V

Troubles Tomorrow?

Separated Neptunium 237 and Americium

DAVID ALBRIGHT AND LAUREN BARBOUR

ALTHOUGH NO NATION IS KNOWN TO HAVE MANUFACtured either neptunium 237 or americium to use in nuclear weapons, the nuclear community has long known that weapons could be made from these materials. In November 1998, the U.S. Department of Energy (DOE) declassified the information that neptunium 237 and americium can be used for a nuclear explosive device. One or more nuclear weapon states may have tested a nuclear explosive using neptunium 237.

Historically, neptunium 237 and americium have been separated by the nuclear weapon states in only small quantities, principally for non-explosive uses—as target materials for plutonium 238 production, and for smoke detectors, neutron generators, and research activities. International commerce in neptunium and americium is very small. Although the information is incomplete, non-nuclear weapon states are believed to possess little separated neptunium or americium.

But this situation may be about to change. Since the early 1990s, several key countries, including several non-nuclear weapon states, have stepped up research into the removal of these and other actinides from highly radioactive nuclear waste. They believe they can make high-level waste significantly easier to dispose of if they separate these long-lived materials from fission products. They also hope to use these materials later, as fuel in fast reactors. Separating neptunium and americium could encourage their commercial uses, and thus increase international commerce in these materials.

One or more nuclear weapon states may have tested a nuclear explosive using neptunium 237.

Separated neptunium 237 and americium have been the focus of recent proliferation discussions, and the growing inventories of these materials, virtually all in spent fuel and reprocessing wastes, should not be ignored.[1] By the end of 1997, the world inventory of neptunium and americium was estimated to exceed 80 tonnes (metric tons), or enough for more than 2,000 nuclear weapons, and the amount is growing at a rate of as many as 10 tonnes per year. If actinide separation becomes routine, inventories of separated neptunium 237 and americium will escalate.

Current controls and monitoring practices do not provide the international community with adequate assurance that these materials are not being used to make nuclear explosives. A principal concern is that a civilian reprocessing facility or a waste treatment facility in full compliance with its safeguards obligations could extract neptunium or americium that would not be under any international inspections. In essence, a non-weapon state could accumulate significant quantities of separated nuclear explosive materials outside IAEA verification.

Neptunium and americium are outside international controls—except for those controls included as part of the Wassenaar Arrangement for neptunium 237. Under that arrangement, which includes more than 30 states, exports of more than one gram of separated neptunium are controlled, although the rationale for the control is related to the production of plutonium 238.[2]

Under the Statute of the International Atomic Energy Agency (IAEA), only plutonium, uranium 233, or material enriched in uranium 235 or 233, are required to be safeguarded. But the IAEA has now begun to consider adopting measures to address the proliferation concern posed by neptunium 237 and americium, and to think about what a program to monitor these materials might include. Although the IAEA Board of Governors is unlikely in the short term to define neptunium 237 or americium as "special fissionable materials" subject to safeguards, the IAEA is likely to increase the monitoring of these materials in non-nuclear states party to the Nuclear Non-Proliferation Treaty (NPT).

The IAEA's proposed monitoring system would include neptunium and americium export reporting; inventory declarations by non-weapon states with past or current reprocessing or plutonium clean-up operations; and monitoring at facilities that have neptunium 237 or americium in spent fuel, high-level waste, or separated plutonium, and have the capability to separate substantial quantities of neptunium 237 and americium. A primary goal of this system would be to provide some assurance that the quantities of separated neptunium and americium in the non-nuclear weapon states remain insufficient to pose a proliferation risk.

By the end of 1997, the world inventory of neptunium and americium was estimated to exceed 80 tonnes

A debate about increasing the IAEA's monitoring of separated neptunium 237 and americium could have important implications not only for international safeguards, but also for export controls, physical protection standards, and nuclear waste disposal practices. The debate may affect the negotiation of a fissile material cutoff treaty.

This chapter provides an introduction to neptunium and americium, offers estimates of the world inventories of these materials, and briefly outlines the need for more information and controls on these materials. The information in this chapter will be supplemented in other reports being prepared by ISIS.[3]

Neptunium

Although no country has stated it has used neptunium 237 in a nuclear explosive device, neptunium 237 is considered usable in nuclear weapons. It has a bare-sphere metal critical mass of about 60 kilograms, and in metal form it is easier to compress than highly enriched uranium (HEU). About 30 kilograms or less would be sufficient to create a crude implosion device. With a half-life of more than two million years, neptunium 237 has no heat or radiation properties that would complicate its use in a nuclear explosive. Because it has a low neutron background, it could also be used in a gun-type device, although a larger quantity would be required.

Production. Neptunium 237 is routinely produced in nuclear reactors as a result of neutron irradiation of uranium 235 and uranium 238, the two most common constituents of nuclear fuel. It is also a decay product of americium 241.

Thus, large quantities of neptunium 237 are found in spent nuclear fuel. Each year, a typical 1,000-megawatt-electric light-water reactor produces about 25 tonnes of spent fuel containing about 10 kilograms of neptunium 237. The same spent fuel contains about 230 kilograms of plutonium. By weight, neptunium 237 discharges are about five percent of plutonium discharges and about 0.05 percent of spent-fuel discharges. ISIS has estimated that at the end of 1997 the world's nuclear power reactors had produced about 35 tonnes of neptunium 237. Current annual production is estimated at about three to five tonnes.

The nuclear weapon states also produced neptunium 237 in their plutonium and tritium production reactors. Because many U.S. production reactors used recycled HEU fuel instead of natural or low-enriched uranium fuel (LEU), the spent fuel contains a higher proportion of neptunium 237 than spent fuel from U.S. civil power reactors. An initial estimate of the amount of neptunium 237 produced in U.S. production reactors is one to two tonnes.[4] Total production in the nuclear weapon states cannot yet be estimated, but it is believed to be several tonnes.

Many research reactors use HEU fuel irradiated to high burnups, which also produces an increased amount of neptunium 237. The amount of neptunium 237 produced in civil research reactors worldwide is crudely estimated at less than one-half tonne.

Separation. A number of countries have conducted research into neptunium separation and the physical and chemical properties of metallic neptunium. Neptunium 237 can be separated from irradiated uranium fuel through the Plutonium/Uranium Extraction (PUREX) process, the most common method of separating plutonium. Depending on how the PUREX process is operated, neptunium can appear in various reprocessing wastes or in the uranium or plutonium product. From each of these “streams,” separation of pure neptunium is a straightforward task. Separating neptunium 237 from high-level waste, however, is significantly more difficult than separating it from medium-level waste or plutonium and uranium products.

The primary reason for separating neptunium 237 has been to obtain material that can be irradiated in a reactor to make plutonium 238, which is used in long-life thermoelectric electricity generators and heat sources in civil and military programs. The United States and Russia have had the largest neptunium separation programs. In the United States, separated neptunium was produced almost entirely in military production reactors. Attempts to separate neptunium from naval reactor fuel failed.

The United States and Russia each possess hundreds of kilograms of separated neptunium 237; Britain and France have tens of kilograms of separated neptunium 237. In 1987, the Savannah River Site in South Carolina had an inventory of roughly 400 kilograms of separated neptunium 237, and the reactors there could produce about 80 kilograms more each year.[5] The United States does not have a current program that produces separated neptunium—the Savannah River reactors were shut down in 1988—but it is planning to restart plutonium 238 production using a stock of several hundred kilograms of separated neptunium stored at Savannah River.[6] Inventories in China are unknown, but they are probably small.

Russia, the United States, and other nuclear weapon states have exported neptunium 237. From 1950 to April 1998, the United States exported only about a kilogram of separated neptunium 237 to 12 countries. In order of amounts, the recipients of more than 98 percent of the material were Germany, Belgium, Britain, Israel, Japan, and India. Russian exports are less known; it has not provided the IAEA with an accounting of its neptunium exports before 1994.

Britain sold Iraq 200 milligrams of neptunium oxide in the 1980s. About a quarter of it was irradiated to produce plutonium 238, which Iraq evaluated as a material for a neutron initiator for nuclear weapons. The rest of the plutonium was used in reprocessing research and development activities at the Tuwaitha Nuclear Research Center south of Baghdad.

So far, commercial reprocessing facilities have not separated large quantities of neptunium 237. During plutonium separation, the vast bulk of neptunium 237 enters various waste streams. An exception is Japan's Tokai reprocessing plant—which is currently shut down. There, almost half of the neptunium ends up in the plutonium product.

Through 1997, roughly 5 to 7 tonnes of neptunium 237 have been contained in civil spent fuel that has been reprocessed.[7] This neptunium is primarily in various waste forms. Some is mixed with separated plutonium.

Because of neptunium's long half-life and the radiotoxicity of its decay products, in recent decades many nuclear programs have considered separating it and other actinides from nuclear waste. Program managers worry that if neptunium becomes dissolved in groundwater, it may migrate from a geological repository more easily than other actinides. And its long half-life means that neptunium decay products will remain a hazard long after plutonium, americium, and curium have essentially disappeared.

Starting in the early 1990s, research into separating neptunium, americium, and other minor actinides accelerated. Based on a search of publications in the International Nuclear Information System (INIS), a number of countries are researching the separation of neptunium 237 or americium. The list includes Belgium, Britain, China, France, Germany, India, Japan, Russia, Switzerland, and the United States.

Of the non-nuclear weapon states, Japan appears to have the largest program investigating the separation of neptunium and other actinides. It also operates a "hot" facility that is designed to demonstrate the separation of neptunium 237 and other actinides from reprocessing operations and high-level waste.

Among the non-weapon states, Japan appears to have the largest program investigating the separation of neptunium and other actinides.

Americium

Common americium isotopes are in general less suitable for making nuclear explosives than neptunium 237 because of their higher output of radiation and heat. However, the DOE recently declassified that it has concluded that the heat and radiation properties of americium could be overcome with a relatively low level of sophistication. The three most important isotopes are americium 241, americium 242m, and americium 243. All three have bare-sphere critical masses, but they vary widely and are uncertain. Americium 241 has a bare-sphere critical mass between about 60 to 100 kilograms. Americium 242m has the lowest bare-sphere critical mass, about 9 to 18 kilograms. The bare-sphere critical mass of americium 243 is somewhere between about 50 and 150 kilograms, indicating that public estimates of its critical mass vary enormously.

Production. Several americium isotopes originate as a result of neutron irradiation in reactors; americium 241 originates from the decay of plutonium 241. The total americium content of fresh spent power reactor fuel is modest, although over time considerable amounts of americium 241 accumulate.

ISIS has estimated that at the end of 1997 the world inventory of americium was roughly 45 tonnes, about half of which was in the United States.[8] Almost all of it is americium 241 and is the result of the decay of plutonium 241 in civil spent fuel. Stocks of weapon-grade plutonium are estimated to contain less than a tonne of americium 241.

The stock of americium continues to grow in spent fuel. Currently, more than 4 tonnes of americium 241 are produced each year.

Separation. Methods for separating americium from aged plutonium or during reprocessing are widely known, although they are not as well demonstrated as plutonium separation methods. During reprocessing, americium normally goes into the high-level waste with the fission products. In nuclear weapon programs and civil plutonium recycle programs, americium 241 has been separated from aging plutonium to purify it and reduce the material handling problems caused by americium's radioactive emissions.

Although the principal reason for separating americium has been to reduce its negative impact on separated plutonium, americium isotopes have also been used as target material to make high-purity plutonium 238 and curium. It is also used in smoke detectors, as medical diagnostic tracers, and in neutron sources. However, all these uses require at most gram quantities.

Total worldwide americium separation is very roughly estimated to be on the order of a hundred kilograms. Several additional tonnes of americium are found in reprocessing wastes.

The United States has separated only kilogram quantities of americium 243. For example, the Savannah River Site has about 10 kilograms of americium 243 in 4,000 gallons of americium-curium solutions. However, the United States is believed to have separated larger quantities of americium 241. The Rocky Flats Plant near Denver currently has an inventory of about 12 kilograms of separated americium 241.[9] Before it was shut down in 1989, Rocky Flats could separate and purify about one kilogram per year of americium 241.

Americium separation, like neptunium separation, has been researched by many countries in various efforts to reduce the long-term hazards of nuclear waste. Americium is a persistent source of alpha radiation in spent fuel and in the high-level nuclear waste produced in reprocessing operations. During extraction processes, all the americium isotopes in the waste are extracted together.

The Future

With americium and neptunium inventories already large and growing, domestic and international controls should be strengthened to ensure that these materials are not used to make nuclear weapons. The IAEA's consideration of proper monitoring of separated neptunium and americium in non-nuclear NPT member states is commendable.

The IAEA's deliberations will increase the discussion of a range of controls for these materials. As part of its deliberations, the IAEA has received considerable information from member states about neptunium and americium exports and existing inventories in non-weapon states. But determining the appropriate level of controls across a range of issues will require more complete information. At a minimum, the following questions need to be better answered by government officials:

- How large are the states' inventories of americium and neptunium?
- What portion of those inventories have been separated? And

which states possess separated inventories? How much of the separated neptunium is mixed with separated plutonium or uranium? (Neptunium 237 mixed with separated plutonium is indirectly covered by safeguards and physical protection arrangements for separated plutonium.) What separation activities occurred in the past, are currently ongoing, or are planned?

- How much neptunium 237 and americium is in waste forms, particularly in forms remaining after separating plutonium or HEU?

A decision to apply full safeguards to neptunium and americium in the non-nuclear weapon states appears premature, although increased monitoring is necessary at reprocessing facilities, nuclear waste processing operations, storage sites for reprocessing waste, mixed-oxide (MOX) fuel-fabrication plants, and scrap recovery sites. The IAEA's new Model Safeguards Protocol gives the agency additional legal authority to monitor the location and separation of neptunium and americium—without defining these materials as special fissionable materials. In addition, the protocol gives the IAEA the right to take environmental samples at many more sites, further complicating the undeclared separation of neptunium 237 and americium.

Physical protection standards may also require revision. Neither neptunium 237 or americium is currently included in international guidelines covering the physical protection of nuclear material. Because the IAEA's guidelines on physical protection (INFCIRC/225/Rev. 3) are periodically revised, adding americium and neptunium 237 should be possible.

International export control regimes also require scrutiny in order to ensure that key americium and neptunium separation technologies are adequately controlled. Several states, including Britain, France, Japan, and the United States, have started this process by requiring domestic controls on neptunium and americium.

To better institutionalize controls, the IAEA needs to encourage all nations separating—or considering separating—neptunium or americium to create a management arrangement similar to that recently created for civil plutonium (see Chapters I and III). In addition to requiring declarations of inventories of neptunium and americium, a management arrangement could also include commitments concerning adequate physical protection and monitoring of these materials. Such an arrangement could help reduce the risk posed by these materials and provide a clearer, non-discriminatory warning when these materials would need to be fully safeguarded.

In addition to broadening controls on neptunium and americium, the international community needs to engage in a general debate about the desirability of limiting the separation of these materials to defined and necessary activities, including research into nuclear waste disposal approaches. In essence, the best goal may be keeping the vast bulk of these materials locked in spent fuel or high-level waste. Because neptunium and americium cannot be used to fuel light-water reactors, their legitimate uses are limited. Both materials can be burned in fast reactors or transmuted by accelerators, but such applications are far in the future, at best. Although the covert separation of these materials cannot be prevented, an agreement to limit separation activities might slow the spread of the capability to separate these materials and complicate covert development of separation capabilities.

---

1. Other transuranics, such as curium and californium, can also be used to make nuclear explosives, but they are not expected to pose proliferation problems for at least several decades.
2. Britain, France, Russia, and the United States agreed in 1994 to establish domestic and export controls on neptunium. In 1998, Britain, France, Japan, and the United States agreed to extend those controls to americium.

3. Estimates of neptunium 237 and americium inventories are based on information in David Albright, Frans Berkhout, and William Walker, *Plutonium and Highly Enriched Uranium 1996* (Oxford: Stockholm International Peace Research Institute [SIPRI] and Oxford University Press, 1997); actinide production is based on rates listed in Oak Ridge publications and the NUS Corporation; and other sources. In addition, this effort has benefited significantly from information generated by the IAEA.
4. Estimate derived from information in *Plutonium and Highly Enriched Uranium 1996*; and W. E. Bickford, “Large Scale Production of Pu-238 to Denature Weapons-Grade Plutonium,” Westinghouse Savannah River Company, Savannah River Site, South Carolina, December 2, 1996, WSRC-TR-96-0382.
5. P. L. Roggenkamp, “Plutonium-238 Production at the Savannah River Plant,” *Transactions of the American Nuclear Society,* vol. 55 (1987), p. 239.
6. Exact U.S. figures are classified, but senior DOE officials have said that the department is starting to evaluate the declassification of neptunium inventories. These officials are optimistic about the prospects of declassifying the total U.S. inventory of separated neptunium 237.
7. This estimate is highly uncertain.
8. This estimate assumes that roughly 10 percent of the 1,100 tonnes of plutonium in discharged spent fuel is plutonium 241, which has a half-life of 13.2 years. Of the 110 tonnes of plutonium 241, we estimate that about 40 tonnes has decayed to americium 241. In addition, the spent fuel contained a total of about five tonnes of americium 241, americium 242m, and americium 243 when it was discharged from reactors. See also Bickford, “Large Scale Production of Pu-238.” The accumulation of americium 241 in military stocks of weapon-grade plutonium is based on assuming a fraction of about 0.4-0.5 percent plutonium 241.
9. Telephone interview with Laura Ramsey, Office of Public Affairs, Rocky Flats Environmental Technology Site, Golden, Colorado, October 16, 1998.