, that study has been roundly criticized on technical and economic grounds (see box). In fact, as members of the NAS committee point out, light-water reactors—ordinary U.S. power reactors—can burn a mixed plutonium-uranium fuel, known as mixed-oxide, or MOX. Most existing light-water reactors are only capable of burning MOX in one-third of their nuclear core, because plutonium requires control elements with a greater capacity to absorb neutrons than does uranium. But several existing reactor designs can run on 100% MOX, which would speed the task.

The catch with burning plutonium in any commercial reactor is that current nonproliferation policy forbids its use in the civilian fuel cycle. The United States adopted this policy to head off the development of commercial reprocessing of spent fuel and the shipment of plutonium around the world, and it has been trying to persuade other countries to follow suit. As a result, says Franz Berkhout of Princeton's Center for Energy and Environmental Studies, a U.S. decision to fuel civilian reactors with plutonium might have "potentially disastrous consequences for proliferation."

One way around these difficulties, says Holdren, might be to have the government buy up a few of the dozen or so large commercial reactors likely to be shut down over the next decade and convert them to burn plutonium. Because the plutonium-burners would be government-run, the scheme would avoid rewriting the civilian fuel policy. Two plutonium burners operating on a government reservation, says Holdren, could make all of the United States' and Russia's weapons plutonium too hot to handle in about 20 years.

Unappetizing mix. The second option in the NAS report offers another way to make the plutonium too hot to handle: include it in the scheme already under way for dealing with the high-level liquid waste left over from creating the plutonium in the first place. Because that radioactive waste, says Holdren, is "unstable, dangerous, and hard to monitor," the government is now planning to turn it into enormous, 1750-kilogram glass logs, a process known as vitrification. Adding plutonium to the waste before it is vitrified would lock up the element in a highly radioactive amalgam that would be both extremely difficult to steal and easy to monitor. "If you lose one log you're likely to know it," says Holdren. And much of the technology is already in place. At the DOE's Savannah River installation, a $1 billion vitrification plant will begin operation within the next few years. Savannah River also has 34 million tons of high-level radioactive sludge waiting to be vitrified.

The scheme, suggested by von Hippel and colleagues at Princeton and the Massachusetts Institute of Technology, still has some unanswered technical questions—among them, how much plutonium can be put into a log. Too little would result in a large number of logs and could strain the capacity of the planned high-level waste repository at Yucca Mountain, Nevada. Too much would increase the possibility of a chain reaction if someday, in thousands of years, water should get into the repository. The logs are made of boron silicate glass, and the boron, which absorbs neutrons and blocks a chain reaction, could leach out faster than the plutonium. Panofsky and his NAS colleagues are optimistic that these technical problems can be solved, should the United States decide that vitrification is the way to go.

Politically, Panofsky thinks vitrification is "quite attractive." For one thing, "you don't have to go the reactor road and address American policy about whether or not you burn plutonium in civilian reactors." What's more, he and his colleagues think a U.S. commitment to vitrifying its plutonium rather than burning it might persuade the Russians to set aside what Panofsky calls their "religious belief" that their plutonium should be used for fuel.

The current preference of the Russian Ministry of Atomic Energy, Panofsky explains, is to store the plutonium until a new generation of breeder reactors, particularly well suited to using plutonium fuel, is up and running. That's worrisome, he says, because most American experts think the breeders won't be online for at least 20 years. The Russians would therefore have to store all their plutonium for a few decades—an unpalatable prospect considering the country's political volatility. "A lot of experts will vote for vitrification," says Holdren, "because it gets you out of the storage business quickly, and if that's important in the United States, it's even more important in Russia."

Officially, however, Panofsky, Holdren, and their colleagues are withholding their votes. The job of sorting through these options and making a recommendation falls to a special interagency task force, recently announced by President Clinton. Von Hippel, who is organizing the task force, says it will include the Departments of Energy, State, and Defense and will be cochaired by the National Security Council. The task force plans to produce a report by next October.

Once a means of disposing of the plutonium has been chosen, the real work will begin. "We've never tried to eliminate the means of war before," says one DOE administrator. "It's going to be a life's work, going to be with us for a long time. There's no way out of it. No button to push to make it go away."

–Gary Taubes

Pork and Plutonium May Not Mix

The prospect of a multibillion-dollar project aimed at getting rid of the plutonium from unwanted nuclear weapons (see main text) has caught the interest of some politicians and the nuclear industry. To many scientists studying the plutonium disposal problem, however, all this interest could be destructive. Indeed, they argue that the Department of Energy's (DOE) first major attempt to study the problem was flawed by political and commercial pressures.

In 1992, after DOE canceled plans for a new reactor to produce weapons tritium at its Savannah River site, the Senate Armed Services Committee earmarked $30 million in the FY 1993 defense authorization bill for DOE to spend on nuclear reactor development. In a letter to DOE head James Watkins, Sen. Strom Thurmond (R–SC), suggested developing the concept of "a triple play reactor," which could burn plutonium, generate electricity, and produce tritium. One DOE staffer called the appropriation a "bone we could throw" to the reactor contractors that had been working on the canceled tritium producer.

Other DOE officials argued, politely, that it would be a waste of money to spend $30 million to design reactors for plutonium burning when they knew nothing about the feasibility of the idea. The result was a compromise with the Senate, reached in January 1993, in which DOE agreed to dole out $5 million to reactor vendors to evaluate their own advanced reactor designs—or as one member of a National Academy of Sciences panel studying the plutonium-disposal problem later put it, "to extol their individual reactor options as God's gift to plutonium disposition."

Not surprisingly, the vendors concluded that dedicated new reactors could effectively dispose of weapons-grade plutonium. They also maintained that, in some cases, the costs could even be offset "with future electricity sales." Indeed, the report stated, "net revenue could reach $20 to $40 billion...." That conclusion, which received considerable press coverage, was disputed in a highly critical peer review—also commissioned by DOE—that got virtually no public attention. The reviewers of the DOE report attacked both the study's modus operandi and its economics, declaring that the report lacked "a thorough analysis of the many uncertainties associated with all the options."

Members of the NAS committee also have harsh words for the DOE report. For starters, University of California, Berkeley, physicist John Holdren points out, the report never considered modifying existing reactors to dispose of the plutonium. Second, he says, the study suggests that weapons plutonium represents a valuable source of energy. Actually, Holdren says, when you do the economics right, you find that burning plutonium is a money-losing proposition. What's more, he adds, the total amount of energy in the surplus weapons plutonium is equivalent to only 4 months of the world's nuclear electricity generation. "It's absolutely crazy," says Holdren, "to say we're going to move heaven and earth to get this energy."

That's not to say that reactors can't help with the plutonium problem: Processing the material in conventional reactors to make it intensely radioactive is getting serious consideration (see main text), and DOE is now launching a second phase of its study to look at that option. But neither pork-barrel politics nor the future of the nuclear reactor business should drive the quest for a means of ridding the world of plutonium, says Stanford University's Wolfgang Panofsky, head of the NAS committee. "Maintaining the plutonium under full national and international control and preventing its distribution and theft are the main priorities," says Panofsky. "The name of the game is security, not economics."

–G.T.