The Plutonium Challenge
Avoiding nuclear weapons proliferation

Today, the basic knowledge about building and manufacturing an atomic bomb is within reach of any industrialized nation. During the Gulf War (1991), for example, there was little doubt that Iraqi scientists and engineers could duplicate the Manhattan Project feats of more than half a century ago. And so, the main uncertainty before that war was whether the Iraqis had obtained sufficient weapons-usable nuclear material to build nuclear weapons.

Limiting Access to Weapons-Usable Materials

Along with political dissuasion, denying access to weapons-usable materials is the best barrier to the spread of nuclear weapons in aspiring states and among rogue leaders and terrorists. As Saddam Hussein discovered, clandestine efforts to produce weapons-usable material are costly. They are also difficult to conceal for long. Uranium has to be enriched to high levels of the isotope 235 (highly enriched uranium, or HEU) by industrial processes whose signatures are clearly visible. Production of substantial quantities of plutonium requires construction of nuclear reactors—an undertaking that is large, visible, and expensive.

Production of plutonium and highly enriched uranium in the five original nuclear powers—the United States, Russia, the United Kingdom, France, and China—has been stopped except at three remaining production reactors in Russia that generate much needed heat and electricity as byproducts. It appears that production in Israel, India, and Pakistan continues. In North Korea, it is currently frozen. South Africa has taken its HEU out of military programs. Table I lists stockpiled amounts of weapons-usable materials.

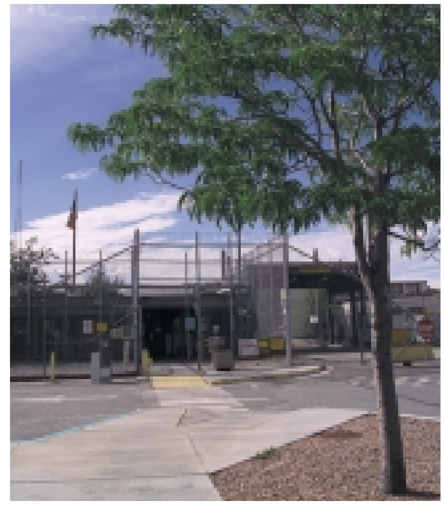
An obvious alternative to the clandestine production of weapons-usable nuclear materials is theft or diversion from existing HEU or plutonium stockpiles. Kilogram quantities of plutonium or HEU pose a significant proliferation concern. However, materials produced for the nuclear weapons programs of the original five nuclear powers have been well protected for many decades. The United States and the western powers developed nuclear safeguards—a stringent system of

President Eisenhower's "Atoms for Peace" speech has become a landmark in the history of international cooperation. To ensure that "the miraculous inventiveness of man shall not be dedicated to his death but consecrated to his life," President Eisenhower proposed setting up an international atomic energy agency whose responsibility would be to protect fissionable materials and develop methods whereby those materials "would be allocated to serve the peaceful pursuits of mankind."

Table I. Stockpiles of Weapons-Usable Materials[a]

Country	Plutonium (tonnes)	Uranium Equivalent (tonnes)
United States	99.5	635
Russia	130[b]	1000
United Kingdom	7.6	15
France	5	24
China	4	20
Israel	~0.5	Not known
India	~0.35	Small quantity
Pakistan	Negligible	0.21
North Korea	0.03	None
South Africa	None	0.4

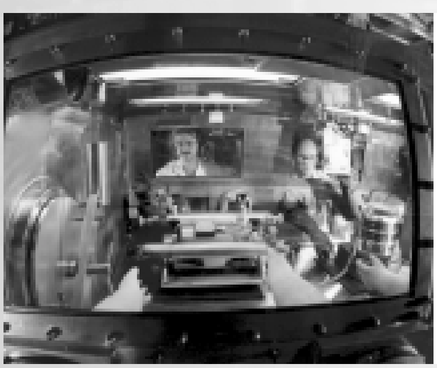
[a] Adapted with permission from *The Challenges of Fissile Material Control*, David Albright and Kevin O'Neill (Eds.), Washington, DC: Institute for Science and International Security Press, 1999.
[b] Hecker believes this amount could be in the range 125–200 tonnes.



Located at Technical Area 55, the Los Alamos Plutonium Facility is a state-of-the-art R&D facility for plutonium processing and handling. Activities conducted here range from chemical and metallurgical research to surveillance of plutonium pits from the U.S. nuclear stockpile and from small-scale production of pits to pilot-scale demonstration of technologies that support arms control agreements. The facility is surrounded by barbed wire fences and has portal monitors equipped with neutron and gamma-ray sensors that detect nuclear materials. Strict assaying and accounting procedures protect nuclear materials from outsider and insider threats.

protection, control, and accounting for nuclear materials. When the Atoms for Peace Program and the 1954 amendment to the Atomic Energy Act cleared the way for the United States to export nuclear materials for peaceful purposes, our government stipulated strict safeguards measures to be enforced by the recipient nations. In 1957, the International Atomic Energy Agency (IAEA) was established under the umbrella of the United Nations to promote peaceful applications of atomic energy and to help safeguard civilian nuclear materials from military use. The role of the IAEA has been increasingly important and assertive in safeguarding civilian nuclear materials around the world. The agency, however, has no jurisdiction over defense nuclear materials.

The United States has exercised its own rigorous nuclear safeguards system intended to prevent, deter, detect, or respond to attempts at unauthorized possession or use of nuclear materials. This system provides physical protection, personnel security, control and accountability of nuclear materials, and administrative controls. To be effective, the system is backed up by federal government laws. In the United States, nuclear materials have never been diverted or stolen. The IAEA has adopted a civilian safeguards system very similar to that practiced in the United States. We believe that the United Kingdom and France operate similarly effective systems.



At the Los Alamos Plutonium Facility, rigorous assaying and accounting procedures within the glove-box system record plutonium as it is moved from one location to another.

A security police officer controls access to a secure area by verifying a photo ID badge.

The robotic nondestructive-assay system includes a large overhead gantry robot to move plutonium to and from several instruments, such as the large cylindrical calorimeter pictured here. With this calorimeter, Los Alamos personnel measure the heat generated by the radioactive decay of plutonium and thus determine the quantity of plutonium present.

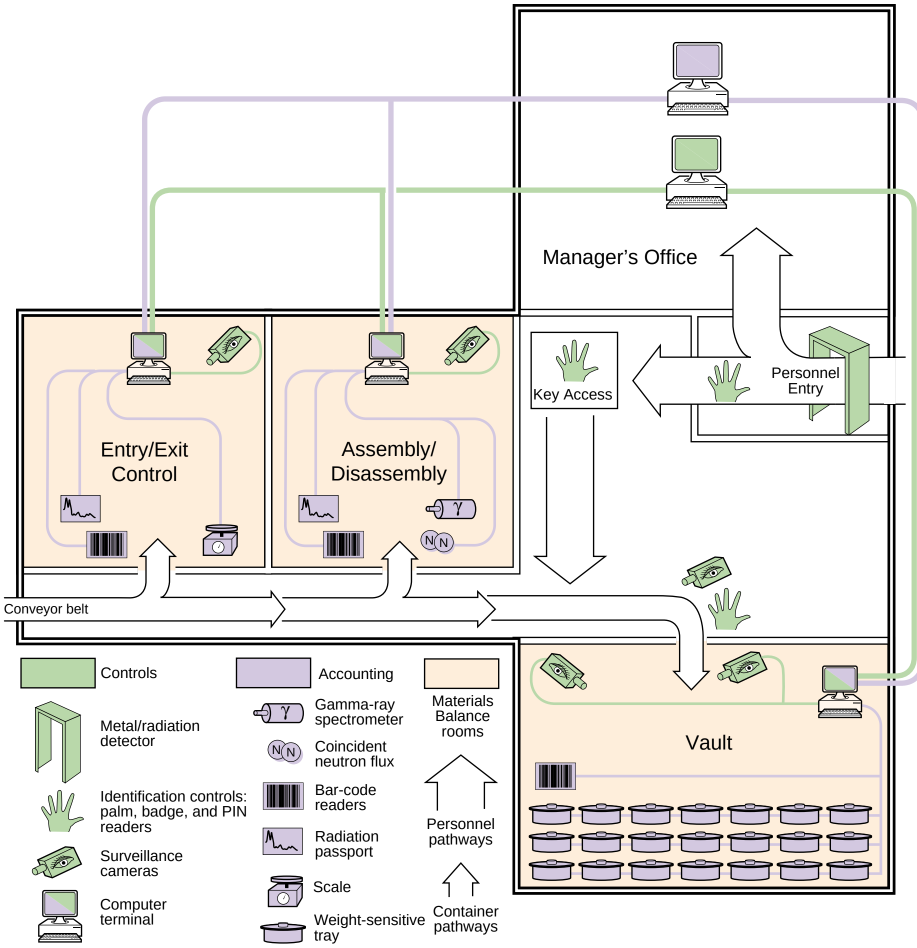
A Clear and Present Danger in Russia

The BN-350 fast breeder reactor outside Aktau in western Kazakhstan is one of the sites where the United States has helped install advanced nuclear materials protection, control, and accounting (MPC&A) systems. The output power (350 MW) of the reactor is used to desalinate Caspian seawater for drinking and industrial purposes, to generate heat for commercial and residential use, and to generate electricity for the local area. The BN-350 achieved first criticality in 1973 and was operational until mid-1999.

Russia inherited the Soviet system that had been designed for a centrally controlled police state. It was often called the system of "grave consequences" or "guns, guards, and gulags"—that is, anyone who might dare challenge it would face serious personal repercussions. Based on rigorous personnel scrutiny and physical protection backed up by impenetrable borders, this system did not rely on modern technology in case the other protective means failed. The Chinese government also appears to have adopted the Soviet safeguards system. Only in the past few years has China begun to learn about more rigorous systems from the West.

Nevertheless, the Soviet system worked during Soviet days—its record for protecting weapons-usable materials was impressive. Today, the dramatic political, economic, and social changes resulting from the breakup of the Soviet Union pose a new and serious proliferation threat—some of Russia's 125 to 200 tonnes of plutonium or its 1000 (or more) tonnes of highly enriched uranium are at risk of being stolen or diverted. When the police state was dissolved, the gulags disappeared and the borders became penetrable, but the custodians of the nuclear materials and the guards protecting the storage facilities were seldom paid, suffered severe personal hardship, and became demoralized. Not surprisingly, the breakdown of a system that relied mainly on the conduct of people ushered in the ingredients for potential disaster.

Generally, weapons-usable materials are more difficult to protect than nuclear weapons. Unlike the weapons, which have serial numbers, nuclear materials exist in forms difficult to analyze, account, and protect. Waste and scrap are two examples of such forms. In Russia, some nuclear sites—such as those of the nuclear navy—became particularly vulnerable because financial support for the entire program dissolved almost overnight. Many of the vessels, storage facilities, and transportation

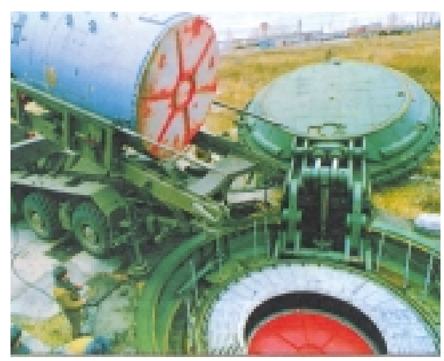


(Opposite page): The map of the former Soviet Union shows the main sites with nuclear-material inventories—nuclear weapons facilities (including nuclear materials, nuclear military R&D, and weapons assembly and disassembly), naval fuel-cycle facilities, and civilian reactor and R&D facilities. All these sites have been involved in the cooperative U.S.-Russian MPC&A program whose mission has been to reduce the threat of nuclear proliferation and terrorism by improving the security of all weapons-usable nuclear materials in Russia and the other countries of the former Soviet Union. (Left): This is a conceptual diagram of the Arzamas-16 (in Sarov) demonstration system for nuclear MPC&A. The United States has helped Russia set it up. Controls (shown in green) limit and monitor access to materials. Accounting instruments are shown in blue, and the three material-balance rooms are shown in peach. Bar-code readers identify containers, and they also track the movements of materials through the facility.

systems were left vulnerable. To make a western-style safeguards system work in Russia, it is imperative for Russia to downsize its huge nuclear complex and consolidate the nuclear materials sites.

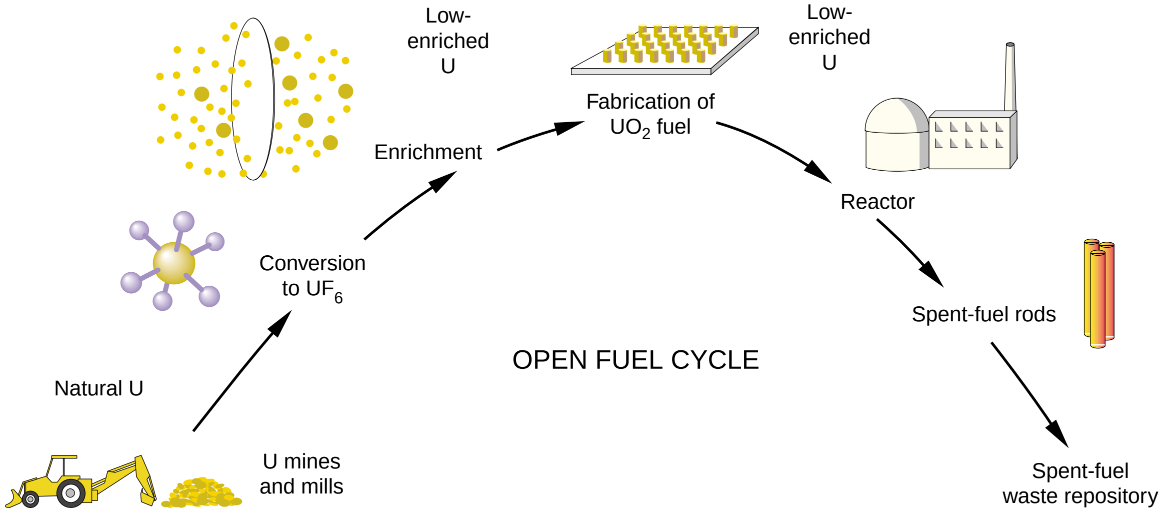
Much of the Soviet nuclear enterprise is now housed in independent nations of the former Soviet Union. With the help of the cooperative threat-reduction program funded by the United States, all the Soviet nuclear weapons have been returned to Russia by the nations of Ukraine, Kazakhstan, and Belarus. These and other countries continue to have weapons-usable materials on their soil—much of it in research reactors and facilities that are even more underfunded and overstressed than those in Russia. In Kazakhstan, for example, several reactors and the huge former nuclear test site at Semipalatinsk are no longer under Russian control.

Over the past eight years, the United States—mainly through the Department of Energy and its laboratories—has helped Russia and other states of the former Soviet Union develop a more rigorous safeguards system although Russian officials showed resistance at first. Fortunately, in the midst of uncertainty and turmoil, no major loss of weapons-usable materials is known to have occurred in these countries. The present danger can be overcome only by close collaboration between Russia and the United States and by support from the international community.



Pictured here is the dismantlement of a missile in Ukraine. This work was done as part of the cooperative threat-reduction program. (Photo reproduced courtesy of *AFP*.)

The test site at Semipalatinsk, Kazakhstan, was ground zero of the first Soviet nuclear explosion (August 29, 1949). The infrastructure for nuclear testing at Semipalatinsk has been dismantled or destroyed with U.S. help. The nuclear "Stonehenge" on the left shows the remains of the diagnostic towers left standing at Semipalatinsk after one of the Soviet tests.



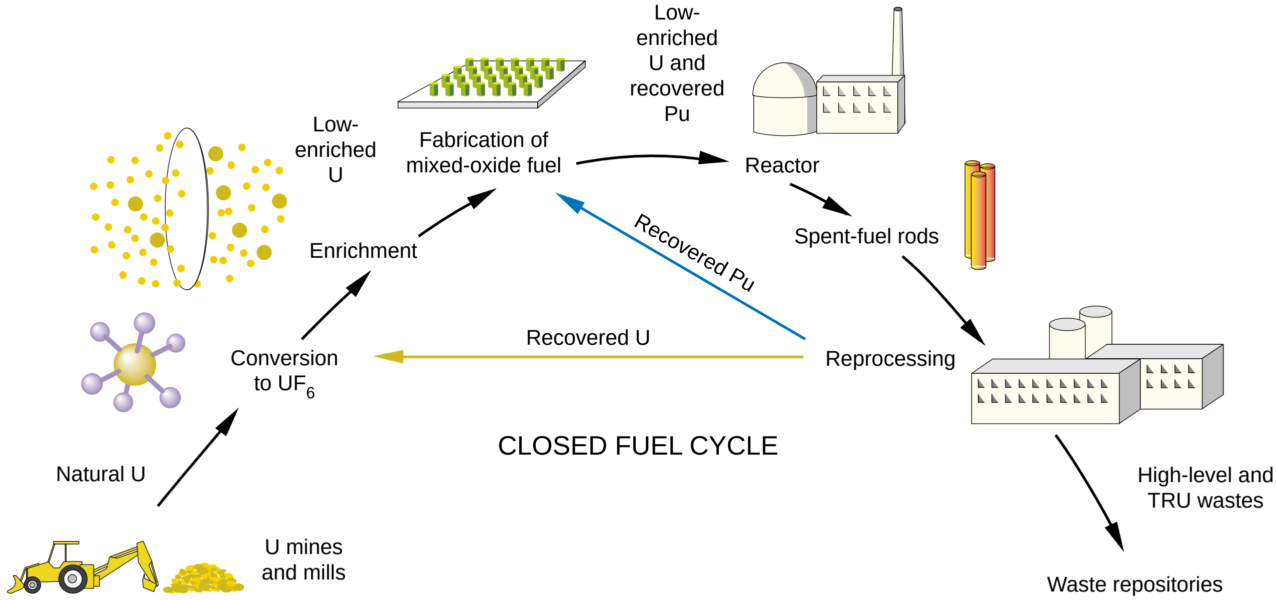
In 1977, the open fuel cycle was the standard chosen for commercial nuclear-power reactors in the United States. Less than 2% of the energy content of the uranium fuel is extracted during one reactor cycle. The spent fuel, together with the fission products, is disposed of geologically.

Strict Control on Civilian Plutonium Is Imperative

In 1970, 170 nations implemented the Nonproliferation Treaty (NPT), a nuclear agreement that no nation beyond the five original nuclear powers would acquire nuclear weapons. In return, access to civilian nuclear technology would be granted to all nations, which would have to comply with IAEA monitoring of international safeguards. The original five states agreed to negotiate in good faith to disarm their nuclear arsenals. In 1995, this treaty was extended indefinitely by 185 nations, with the notable exception of states such as India, Pakistan, and Israel. Controversy is still alive about best ways to control the proliferation risk inherent in the commercial nuclear fuel cycle. How well it is resolved will to a large extent determine the future of commercial nuclear power.

What are the risks and what safeguards are in place in the commercial nuclear-power industry? The enriched fuel used in most commercial power reactors—containing 3 to 4 percent uranium-235—presents no proliferation danger. According to the IAEA, only fuel that has been enriched in uranium-235 to greater than 20 percent is weapons usable. Naval-reactor and research-reactor fuels are often enriched to much more than 20 percent uranium-235—mostly to achieve compactness. Unused fresh fuel intended for such reactors is therefore at risk from diversion for military purposes. However, diluting HEU with uranium-238, which is abundantly present in nature, is an easy remedy for rendering HEU unsuitable for weapons. Moreover, the blended material can be used as commercial-reactor fuel. However, we must continue to monitor the proliferation risk posed by advanced, more-compact enrichment technologies that could reverse the benefits of blending or that could more easily enrich natural uranium.

Plutonium is produced by the transmutation of uranium-238 in power reactors. It is therefore intimately interspersed with uranium and fission products. The fuel rods in power reactors are “burned” to a greater extent than those in plutonium production reactors, so they contain a significantly larger fraction of the higher isotopes of plutonium. For example, weapons-grade plutonium is typically greater than 93 percent plutonium-239, whereas reactor-grade plutonium contains as little as 60 percent plutonium-239 (with as much as 25 percent plutonium-240). For many years, the hope had been that the isotopic mixtures of reactor-grade plutonium would prove to be unattractive for weapons use. However, it is now widely recog-



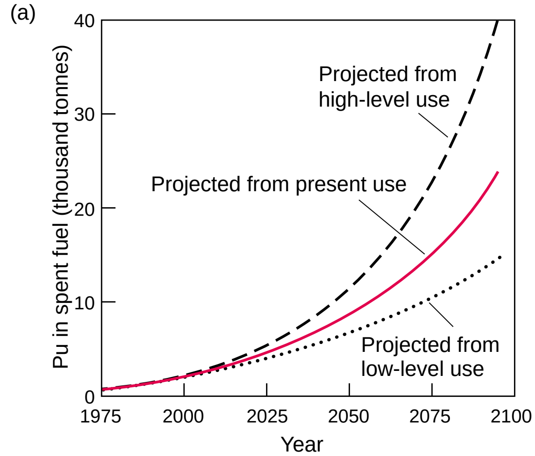
In the closed fuel cycle, which has been adopted by most countries, the spent fuel is reloaded into the reactor and reprocessed to burn the remaining uranium fuel and the newly bred plutonium.

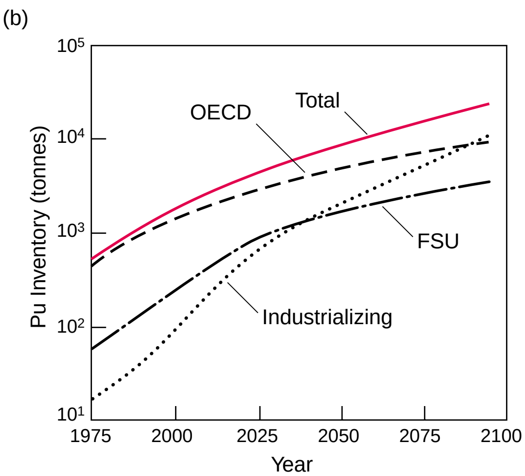
nized that, once plutonium is separated from uranium and fission products, most isotopic mixtures provide little deterrent for weapons use. The IAEA classifies as weapons usable all isotopic mixtures except those containing more than 80 percent plutonium-238, which would literally melt before being of use as weapons materials. Because blending plutonium-239 is not a viable solution to the risk of proliferation, plutonium is the material posing the greatest long-term proliferation concern. In recent years, the U.S. government has also expressed its concerns over the potential availability of neptunium-237 and americium, both of which are byproducts of nuclear reactors.

To date, commercial nuclear reactors in the world have produced more than 1000 tonnes of plutonium, growing at a rate of about 75 tonnes per year. Approximately 200 tonnes of the total civilian plutonium has been separated from the remaining uranium and fission products, mostly in the United Kingdom and France. The Soviet Union made little distinction between military and commercial reactors, but Russia has now declared 30 tonnes of separated civilian plutonium.

One approach to protecting plutonium produced in power reactors from diversion to military use is not to separate it from the fission products in spent fuel. These products exhibit intense penetrating radiation—mostly from cesium-137 and strontium-90 with half-lives of approximately 30 years. This self-protecting feature provides a significant barrier for several decades because remote manipulators and heavy shielding are required to chemically separate plutonium. Other protective methods are often compared with the spent-fuel standard, which is defined as greater than 100 rads per hour at a distance of 1 meter. However, after more than 50 to 100 years, this self-protection will be reduced to the point at which spent fuel also becomes an attractive source of plutonium. We must also recognize that a technologically sophisticated adversary is able to overcome the self-protecting barrier of even fresher fuel.

The principal issue then is the nature of the fuel cycle used in commercial nuclear power reactors. Proponents of the spent-fuel standard for proliferation resistance favor the “once-through” or open fuel cycle. In this case, only 2 percent of the energy content of the uranium fuel is extracted during one reactor burn cycle. The spent fuel is allowed to cool off (from its radioactive decay). Then, it is disposed of geologically, together with the fission products. In 1977, President Carter chose this option for the United States to set an example for the rest of the world.





(a) Global inventories of plutonium in spent fuel are certain to rise even if use of nuclear energy stays at present or lower levels. However, that use may increase because of increased energy demand from industrializing nations as well as efforts to control fossil fuel emissions and thereby minimize global climate change. Compared with its present level, nuclear energy use could quadruple by 2050. (b) Although today the primary users are the developed nations belonging to the Organization for Economic Cooperation and Development (OECD)—the United States, Western Europe, and Japan—recent Los Alamos analyses suggest that, by 2075, the former Soviet Union and other industrializing nations such as China will become the primary users of nuclear energy and will have the largest inventories of plutonium in spent reactor fuel. (These graphs are courtesy of Ed Arthur of Los Alamos.)

In the United States, however, there are also numerous advocates of a closed fuel cycle—one in which the spent fuel is reprocessed so that the remaining uranium fuel and the newly bred plutonium can be burned in a reactor. More important, most nations that have commercial nuclear power programs are not willing to forego the energy content of the spent fuel. They want to extract the energy inherent in uranium more efficiently and favor developing plutonium breeder reactors as the ultimate future power source. Besides, those countries view the closed fuel cycle as more benign environmentally because the highly radioactive products are separated out, making nuclear-waste disposal easier.

The fuel-cycle controversy has no simple solution. The United States and much of the rest of the world have gone in different directions for nearly a quarter of a century. Perhaps the most serious consequence of President Carter's decision not to allow reprocessing of civilian spent fuel is that the United States has become much less influential in global decisions that affect the future of nuclear power. And those future developments would benefit from greater U.S. influence.

Fight Proliferation through International Cooperation

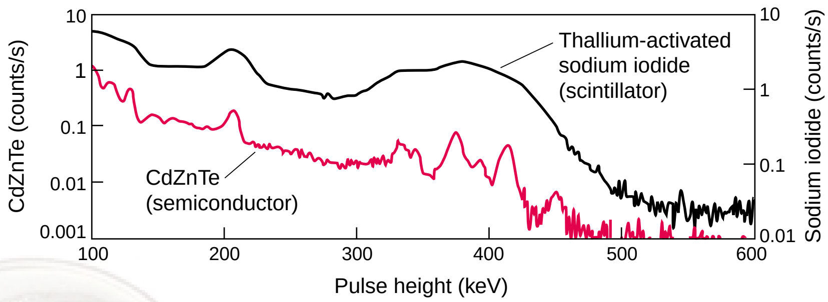
Technical advances are required at each stage of the fight against nuclear proliferation. The continuous radioactive decay of plutonium allows passive measurements. The plutonium signature is distinct and thus easy to recognize. However, increasingly sensitive and reliable passive measurements would allow detection of constantly smaller amounts of plutonium at greater distances. Likewise, improved systems of verification, monitoring, and real-time accounting are required. In addition, we must continue to develop increased proliferation barriers inherent in the fuel cycle—such as proliferation-resistant fuels and alternative reactors or reactor operations. For example, a fuel cycle based on thorium instead of uranium offers potential proliferation benefits because it does not produce plutonium. Also, several reactor schemes and accelerator-based systems are being developed, which may dramatically reduce the inventory and availability of plutonium from the civilian reactor cycle.

Any effective safeguards system must include strict control over all stockpiles of weapons-usable materials. Clearly, each of the five original nuclear powers will insist on managing its own military stockpile of nuclear materials. As already pointed out, the Russian safeguards program is in a state of transition. It is of the utmost importance that its nuclear materials—military and civilian—are fully protected at all times. Continued cooperation with the United States will help the Russian Federation make a safe and secure transition to a modern system of nuclear materials safeguards. Although the Russian Federation and the United States have agreed to remove from their stockpiles substantial quantities of nuclear materials no longer required for military purposes, it is crucial that materials protection be given highest priority because all nuclear materials disposition schemes will require decades to complete.

The IAEA has played a seminal role in managing the proliferation risks inherent in the civilian nuclear fuel cycle. This role will become more important as the amount of plutonium produced in currently operating civilian reactors continues to increase (see graphs to the left). And the challenge becomes even greater if nuclear power takes on an increasing share of energy production in the future. Although very few nuclear power plants are currently being constructed in the industrialized nations of the West, it will be difficult to meet the projected doubling of energy demand over the next 50 years without an increasing share from nuclear power and without doing irreparable damage to the environment.

Increased international cooperation and an even-stronger future role for the IAEA will be necessary to deal with potential proliferation threats. The U.S. government pursued international control of nuclear materials immediately following the end of World War II. Bernard Baruch offered such a plan to the United Nations Atomic

Energy Commission in 1946, but the Soviet Union rejected it. Several years later, however, President Eisenhower's Atoms for Peace initiative ushered in a new era of international cooperation on nuclear matters. And today, the end of the Cold War opens the possibility of exploring novel international-management approaches to the nuclear fuel cycle. For example, the idea of creating several internationally monitored, well-protected storage facilities for retrievable spent fuel in a few key locations around the world is being evaluated. The cost of such facilities is substantial, but it is much less than the cost of building numerous smaller storage facilities. The concept of a "world plutonium bank" has also been considered as a way to deal with mounting inventories of civilian reprocessed plutonium. In addition to shaping its own nuclear complex, the United States would have to play a leading role in shaping the international nuclear complex.

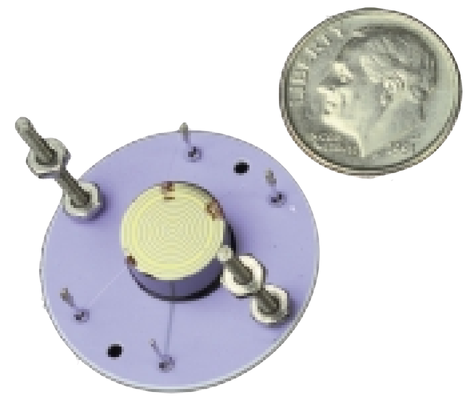


This graph compares two gamma-ray spectra from low-burnup plutonium measured by the CdZnTe detector and a sodium iodide scintillation detector. For the first time, we can obtain isotopic information needed for nuclear-material safeguards by using a hand-held detector.

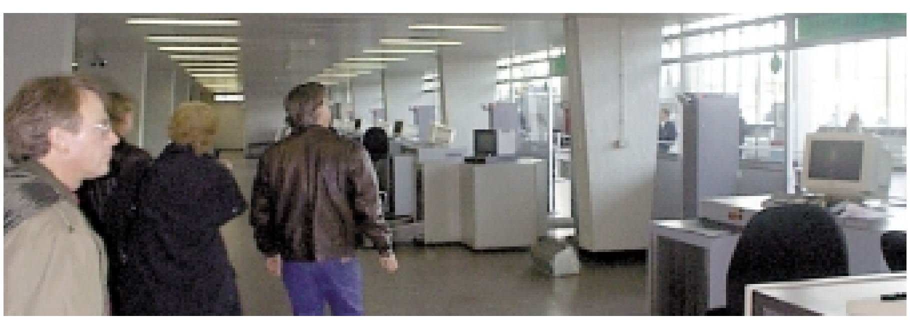
International cooperation is also needed to deal with the challenge posed by the 1998 nuclear tests conducted by India and Pakistan. Specifically, reaching an international agreement for a cutoff in the production of fissile materials would help stem the arms race escalation in South Asia. In addition, close cooperation among the current nuclear powers on the export of civilian nuclear technology to India or Pakistan will be necessary to adequately safeguard the potential use of civilian nuclear materials for military applications. In all these areas, close cooperation between the United States and Russia and a stronger IAEA presence are essential.

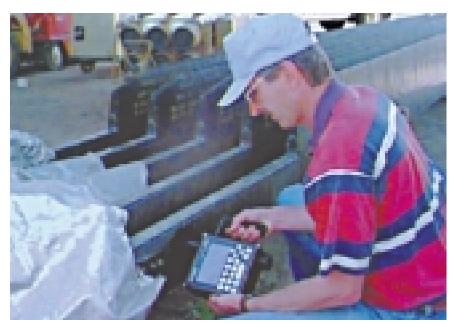
The proliferation danger posed by the dissolution of the former Soviet Union can be resolved in the near term only by close cooperation between Russia and the United States. It is time to tackle the immediate threats—namely, loss of nuclear weapons, materials, or knowledge—with a greater sense of urgency. Fighting nuclear terrorism and nuclear emergencies is also best accomplished jointly by the United States and Russia. Likewise, shrinking Russia's huge nuclear military complex can be expedited if the West helps convert military activities in Russia's closed nuclear cities into commercial and civilian ventures. Working together, Russia and the United States could help complete the removal of all weapons-usable materials from the other states of the former Soviet Union and thus lessen a serious, immediate proliferation threat.

In the long term, current U.S. programs that help Russia reduce its huge inventories of weapons-usable materials become increasingly important. And so does reaching an agreement on ending the production of fissile materials. The United States and the West have now an opportunity to increase their help. The price tag may seem large, but it is truly insignificant compared with the amounts to be spent if a nuclear catastrophe were to occur. ■



The CdZnTe (or "cad-zinc-tel" for short) detector developed at Los Alamos has opened the way for a new generation of compact, low-power gamma-ray sensors to be used in nuclear-material safeguards. In this photo, the detector is shown next to a dime. The circular pattern of electrodes (gold on platinum) allows high-quality measurements of gamma-ray spectra. (For details on the CdZnTe detector, see T. H. Prettyman et al. 1999. In *Hard X-Ray, Gamma-Ray, and Neutron Detector Physics* Vol. 3768, p. 339. Bellingham, WA: SPIE.)





(Left): Video portal monitors guard the departure area at Sheremetyevo Airport in Moscow to help prevent nuclear smuggling. (Right): An official with the United Nations Special Commission uses a hand-held radiation detector at an inspection site in Iraq. The detector was originally developed at Los Alamos.