Union of Concerned Scientists

EXECUTIVE SUMMARY

Excess Plutonium Disposition

The Failure of MOX and the Promise of Its Alternatives

HIGHLIGHTS

For the past 20 years, the United States has been developing and trying to execute plans to dispose of about 50 metric tons of weapons-usable plutonium that the military no longer needs. The primary goal of the program is to convert plutonium into a form much harder for terrorists to steal and use to make a nuclear bomb. The U.S. Department of Energy has focused on a risky plan to turn the plutonium into fuel for commercial nuclear power reactors. But due to poor planning and bad decisions, the program has experienced major delays, and its estimated total cost has ballooned from $1.5 billion to over $30 billion. The Obama administration now says it is unaffordable. Cheaper and safer alternatives exist, which do not require using nuclear reactors, but implementing any of them will require concerted national effort and the political will to move the program in the right direction.

"A Clear and Present Danger"

2014 marked the 20th anniversary of a National Academy of Sciences report that issued a stark warning. Growing stockpiles of weapons plutonium, being removed from dismantled U.S. and Russian nuclear warheads that were no longer needed after the end of the Cold War, represented a "clear and present danger."

The National Academy was concerned that plutonium stored in the form of pits, or finished weapon components, could quickly and easily be returned to use in weapons should tensions again increase between the superpowers. The National Academy also feared that separated plutonium could be stolen by sub-national groups, especially in Russia, where the state of nuclear security was precarious amidst the social and economic crisis that followed the collapse of the Soviet Union. Theft of plutonium is a serious risk because the amount of plutonium needed to make a crude nuclear bomb is small and light enough to be easily carried and does not pose an immediate risk of severe injury to the thief.

To deal with these threats, the National Academy recommended that both the United States and Russia undertake efforts to convert surplus separated plutonium into a form much harder to steal or convert back for use in nuclear weapons. The goal was to meet the "spent fuel standard"—that is, to make the plutonium as inaccessible and hard to steal as the plutonium contained in commercial light-water power reactor spent fuel assemblies, which are large,

Construction of the MOX Fuel Fabrication Plant at the Savannah River Site, years behind schedule and billions over budget, remains unfinished.

heavy, and lethally radioactive. The National Academy recommended that the two countries' plutonium disposition programs proceed essentially in parallel and operate under stringent bilateral and international monitoring.

The U.S. government heeded the National Academy's call. It designated around 50 metric tons of plutonium as surplus to its weapons programs and initiated a major and costly program to dispose of it. In 2000, the United States and Russia signed an agreement in which each country committed to disposing of 34 metric tons of excess plutonium.

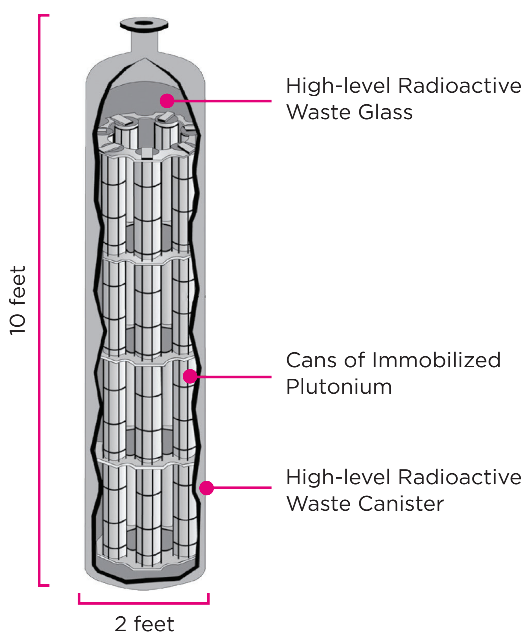
The U.S. Department of Energy (DOE), the agency responsible for management of the plutonium, decided to pursue a "dual track" disposition strategy. The first approach was to blend high-purity plutonium from weapons with uranium and make the mixture into fuel—called mixed-oxide (MOX) fuel—for commercial nuclear power reactors. Once the MOX was irradiated in a reactor, it would meet the spent fuel standard. This approach had appeal because the basic idea was to convert "swords into ploughshares."

The second method, known as immobilization, involved incorporating plutonium into a corrosion-resistant ceramic matrix and then encasing the immobilized plutonium in glass along with highly radioactive nuclear wastes that already existed at DOE sites. Immobilization was intended for impure plutonium that would be difficult to make into reactor fuel, although in principle all surplus plutonium could be immobilized. Immobilization would meet the spent fuel standard by encapsulating plutonium in a large, heavy, and highly radioactive waste form so as to deter theft, without the complication of having to irradiate it in a reactor to achieve a similar end state.

The MOX approach entailed construction of a factory to turn the surplus plutonium into MOX fuel at the DOE's Savannah River Site (SRS) in South Carolina, and recruitment of a number of commercial nuclear power reactors willing to use the fuel.

The immobilization approach that the DOE chose, known as "can-in-canister," also required construction of a new facility to incorporate the plutonium in hockey-puck-sized ceramic disks. The ceramic disks would be packed into cans, which then would be loaded into large metal canisters and sent to the Defense Waste Processing Facility (DWPF) at SRS, where the canisters would be filled with vitrified highly radioactive waste (waste converted into a glass form) as a security barrier to theft (Figure 1).

FIGURE 1. The Can-in-Canister Method



In the can-in-canister method of plutonium disposal, 28 cans of ceramic or glass, each containing about one kilogram of excess weapons plutonium, would be placed in a canister. The cans would be surrounded by glass containing radioactive reprocessing waste at the Department of Energy's Savannah River Site in South Carolina.

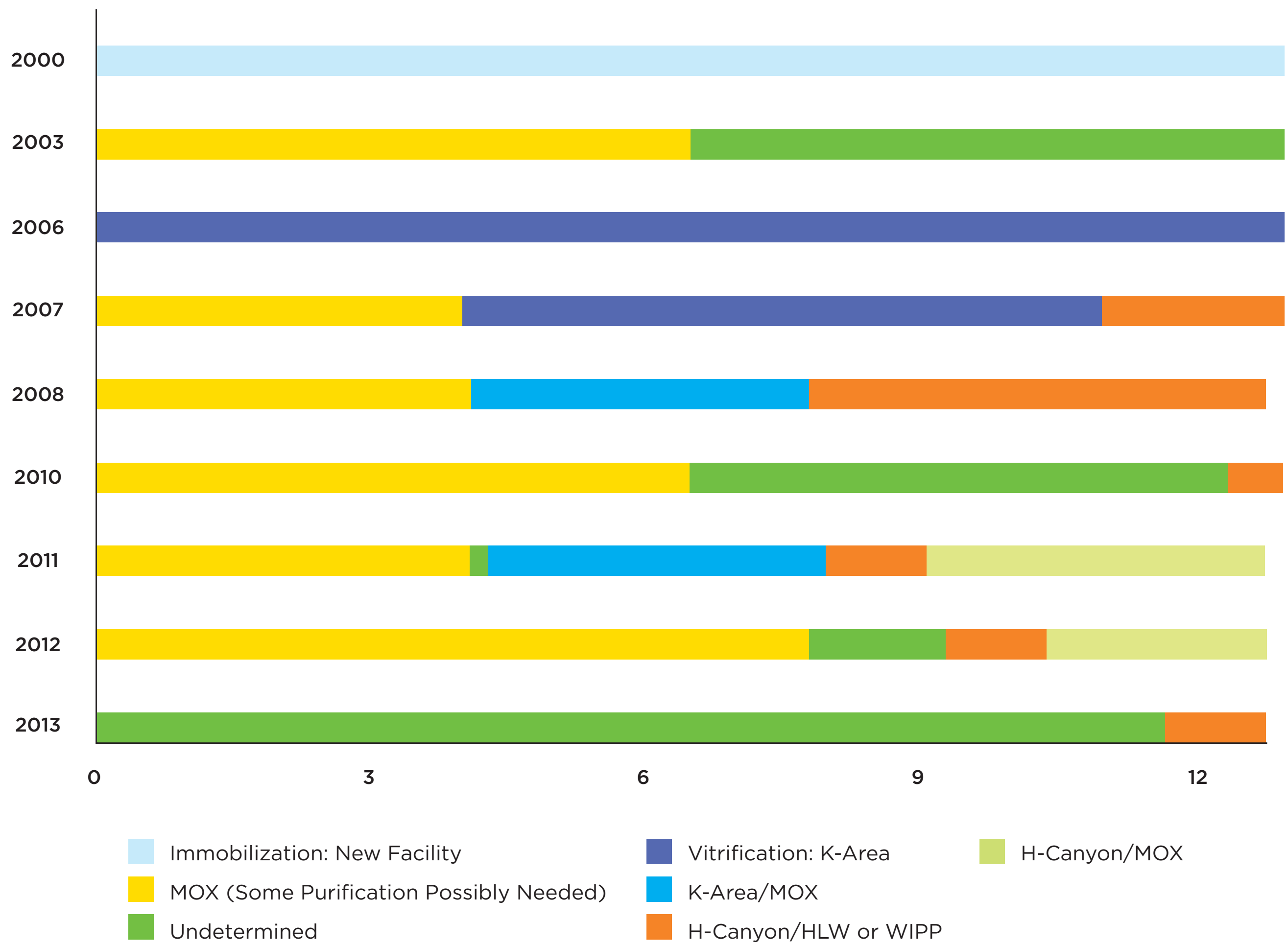
SOURCE: U.S. DEPARTMENT OF ENERGY

TODAY THE U.S. PLUTONIUM DISPOSITION EFFORT IS FLOUNDERING

In 2002 the DOE decided to cancel the immobilization program and focus exclusively on MOX. However, the MOX approach itself has proven far more expensive, technically difficult, and time-consuming than originally anticipated. The MOX Fuel Fabrication Plant at SRS is many years behind schedule. Originally projected to cost about $1.5 billion (in 2014 dollars), it is now estimated to cost at least $30 billion, of which about $4 billion has already been spent. Because of the delays and cost overruns, the DOE now considers the project "unaffordable" and has stated its intention to suspend construction on the plant while it considers alternatives. Congress and the state of South Carolina, however, have other ideas, and have successfully kept the money flowing by compelling the DOE to continue construction of a facility that it no longer wants.

The DOE's mismanagement of the plutonium disposition program was also a major contributor to the cost overruns, delays, and other difficulties that the project is now facing. The DOE was forced to make numerous mid-course corrections to the program due to its chronic inability to resolve problems early or anticipate all the impacts of its decisions. A good example is the DOE's rapidly shifting strategy to dispose of its stockpile of 13 metric tons of excess

FIGURE 2. Evolution of the DOE's Plan for Disposition of 13 Metric Tons of Non-pit Excess Plutonium



Between 2000 and 2013, the DOE proposed changes to its strategy to dispose of 13 metric tons of plutonium no fewer than eight times.

Notes: K-Area is at Savannah River Site; H-Canyon is a chemical processing facility at SRS; WIPP is the Waste Isolation Pilot Project in New Mexico; HLW is high level waste. The total amount of plutonium varies from year to year because of the DOE's changing assumptions and uncertainties.

non-pit plutonium, most of which is weapons-grade. Much of this material was stranded without a disposition path when the DOE decided in 2002 to cancel the immobilization program. Between 2000 and 2013, the DOE proposed changes to its strategy to dispose of the material no fewer than eight times (Figure 2). To date, the DOE has disposed of only a small fraction of this material.

Is the Cure Worse Than the Disease?

In addition to cost, there are other reasons why it makes sense to end the MOX program and replace it with an alternative. Perhaps most notably, the U.S. MOX program is actually helping to weaken domestic and international standards for securing nuclear materials, rather than strengthening them as the National Academy envisioned.

Fundamentally, the purpose of plutonium disposition is to increase international security by reducing the risk that the plutonium will be used again in nuclear weapons. When it first proposed a plutonium disposition program, the National Academy cautioned that the temporary plutonium storage, transportation, and processing activities needed to achieve the spent fuel standard and eventual permanent sequestration in a repository would themselves increase the risk that plutonium could be stolen in the near-term. Every year, several metric tons of plutonium would be processed—enough for hundreds of nuclear weapons. When so much material is being handled and moved around, it is very difficult to protect and keep

> ***The amount of plutonium needed to make a crude nuclear bomb is small and light enough to be easily carried.***

track of all of it down to a precision of eight kilograms, the approximate amount that terrorists could use to make a bomb (see Figure 3 on p. 6).

Unless authorities can minimize the in-transit and in-process risks by requiring very stringent measures for security and accounting for material, the cure for the problem of separated plutonium—disposition—could well be worse than the disease. The goals of the program would be undermined if terrorists were able to divert or steal plutonium made more vulnerable during the disposition process. To address this concern, the National Academy also introduced the concept of the "stored weapons standard": that is, "an agreed and stringent standard of security and accounting must be maintained throughout the disposition process, approximating as closely as practicable the security and accounting applied to intact nuclear weapons."

If the DOE had accepted the National Academy's recommendation and adopted the stored weapon standard for plutonium disposition, it likely would have had to strengthen security relative to its normal practices. Instead, it went in the other direction. The cost and inconvenience of meeting existing security and accounting requirements proved too burdensome for the disposition program contractors, who sought and received numerous exceptions from the Nuclear Regulatory Commission (NRC). (Congress gave the NRC, which licenses commercial nuclear facilities, the authority to license the MOX plant, even though it is a government facility.)

One example of an exception that lowered security is the plan developed by the MOX plant contractor, Shaw AREVA MOX Services, for accounting for plutonium within the plant. Because of flaws in the plant's design, Shaw AREVA MOX Services was unable to demonstrate that it could meet the NRC's requirements for detecting diversions or thefts of small quantities of plutonium in a timely manner. But the NRC overlooked these flaws (whether intentionally or accidentally is not known) and in 2005, authorized Shaw AREVA to begin constructing the plant. Because it was too late to make major changes to the plant's design after construction began in 2007, Shaw AREVA proposed a novel approach to meeting the requirements. Instead of direct inspection of plutonium items to ensure that they were where they were supposed to be at all times and had not been tampered with, the plant operator would rely on computer data. Despite a challenge by public interest groups, the NRC's technical staff and a majority of its board of administrative judges accepted this approach—which renders the MOX plant's material accounting system unacceptably vulnerable to cyberattack. If this decision stands, as is likely, it would set a dangerous precedent.

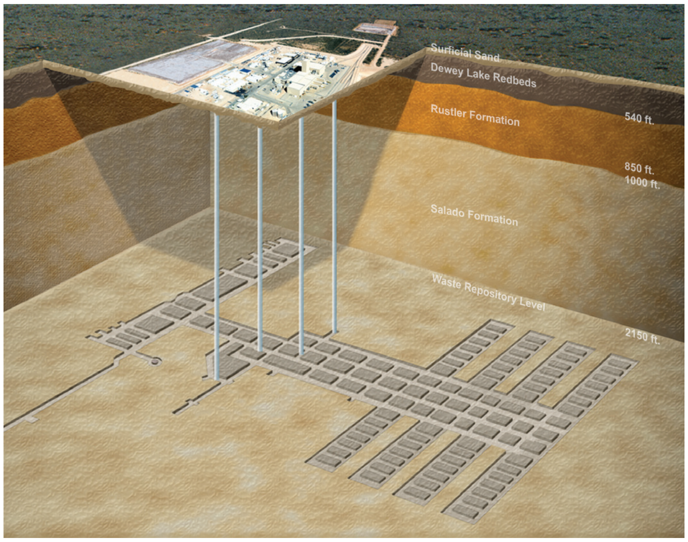
Shaw AREVA and other MOX program contractors also argued that unirradiated MOX fuel is less attractive to terrorists than separated plutonium and does not need to be protected as rigorously when stored at reactors. This assertion is highly dubious because a single MOX fuel assembly contains several bombs' worth of plutonium, and the plutonium can be separated from the uranium in the fuel assembly using relatively simple chemical techniques. Nonetheless, the NRC accepted the argument and authorized a reduction in security requirements. Even worse, the agency is now proposing to weaken security standards more broadly in the United States by applying this concept of "attractiveness" to all facilities and materials through a wide-ranging rulemaking that will be finalized in 2018. It is also promoting the material attractiveness concept internationally, sending a dangerous signal to Russia and other countries with MOX programs. There is little reason to hope that Russia would adopt stronger security standards on its own without the United States leading by example.

A pause in the MOX program would give the DOE a badly needed opportunity to review all security and material accounting problems, and correct them as it pursues an alternative.

The Way Forward

That early period of "clear and present danger" has now passed without serious incident. Russia is no longer in desperate financial straits, and fears of significant diversions of plutonium from Russia's military stockpile have not been realized (although security of the large stocks of plutonium at less well-protected civil facilities remains a major concern). Nonetheless, even though the situation today may be less urgent, it could change rapidly in the future. The long-term objectives of plutonium disposition are still worthwhile. However, the benefits are not unlimited, and the costs of achieving them must be considered in the context of a constrained security budget.

Finding a practical and cost-effective alternative to MOX for plutonium disposition is not a simple task. The DOE put all its eggs in the MOX basket more than a decade ago, and the state of development of immobilization technology



U.S. Department of Energy

The Waste Isolation Pilot Plant in New Mexico is the only functioning geologic repository for nuclear waste in the United States.

was essentially frozen at that time. Moreover, the physical infrastructure that has already been built to support the MOX approach may be difficult to repurpose for other options. This is unfortunate because at the beginning of the disposition program, it appeared that immobilization had the potential to be faster and cheaper than MOX. However, in order for immobilization to be a viable option today, the DOE would have to invest heavily in its development to make up for lost time.

There is another alternative approach that the DOE has already used to dispose of several metric tons of surplus plutonium, and in principle it could be implemented more cheaply and quickly than immobilization. This third alternative is downblending: diluting plutonium with an inert and nonradioactive material, to a concentration of less than 10 percent by weight, and disposing of it underground at the Waste Isolation Pilot Plant (WIPP) in New Mexico. (Currently WIPP cannot accept more concentrated and sensitive forms of plutonium because it does not have the appropriate level of security.) WIPP is the only functioning geologic repository for nuclear waste in the United States, so this approach could potentially result in the most rapid disposal of the surplus plutonium. The key word here is "potentially." In February 2014, operations at WIPP were halted indefinitely after a barrel of radioactive waste overheated and released plutonium into the repository and the environment. However, even if the repository does not reopen for several years, downblending would still be a relatively attractive disposition option compared to the costly and slow MOX approach.

The WIPP approach does not strictly meet the "spent fuel standard" as defined by the National Academy, in that it does not add a radiation barrier to make the waste forms as hazardous for a thief to access as spent nuclear fuel. The DOE asserts that the material it uses to blend down the plutonium, referred to informally as "stardust," has special chemical properties that would make it difficult for terrorists to extract the plutonium for use in weapons. Although the DOE has stated that this approach provides a level of protection equivalent to that of the spent fuel standard, the National Academy report rejected the notion that simply mixing plutonium with non-radioactive chemicals would be adequate. Nevertheless, if the diluted plutonium can be moved quickly to a geologic repository where it would be permanently sealed off, the addition of a radiation barrier may be less important. To directly address the Academy's concerns and provide convincing assurance to the public, the DOE should make the analysis underlying its conclusion—that the combination of dilution and early geologic disposal would provide a level of security comparable to that of a radiation barrier—publicly available.

The specific composition and properties of stardust are classified information. The disposal of classified materials in WIPP is problematic for a number of reasons. First, it makes it more difficult—or even impossible—for civil environmental authorities and the public to fully assess and approve the safety risks posed by the material. Complete knowledge of all materials is particularly important in the wake of the February 2014 event, which was caused by a still-yet-to-be-determined chemical reaction that occurred after an unapproved combination of materials was placed in the drum. Second, classified materials place an obstacle

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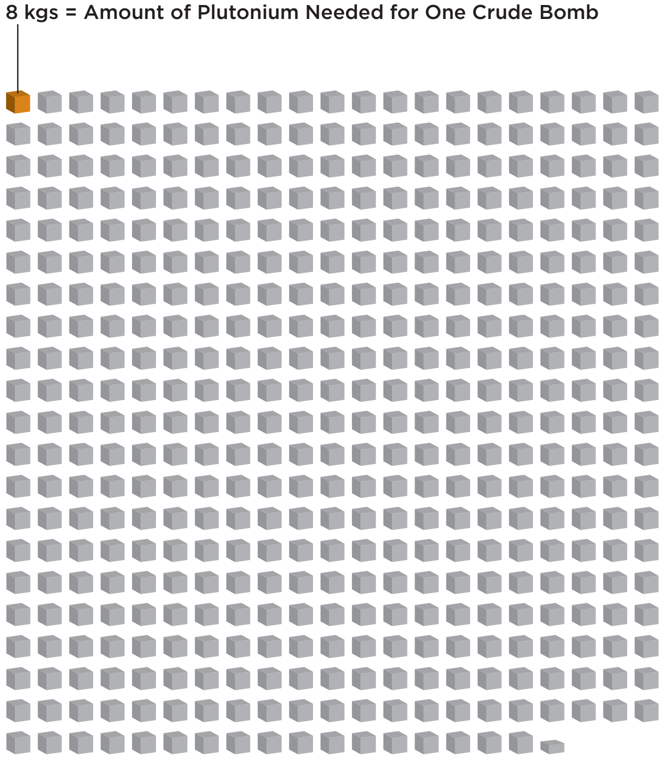
in the way of international verification of the disposition program. Inspectors from the International Atomic Energy Agency would likely be unable to directly access and verify the contents of waste drums that contain classified materials.

Any disposition alternative would likely have to leverage the DOE's existing infrastructure to the greatest extent possible, given the prohibitive capital cost of building entirely new facilities. The DOE has an array of facilities that could play a role in implementing a disposition option. These include:

- Defense Waste Processing Facility (DWPF): The SRS facility that vitrifies high-level radioactive wastes for eventual geologic disposal. The original plutonium immobilization program would have piggy-backed on DWPF operations.

- K-Area Complex: A former plutonium production reactor at SRS that has been converted to a storage facility for non-pit plutonium and has available space that could be used to house plutonium processing equipment.
- H-Canyon: A chemical processing plant at SRS originally used to support nuclear weapon production.
- HB-Line: A plutonium processing facility on top of H-Canyon.
- Mixed-Oxide Fuel Fabrication Facility (MFFF): now partially complete, the building could potentially be used for purposes other than MOX production.

FIGURE 3. Amount of Plutonium Necessary to Create a Bomb, Versus Amount of Plutonium Requiring Disposition



The amount of plutonium needed to create a bomb is a tiny fraction of the amount to the Unites States has agreed to process each year, making security an important factor in selecting a disposition method.

- Waste Solidification Building (WSB): A nearly complete facility at SRS intended to solidify and prepare certain types of radioactive waste from the MOX plant for disposal.
- TA-55: The plutonium processing facility at Los Alamos National Laboratory in New Mexico.

While using existing infrastructure has inherent advantages, these would be offset if significant upgrades were needed to maintain high levels of safety and security, or if the project would significantly extend the operating lifetimes of facilities that were scheduled for shutdown and decommissioning.

In April 2014, the DOE released the report of the internal Plutonium Disposition Working Group that it had convened a year earlier to evaluate alternatives to the MOX program. The report discussed three non-reactor disposition options: immobilization with high-level radioactive waste, downblending and disposal, and disposal in deep boreholes.

The report's examination of the alternatives fell short in a number of respects. With regard to immobilization, the report considered only a couple of options and judged they had insurmountable problems. It did not attempt to come up with ideas about how to make immobilization work.

For instance, the report claimed that can-in-canister immobilization could not be implemented at SRS because there is not enough high-level radioactive waste remaining there to provide a sufficient radiation barrier to dispose of 34 metric tons of surplus plutonium (the quantity subject to the U.S.-Russian agreement) in a way that meets the spent fuel standard. But in fact, because of ongoing delays in waste vitrification at SRS's Defense Waste Processing Facility (DWPF), there appears to be sufficient cesium-137 still left in the liquid waste tanks to accomplish the task without causing further significant disruptions to the DWPF schedule, provided that immobilization can begin by around 2025.

The DOE is now conducting a follow-on study to the April 2014 report. In this follow-on study, the DOE should consider a broader range of non-reactor alternatives, either singly or in combination, in order to establish which are compatible with the capabilities of the existing infrastructure. Combinations of options might work where there are commonalities in the processes needed to prepare plutonium for disposition.

In its review, the DOE should also reconsider the original goals of plutonium disposition and to what extent they continue to be the right ones today. In particular, it should reexamine the spent fuel standard and determine whether alternatives to a strict interpretation may achieve an acceptable outcome at an affordable cost. In doing so, it should develop—and make public to the extent possible—a framework in which to compare the

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In the can-in-canister approach, canisters are filled with vitrified highly radioactive waste, and stored in the Defense Waste Processing Facility.

security benefits of various options on a consistent basis, as well as to make plutonium disposition compatible with DOE's overall policy on nuclear material security.

Revisiting the spent fuel standard could extend the range of acceptable options for disposition. For instance, if the DOE lowered the acceptable radiation-barrier dose rate, the issue of the remaining supply of cesium-137 would be less critical. However, options that can fully meet the spent fuel standard should be given priority consideration. The options that should be studied further include:

Can-in-canister immobilization. Can-in-canister immobilization at SRS should remain the top alternative. In this option, a glovebox line (where personnel could carry out operations manually) to immobilize plutonium in glass or ceramic would be installed in the K-Area Complex. The issues associated with this option include how long it would take to start up such a facility and whether its production capacity could be high enough to achieve a reasonable disposition rate. The approach must also be compatible with the DWPF waste vitrification schedule.

Homogeneous immobilization. Another immobilization alternative would entail dissolving the plutonium in acid in the H-Canyon/HB-Line and transferring the liquid solution to the high-level waste tanks for vitrification in DWPF. The resulting glass canisters could accommodate about 1 percent

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plutonium by weight and would be a relatively homogenous waste form. Such homogeneous immobilization would be relatively slow because it is limited by the rate at which plutonium could be dissolved in H-Canyon/HB-Line. However, it could be a useful approach to dispose of a fraction of the surplus plutonium inventory in parallel with one of the other options.

Downblending and WIPP disposal. The range of potential options for downblending and disposal in WIPP is also broader than that considered in the DOE's April 2014 report. For instance, the amount of plutonium that could be disposed of in WIPP per unit volume of waste could be increased, thereby increasing the amount of plutonium without using up more of the available disposal volume. Our estimate indicates that several downblending approaches would allow 34 metric tons of plutonium to be disposed of in WIPP without requiring an increase in the maximum waste volume capacity as established by the Waste Isolation Pilot Plant Land Withdrawal Act. Not requiring additional capacity is important because a disposition option that would require a change in the law to increase capacity would likely be very controversial.

An attractive option for downblending is not to use a classified material such as stardust to dilute plutonium below a concentration of 10 percent by weight but to further dilute it to below 1 weight-percent in a matrix of concrete. This would not increase the number of waste drums necessary to dispose of a given quantity of plutonium. Downblending into concrete can be done at a far lower temperature than either immobilization into glass or producing MOX fuel, and therefore would pose a lower accident risk. In addition, by not using stardust, the DOE can avoid the problems associated with placing substances with classified compositions into WIPP.

All WIPP options, of course, are contingent on the DOE's ability to safely reopen the repository, determine the root cause of the February 2014 waste drum release, and take all necessary steps to ensure that such an event does not occur again.

[A pause in the MOX program would give the DOE a badly needed opportunity to review all security and material accounting problems, and correct them as it pursues an alternative.]

Conclusion

The MOX program has veered off on the wrong track. Immobilization or downblending are the only technologies clearly capable of handling the bulk of the current and projected future inventories of excess plutonium. The DOE should explore the full range of options before making a decision and revising its disposition plan. Given the lengthy period of time that will be needed to complete the task under any option, the DOE should take the time it needs to carefully consider the options and to make the right decision. A well-justified proposal will also help to obtain Russia's consent, which will be required for any change to the U.S. plan for disposing of the 34 metric tons of plutonium covered under the bilateral agreement.

And finally, every dollar spent on finishing construction and installing equipment in the MOX plant that may never be used is a wasted dollar, and moves a potential repurposing of the structure further out of reach. Congress should give the DOE the flexibility to stop throwing good money after bad while it determines the best path to future success.

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