Evolution of Surplus Plutonium Management and Disposition Strategies in the United States

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Abstract

Several nations possess stockpiles of separated plutonium-239, principally resulting from the development of nuclear weapons, but also from reprocessing commercial spent nuclear fuel. The United States has declared about 50 metric tons of weapons-grade plutonium in various physiochemical forms as surplus. Much of this inventory (34 metric tons) is subject to a bi-lateral disposition agreement (the Plutonium Management and Disposition Agreement, PMDA) signed by the United States and the Russian Federation in 2000, when the initial paths for disposition in the United States were: (1) the generation of irradiated MOX fuel and (2) immobilization in high-level waste (HLW). In 2010 the PMDA was amended such that the United States indicated it would pursue only the irradiation of MOX fuel. Disposition was largely about rendering the plutonium unattractive and inaccessible (as irradiated MOX spent fuel) and was more muted on the issues of disposal, as its subsequent permanent isolation was expected to be in the national geologic repository at Yucca Mountain. Since 2010, the geopolitical and technical dynamic has shifted considerably, forcing the United States to adjust its plutonium disposition strategy. Such shifts include the termination of United States MOX fuel development, the cancellation of a deep borehole field test demonstration, uncertainty in the availability of Yucca Mountain or other repository, efforts to expand the Waste Isolation Pilot Plant volume disposal capacity, the potential for advanced reactors using plutonium fuels has risen, and the desire for renewed plutonium pit production has emerged. Most recently the Department of Energy has elected to pursue a multi-decade strategy of ‘dilute and dispose’ wherein weapons-grade plutonium is down-blended with an adulterant to ensure it “is not recoverable without extensive reprocessing” and disposed as transuranic waste in the Waste Isolation Pilot Plant. The dilute-and-dispose strategy faces new technical, regulatory, and geopolitical challenges. This paper will illuminate the challenging path of the U.S. plutonium disposition program, discussing the evolution of disposition strategies in light of shifting domestic and international geopolitical environments and changing technical influences. Insights from this review may be useful to those nations now beginning to contemplate their own objectives for surplus plutonium disposition.

1. Introduction

Several nations, including the United States (U.S.), have amassed stockpiles of separated plutonium-239, principally resulting from the development of nuclear weapons, but also from reprocessing commercial spent nuclear fuel. Resulting from the 1993 Clinton administration policy on Nonproliferation and Export Control (White House, 1993), a substantial portion of the U.S. total inventory of separated weapons-usable plutonium was determined to have exceeded strategic needs and was declared surplus. Further, in January 1994, President Clinton and Russia’s President

Yeltsin issued a Joint Statement Between the United States and Russia on Non-Proliferation of Weapons of Mass Destruction and the Means of Their Delivery (White House, 1994), helping to couple the nonproliferation efforts for disposition of surplus weapons-usable fissile plutonium in both countries.

To date the U.S. has declared more than 60 metric tons (MT) of weapons-useable plutonium material as surplus (DOE, 2015, fig. S-7), though the reported total can vary slightly due to minor accounting and inventory changes (GAO, 2019, p.7, NASEM, 2020, p. 18). Regardless, the plutonium material within the designated surplus inventory takes many differing physical forms including plutonium pits used as the core of nuclear weapons, pit production scraps and residues, plutonium metals and oxide stocks not made into pits, and DOE-managed spent nuclear fuel (GAO, 2019, fig. 2, NASEM, 2020, p. fig 2.1). Such quantities of separated plutonium can present security and proliferation risks thereby necessitating some form of disposition that, by the International Atomic Energy Agency (IAEA) definition (IAEA, 1972, p. 4) renders it "practicably irrecoverable" by treatment into "forms unusable for nuclear weapons" (DOS, 2000, p. 1).

Since the mid-1990s the DOE has pursued various programs and approaches for effecting the disposition of the surplus plutonium inventory. The differing surplus plutonium forms, quantities, and locations, in addition to unanticipated changes in the availability of certain disposition pathways, has led to an evolving mix of disposition strategies over the past two decades.

1.1 What is disposition?

Conceptually disposition of surplus plutonium involves two aspects to effectively achieve both non-proliferation security objectives and long-term environmental stewardship:

1. the rendering of the plutonium material into "forms unusable for nuclear weapons" and,
2. the emplacement of the rendered material in a deep geologic disposal facility.

In the context of safeguards, surplus plutonium being rendered 'unusable for nuclear weapons' is to make it 'practicably irrecoverable'; that is the physiochemical form, not the location, is such that it would be seen as more practicable to recover weapons-usable plutonium from less physiochemical altered stocks or new plutonium production. Indeed, the retrieval of otherwise unaltered weapons-grade plutonium from a repository sometime in the future might be viewed as more practicable than new plutonium production.

As a non-proliferation matter, a principal disposition objective is to render the surplus plutonium unavailable for use in weapons, using a metric known as the 'spent fuel standard' put forth by the National Academy of Sciences in 1994 (NAS, 1994). The Department of Energy adopted the spent fuel standard as "a concept to make the plutonium as unattractive and inaccessible for retrieval and weapons use as the residual plutonium in the spent fuel from commercial reactors" (DOE, 1996a).

Regarding disposal, regulations for deep geologic repositories in the U.S. and elsewhere are generally designed to support the permanent disposal of the emplaced waste by isolation from the accessible environment, i.e., the environmental stewardship objective. Typical disposal regulations note the emplacement of waste for disposal is performed without the <u>intention</u> to retrieve the waste. The same disposal regulations also call for not precluding the subsequent retrieval of waste, as a form of assurance that, if necessary, remedial actions could be accomplished. While it is technically conceivable that weapons-usable surplus plutonium emplaced in a mined disposal facility could maintain the environmental safety objective (the post-closure repository performance criteria), underground emplacement alone would not achieve the objective to render it 'unusable for nuclear weapons', though there is some flexibility in the distinction as will be seen with deep borehole disposal.

Thus, regarding weapons-usable surplus plutonium it is thought necessary to render it into a form 'unusable for nuclear weapons' *before* disposal to first make it 'practicably irrecoverable'; disposal in a geologic repository is then intended to achieve the long-term environmental safety objective, and while thwarting retrievability, repository emplacement does not prevent it's retrieval.

The context for both aspects of non-proliferation objectives and environmental stewardship have changed over time, driven largely by geopolitical and technical dynamics, and reflected in the evolution of the surplus plutonium disposition strategies of the last twenty years.

2 Evolution of U.S. Surplus Plutonium Disposition Strategies

Concise summaries of the history of surplus plutonium disposition (SPD) strategies are provided in NASEM, 2020 (Box 2-2), GAO, 2019 (Appendix II and Appendix III), and CRS, 2017. Exhaustive details for those summaries are largely drawn from the numerous records of key DOE National Environmental Policy Act (NEPA) documentation, including:

1. 1996: DOE/EIS-0229, Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement (**1996 PEIS**).
2. 1999: DOE/EIS-0283, Surplus Plutonium Disposition Final Environmental Impact Statement (**1999 SPD EIS**), which was tiered from DOE/EIS-0229, and later supplemented in,
3. 2015: DOE/EIS-0283-S2 Final Surplus Plutonium Disposition Supplemental Environmental Impact Statement (**2015 SPD SEIS**).

The Environmental Impact Statement documents noted above are augmented by various NEPA action documents (records of decisions, supplemental analyses, notices of preferred alternatives, interim action determinations, amendments. etc.) sometimes involving kilograms of plutonium material (DOE 2011), but which also help provide additional context and insight to the evolving efforts to provide disposition.

2.1 The 1996 Storage and Disposition of Weapons-Usable Fissile Materials Final PEIS

Beginning with the 1996 PEIS the DOE considered a sweeping range of 37 programmatic alternatives for disposition of surplus plutonium (DOE 1996, fig. S.3-2). The baseline 'no action' option and those disposition options deemed "reasonable" by the PEIS are extracted and presented in Figure 1, below.

In all cases, the intent for disposition was to meet the Spent Fuel Standard as defined by the National Academy of Sciences (NAS, 1994), which the PEIS took to mean that the "surplus weapons-usable Pu should be *made as inaccessible and unattractive for weapons use* as the much larger and growing quantity of Pu that exists in spent nuclear fuel from commercial power reactors" (emphasis added).

PEIS Storage and Disposition Alternatives

Storage Options		
S1	No Disposition Option Continued Storage	Baseline
Direct Disposal Options		
D2	Deep Borehole (Immobilization)	**Reasonable**
D3	Deep Borehole (Direct Emplacement)	**Reasonable**
Immobilization Options with Radionuclides		
I3	Vitrification Borosilicate Glass Immobilization (New Facility)	**Reasonable**
I4	Ceramic Immobilization	**Reasonable**
I5	Electrometallurgical Treatment	**Reasonable**
Reactor And Accelerator Options		
R2	Existing LWRs	**Reasonable**
R2a	Partially Completed LWRs	**Reasonable**
R3	Evolutionary Or Advanced LWRs	**Reasonable**

Figure 1. Excerpted Screening Process Results of 1996 PEIS for Surplus Plutonium Disposition Options (adapted from DOE 1996, fig. S.3-2)

Most of the options were disqualified or eliminated over concerns of retrievability, technical viability or maturity, or ES&H, including the option for disposal at WIPP over concerns of sufficient capacity. At the time, deep borehole disposal of surplus plutonium (with immobilization in glass/ceramic or direct emplacement) was considered as primarily a disposition alternative (to thwart recovery of the plutonium), and the emplacement in a deep (> 4 km) borehole was a means to achieve it. However, a deep borehole disposal development program was not being pursued by the DOE at that time, ostensibly due to the Nuclear Waste Policy Act (NWPA) of 1982 (as amended 1987) designating a deep geologic disposal facility for spent nuclear fuel and high-level waste be developed at Yucca Mountain. This would later change after 2010.

In the end, the 1996 PEIS "preferred alternative" strategy for disposition was to allow for immobilization in glass or ceramic forms and burning as a mixed oxide (MOX) fuel in existing reactors. In this regard, subsequent *disposal* was assumed to occur in the nations designated deep geologic disposal facility for spent nuclear fuel and high-level waste, though strictly speaking glass/ceramic immobilization and irradiated MOX fuel alone provided the *disposition*, by rendering the surplus plutonium inaccessible and unattractive for weapons use. The timing and extent to which either immobilization or MOX irradiation would occur was subject to technology development, detailed cost proposals, nonproliferation considerations, and negotiations with Russia.

To this last point, we note in 1998 the U.S. and Russia signed a 5-year agreement (1999: DOE/EIS-0283, Vol. 2, Appendix A.8) to provide a basis for cooperation over how surplus plutonium would be managed (and that stated the intention of removing ~50 metric tons of plutonium from each country's stockpile), the coupling the disposition strategies of the U.S. and Russia was furthered.

2.2 The 1999 Surplus Plutonium Disposition EIS

As noted, the 1999 SPD EIS is tiered from the 1996 PEIS, and was to address the extent to which each of the two plutonium disposition approaches (immobilization and MOX) could be implemented.

The 1999 SPD EIS noted that 17 metric tons of the surplus plutonium inventory was not suitable for use in MOX fuel and should be immobilized, and therefore fabricating all (of the then 50 metric tons) of surplus plutonium into MOX fuel was no longer a reasonable alternative to consider. Conversely, the alternative for immobilization of all the surplus plutonium inventory was analyzed. Further, the 1999 SPD EIS noted the disposition of surplus plutonium would also involve disposal of both the immobilized plutonium and the MOX spent fuel in the geologic repository designated by the NWPA.

The 1999 SPD EIS provided the DOE's then preferred alternative for the disposition of up to 50 metric tons of surplus weapons-usable plutonium using a hybrid approach that involved both a ceramic can-in-canister immobilization approach and the MOX spent fuel approach. Under the hybrid approach ~17 metric tons were to be immobilized in a ceramic form, placed in cans, and embedded in larger canisters containing high-level vitrified waste for ultimate disposal in a potential geologic repository pursuant to the NWPA. The remainder ~33 metric tons were to be used to fabricate MOX fuel, which would be irradiated in existing domestic commercial reactors.

In preferring a hybrid approach of immobilization and irradiating MOX fuel, the 1999 SPD EIS articulated the need for three types of facilities: a facility for pit disassembly and conversion into plutonium dioxide suitable for disposition, a facility for performing immobilization for eventual disposal in the NWPA designated repository, and a facility for the fabrication of MOX fuel. The 1999 SPD EIS analyzed numerous combinations of alternative locations for the three facilities and ended with a preference for siting all three facilities at the Savannah River Site (SRS).

Perhaps more notable than the disposition approaches and facility siting is the anticipated geopolitical value of the preferred disposition strategy with regard to furthering nonproliferation objectives with Russia. As noted in the 1999 SPD EIS, "Pursuing the hybrid approach provides the best opportunity for U.S. leadership in working with Russia to implement similar options for reducing Russia's excess plutonium in parallel. Further, it sends the strongest possible signal to the world of U.S. determination to reduce stockpiles of surplus weapons-usable plutonium as quickly as possible and in a manner that would make it technically difficult to use the plutonium in weapons again. Pursuing both immobilization and MOX fuel fabrication also provides important insurance against uncertainties of implementing either approach by itself. The construction of new facilities for the disposition of surplus U.S. plutonium would not take place unless there were significant progress on plans for plutonium disposition in Russia."

Indeed, the nonproliferation groundwork laid prior to and during the 1999 the SPD EIS is evidenced by the subsequent agreements between the United States and the Russian Federation to further the disposition their respective surplus plutonium inventory.

2.3 The 2000 Plutonium Management and Disposition Agreement

The 2000 "Agreement Between The Government Of The United States Of America And The Government Of The Russian Federation Concerning The Management And Disposition Of Plutonium Designated As No Longer Required For Defense Purposes And Related Cooperation" (DOS, 2000), or simply the Plutonium Management and Disposition Agreement (PMDA), can trace its existence to substantial precursor nonproliferation work between the U.S. and Russia, and as acknowledged in the 1996 PEIS and 1999 SPD EIS.

The PMDA served to affirm "the intention of each country to remove by stages approximately 50 metric tons of plutonium from their nuclear weapons programs and to convert this plutonium into forms unusable for nuclear weapons" and to commit that "Each Party shall, in accordance with the terms of this Agreement, dispose of no less than thirty-four (34) metric tons of disposition plutonium."

Thus, of the more than 60 metric tons of weapons-useable plutonium material declared as surplus by the U.S., 34 metric tons became an important political commitment to disposition by the PMDA, and thereby supporting the development of the disposition preferred alternatives expressed in the 1999 SPD EIS.

The PMDA calls out that disposition shall be by one or more of the following methods:

a) irradiation of disposition plutonium as fuel in nuclear reactors;
b) immobilization of disposition plutonium into immobilized forms; or
c) any other methods that may be agreed by the Parties in writing.

Referring to the discussion in Section 1.1, we note that the PMDA does not explicitly call for the disposal of dispositioned plutonium. While ultimate disposal in a geologic repository can be assumed, the PMDA acknowledged that disposition by immobilization or irradiated MOX fuel was sufficient treatment into "forms unusable for nuclear weapons", i.e., rendering the plutonium 'practicably irrecoverable'.

In 2000, Russia agreed to incorporate all 34 metric tons into MOX fuel for irradiation in its nuclear power reactors, while the U.S. agreed to the hybrid approach of immobilization and MOX fuel irradiation. However, by 2002 in an amended record of decision (DOE, 2002) to the 1999 SPD EIS, the DOE/NNSA cancelled the immobilization approach due to budgetary constraints.

Effectively from about 2002 on the U.S. and Russia were both committed to disposition at least 34 MT of surplus plutonium by irradiating MOX fuel. This change in U.S. disposition strategy was later also reflected in the 2010 amendment to the PMDA (DOS, 2010) "Disposition shall be by irradiation of disposition plutonium as fuel in nuclear reactors *or any other methods that may be agreed by the Parties in writing*.". This latter emphasis will be revisited in Section 2.7

However, on the basis of the 2000 PMDA and the cancellation of immobilization development in 2002, the U.S. began the development of MOX fuel fabrication capacity in earnest.

2.4 The MOX Fuel Fabrication Facility

Despite the political weight of the PMDA, the development of MOX fuel fabrication capability, and the intention to irradiate MOX fuel in commercial reactors, was not without challenges.

2.4.1 The Beginning of MOX

In March 1999, DOE awarded a contract for non-site-specific work associated with the development of the initial design for the MOX fuel fabrication facility and plans. Once the 1999 SPD EIS Record of Decision was issued (January 2000) efforts to develop a MOX fuel fabrication facility (MFFF) gained additional momentum.

By February 2001, the Nuclear Regulatory Commission had received an application to construct a MFFF on the DOE's Savannah River Site (SRS) near Aiken, South Carolina. Four years later, the NRC issued a construction authorization (NRC, 2005) with construction beginning in 2007.

Costs and schedule delays began to rise almost immediately. As reviewed in (CRS, 2017), the estimated MFFF project costs were asserted to be ~$1 billion in 2002, rising to $4.8 billion in 2007 at start of construction, and by the FY2014 budget request, the estimate had risen to $7.78 billion. One year later in the FY2015 budget request the MOX fuel program for plutonium disposition had risen to $30 billion, and by 2018 the cost was $49.4 billion.

Understandably, the DOE slowed construction during FY2013 and FY2014 while other disposition options were evaluated. Before turning to alternative disposition strategies (see Section 2.5), it is necessary to conclude the MOX saga.

2.4.2 The End of MOX

The National Defense Authorization Act for Fiscal Year 2018 (GPO, 2017, Sec. 3121) allowed DOE to terminate construction of the MFFF if, among other things, DOE identified an alternative that would cost less than approximately half of the MOX fuel strategy. Accordingly, the NNSA Office of Cost Estimating and Program Evaluation did estimate in 2018 (NNSA, 2018), that a dilute and dispose strategy would be less than half the cost of the MOX strategy. Consequently, DOE notified Congress of its decision to cancel MFFF construction, and by the fall of 2018, DOE had issued a notice of termination of the contract for the MFFF and following suit the MOX construction contractor requested the NRC to terminate the construction authorization (NRC, 2018) issued in 2005. The construction authorization was terminated several months later (NRC 2019).

In authorizing the MOX plutonium disposition program, Congress gave DOE certain milestone to begin processing plutonium in the MFFF or otherwise remove the plutonium stockpile from the state of South Carolina, or face fines of $100M per year. Having failed to meet those milestones, the federal government agreed in 2020 (Exchange Monitor, 2020) to pay $600M to settle a lawsuit filed by South Carolina, and further agreed to move 9.5 metric tons out of South Carolina by 2037 or face another $1.5B in additional payments to the state.

2.5 2014 - The Search for Alternatives

As it became evident that the MOX fuel approach would cost significantly more and take longer than initially anticipated, the DOE opted to assess alternative plutonium disposition strategies, and established in 2013 an internal Plutonium Disposition Working Group.

The working group evaluated five options against five criteria (DOE, 2014):

Options		Criteria
• Irradiation of MOX Fuel in Light Water Reactors • Irradiation of Plutonium Fuel in Fast Reactors • Immobilization (Ceramic or Glass Form) with High-Level Waste • Downblending and Disposal • Deep Borehole Disposal		• Meeting international commitments • Cost • Duration to begin disposition and to complete the U.S. 34 MT mission • Technical viability • Legal, regulatory, and other issues

While the irradiation of plutonium fuels would provide the for spent fuel standard, the cost and schedule implications were already evident. Immobilization with HLW glass was discarded over concerns of sufficient HLW stocks (at SRS) and a desire to not distract from completing the Hanford Waste Treatment and Immobilization Plant then under construction to vitrify the 56 million gallons of tank waste.

Considerable development of a deep borehole disposal concept had been ongoing since ~2009, with the turn away from the Yucca Mountain project by the Obama Administration. Those efforts included the fielding of deep borehole demonstration project (DOE, 2013) that progressed to the selection of four companies to identify a demonstration site. These plans were abandoned at the beginning of the Trump Administration as it initially turned back toward Yucca Mountain (DOE, 2016).

Ultimately, 'dilute and dispose' was selected by the Plutonium Disposition Working Group as the most viable option.

2.5.1 Dilute and Dispose

The dilute and dispose disposition option calls for plutonium oxide to be "mixed/blended with inert material.... Inert material would be added to reduce the plutonium content to less than 10 percent by weight and inhibit plutonium recovery and could include dry mixtures of commercially available materials" (DOE, 2015, p. S-31). The inert material is a classified adulterant added as a dry mixture to the plutonium oxide to ensure that the plutonium "is not recoverable without extensive reprocessing" (SRNS, 2016, p. 8), in the effort to adhere to intent of rendering the plutonium into "forms unusable for nuclear weapons" if not the letter of the spent fuel standard (see Section 1.1).

Upon diluting the surplus plutonium material with the classified adulterant, the resulting product is packaged in specialized criticality control containers and overpacks, declared as transuranic waste, and readied for transport to the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico for permanent disposal as defense transuranic waste. WIPP is a geologic repository for disposal of transuranic waste generated by atomic energy defense activities. It is not authorized for the disposal of spent nuclear fuel (MOX or otherwise) nor other high-level waste forms. The dilute and dispose option is in contrast to the immobilization or irradiation options that would result in SNF/HLW for disposal in the repository designated by the NWPA.

The dilute and dispose option is discussed in more detail in Section 2.7, but first it had to become recognized as the preferred alternative for surplus plutonium disposition through the NEPA process.

2.6 The 2015 Surplus Plutonium Disposition Supplemental EIS

Having considered alternatives for surplus plutonium disposition other than MOX, it was necessary for DOE to prepare a supplement to the 1999 SPD EIS to effect a change in disposition strategy. Recalling that the MOX MFFF had not yet been cancelled but that cost/schedule concerns drove consideration of alternative in 2014, the purpose of the SPD SEIS (DOE, 2015) was explicitly "not to reconsider DOE's previous decisions about pursuing the MOX fuel approach for 34 metric tons". Rather the SPD SEIS to evaluated one or more options, including immobilization (via can-in-canister or vitrification with HLW), MOX, and preparation as contact-handled transuranic waste for potential disposal at WIPP, for the disposition of 13.1 metric tons, consisting of pits and non-pit metals and oxides separate from the 34 metric tons of pits, metal and oxides targeted for MOX fuel fabrication (see DOE 2015, Fig. S-7).

The subsequent April 2016 record of decision (DOE, 2016a, p. 19588) selected the dilute and dispose at WIPP option for dispositioning 6 metric tons of diluted non-pit plutonium and later amended the record of decision (DOE, 2020) to add the remaining 7 metric tons of the 13.1 metric tons considered in the SPD SEIS.

For all practical purposes, this SPD SEIS served as a turning point in disposition strategy; from a combination of MOX and immobilization in the 1999 SPD EIS, to the first inclusion of the option to dilute and dispose at WIPP, and with the end of MOX eventually a full turn to dilute and dispose at WIPP as the only strategy for disposition of more than 48 metric tons of the surplus plutonium inventory.

2.7 2016 Review of DOE Plans for Disposal of Surplus Plutonium in WIPP

Any change in disposition strategy can rightfully cause new concerns about its viability, cost, project feasibility and risks, etc. Such was the case for the relatively rapid turn of events involving the circa 2014 MFFF costs and the evaluation of disposition alternatives that gave rise to the dilute and dispose concept. Accordingly, in the Energy and Water Development Appropriations Bill (U.S. Congress, House, 2016, p. 114), the National Academies of Sciences, Engineering, and Medicine (NASEM) was tasked to evaluate the general viability of the DOE's conceptual plans to dilute and dispose surplus plutonium in WIPP to **support U.S. commitments under the PMDA**, identify gaps, and recommend actions to address those gaps (emphasis added).

The NASEM review committee met from late 2017 through spring 2020, and quickly determined that a) the total inventory of surplus plutonium material was ~62.4 metric tons, and b) that in addition to the 34 metric tons pursuant to the PMDA, another 14.2 metric tons (48.2 total) was either under consideration or already slated (per the 2015 SPD SEIS ROD) for emplacement in WIPP as diluted surplus plutonium TRU waste.

The NASEM committee issued an Interim Report in late 2018 and its final report in April 2020 (NASEM, 2020). Among its many findings and recommendations, some main messages were:

- The DOE plan is technically viable with most process steps being demonstrated but only at a prototype scale.
    - The technical steps to prepare and dilute plutonium oxide have been exercised, but nowhere near the scale necessary to process 34 to 48 metric tons in a timely manner, especially considering a single completed disposal container will contain a nominal 300 grams of diluted plutonium oxide.
- The amount of surplus plutonium for dilute and dispose is more than 34 MT – up to 48.2 MT.
    - In its consultations with DOE and NNSA, the committee determined that in addition to the 34 metric tons pursuant to the PMDA, another 14.2 metric tons (48.2 total) was either under consideration or already slated (per the 2015 SPD SEIS ROD) for emplacement in WIPP as diluted surplus plutonium TRU waste.
- The plan is not currently recognized by the PMDA.

- As noted in Section 2.3, the 2010 PMDA notes that "Disposition shall be by irradiation of disposition plutonium as fuel in nuclear reactors *or any other methods that may be agreed by the Parties in writing*.". To date, there is no record of the U.S. having engaged Russia on the matter, despite Russian Federation President Vladimir Putin expressing specific concerns with the concept (IFPM, 2016). However, the issue may be moot given more recent developments concerning the PMDA (see Section 2.7.1).

- The additional DSP-TRU waste inventory is not likely to exceed the EPA's containment standards for WIPP's pre- and post-closure safety and performance.
    - The committee recognized that WIPP is a robust repository with a 10K year post-closure performance period that historically been evaluated to show no release unless disturbed (e.g. human intrusion) but as yet the full projected inventory has not been included in EPA compliance recertification applications.
- Several implementation challenges and system vulnerabilities exist, and both need to be addressed.
    - The committee noted several implementation challenges such as the sustainability of the dilute and dispose program in the face of resource competition with e.g., pit production, as well as several system vulnerabilities, concluding that diluted plutonium does not meet the spent fuel standard, the availability of WIPP disposal volume, and changing nature of WIPP affecting 'social contract' between WIPP and the State of New Mexico, and recommending a new comprehensive programmatic environmental impact statement (PEIS) be undertaken (see also Section 2.8).

2.7.1 2018 to 2021 PMDA Updates

As noted in Sections 2.3 and 2.4, the inter-governmental commitments made in the PMDA was seen to provide important political backing for sustaining implementation throughout the evolution of the surplus plutonium disposition strategies. This appeared to be the case even after the cancellation of the MOX alternative, as the PMDA commitments were expressly noted by the 2014 Plutonium Disposition Working Group search for alternatives (see Section 2.5) and in the Congressional tasking for the 2016 NASEM review of DOE plans for dilute and dispose.

However, the role of the PMDA as a driver for setting disposition strategy and sustaining political support (i.e., appropriations) appears to have waned in the last few years.

The Department of State releases an annual report providing assessments of the adherence of the United States and other nations to arms control, non-proliferation, and disarmament agreement or commitment obligations. The last several annual assessments provide insight into the changing nature of the PMDA regarding sustaining a disposition strategy.

The 2019 report (DOS, 2019, p. 9-10) notes with regard to the PMDA:

> "The United States has not undertaken any activities during or prior to the reporting period that are inconsistent with its obligations under the Plutonium Management and Disposition Agreement (PMDA). This includes U.S. activities during the reporting period to terminate the project to construct a mixed-oxide (MOX) fuel fabrication facility that would have been used to dispose of plutonium under the agreement by turning it into fuel for irradiation in commercial nuclear reactors and to develop plans for a less expensive alternative disposition through dilution and burial of the plutonium. **Russia's assertion that this change in U.S. disposition plans**

> **violates the agreement, which was addressed in the 2018 Compliance Report, remains without merit.** ... **The administration will continue to work with Congress to finalize plans for U.S. disposition by the alternative dilute- and-dispose method. Further steps are needed in this respect before engaging Russia to obtain its agreement to this alternative method of disposition as required under the PMDA."** (Emphasis added).

This phrasing largely remained in the 2020 report (DOE, 2020, pp. 10, 27), but also noted:

> "The United States is not ready to begin its disposition. As a result of its reviews since 2014, for budgetary reasons, the United States has sought a less expensive alternative to irradiation for its disposition of plutonium under the agreement. In 2019, the Department of Energy took steps to terminate the project to build a mixed-oxide (MOX) fuel fabrication facility. The United States previously had been planning to use that facility to dispose of plutonium under the agreement by turning it into fuel for irradiation in commercial nuclear reactors. **Further steps are required to finalize plans for U.S. disposition by an alternative method (dilute and dispose in a geologic repository) before engaging Russia to obtain its agreement to this method as required under the PMDA**." …"There is no indication that Russia has violated any of its obligations under the PMDA. Russia's October 2016 notification of its purported suspension of the PMDA raised concerns regarding Russia's future compliance with its PMDA obligations. Those **concerns may be resolved one way or the other once the United States is in a position to engage Russia on the U.S. proposal for an alternative to irradiation for disposition of its PMDA plutonium.**" (Emphasis added)

However, the 2021 report (DOE, 2021) would seem to acknowledge the PMDA impasse, with a single mention simply stating:

> "Plutonium Management and Disposition Agreement (PMDA) will no longer be covered in this Section of the Compliance Report, unless a significant issue is newly identified."

Thus, the issue of whether the 'dilute and dispose' disposition strategy either meets the spent fuel standard or is to be recognized in a written agreement to the PMDA would for the time being seem moot. Further, it is unclear the effect the impasse on the PMDA could have on the sustainability and direction of the U.S. disposition strategy and implementation.

2.8 The 2020 Surplus Plutonium Disposition Program EIS

Continuing the trend to incrementally disposition the total surplus plutonium inventory, and likely completing the move toward the use of the dilute and dispose disposition strategy, the NNSA has issued a notice of intent (NNSA, 2020) to prepare a Surplus Plutonium Disposition Program (SPDP) Environmental Impact Statement (EIS) and identifying its preferred alternative "to evaluate the dilute and dispose alternative…to disposition the full 34 metric tons of surplus plutonium that is the responsibility of the Surplus Plutonium Disposition Program".

Since ~2015, using the dilute and dispose strategy has been decided for 13.1 metric tons, with the additional 34 metric tons likely to follow, as only the "no action" alternative (continued storage) is reasonably available. Thus, in this regard at least, the NASEM review committee (see Section 2.7) was correct in anticipating the DOE/NNSA desire to disposition essentially all the ~48.2 metric tons of surplus plutonium by dilution and disposal in WIPP.

The SPDP EIS notice of intent also recognizes that the dilute and dispose approach would require new, modified, or existing capabilities at the Savannah River Site, Los Alamos National Laboratory, Pantex Plant, and the Waste Isolation Pilot Plant. Whether the SPDP EIS will be structured as individual supplements to existing EISs for those facilities or treated as a new comprehensive programmatic EIS as recommended by the NASEM committee (NASEM, 2018, Rec. 5-5) remains to be seen.

The draft SPDP EIS is expected sometime in the second half of calendar year 2021.

2.9 2021 Developments

The efforts to implement a dilute and dispose program could ostensibly have begun with the April 2016 record of decision to disposition 6 metric tons of diluted non-pit plutonium at the Savannah River Site (DOE, 2016a, p. 19588). In June of 2021, the Savannah River Site, announced (SRS, 2021) that it has placed its first 'dilute and dispose' waste drum (a criticality control container containing a nominal 300 grams of surplus plutonium placed inside an 55-gallon drum overpack) into the new K Area Characterization and Storage Pad facility, where it will be characterized to ensure compliance with the WIPP waste acceptance criteria, and await shipment to WIPP.

To date, no overpacked criticality control containers have been received or emplaced underground at WIPP.

3 Conclusions

Since 1993 the U.S. has declared more than 60 metric tons of weapons-useable plutonium material as surplus (DOE, 2015, fig. S-7) with ~ 48 metric tons existing as nuclear weapon pits, pit production scraps and residues, plutonium metals and plutonium oxide, which with suitable processing could be dispositioned to render it "practicably irrecoverable" by treatment into "forms unusable for nuclear weapons". Only a very small fraction of the surplus plutonium inventory has undergone such disposition.

Since the mid-1990s, disposition strategies and implementation efforts for the U.S. surplus plutonium inventory have experienced substantial investment and evolution, driven by both internal and external factors. And while it seems a new single disposition strategy has emerged with 'dilute and dispose', many of the uncertainties and risks of implementation previously identified (GAO 2019, NASEM 2020) remain.

No single document, including this one, describes disposition plans and history for the entirety of the U.S. surplus plutonium inventory, though as seen herein, there is a substantial volume of documentation to work with. History can be a valuable teacher if one heeds its lessons.

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