Final Report of the Plutonium Disposition Red Team

Date: 13 August 2015

Oak Ridge, Tennessee

Thom Mason, Chair

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Name/Org: John W. Krueger/ORNL Date: August 13, 2015
Guidance (if applicable): NA

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Acronyms and Abbreviated Terms

ADR	Advanced Disposition Reactor
AFS	Alternate Feedstocks
AP	aqueous polishing
BCP	baseline change proposal
BWR	boiling-water reactor
CCO	Criticality Control Overpack
CD	Critical Decision
CISAC	NAS Committee on International Security and Arms Control
COE	U.S. Army Corps of Engineers
DMO	Direct Metal Oxidation
DOE	U.S. Department of Energy
EM	U.S. Department of Energy Environmental Management Program
ETC	estimate to complete
HEU	highly enriched uranium
IAEA	International Atomic Energy Agency
ICE	independent cost estimate
IROFS	items relied on for safety
KAMS	K-Area Material Storage
LANL	Los Alamos National Laboratory
LCC	life cycle cost
LWA	WIPP Land Withdrawal Act of 1992
MFFF	Mixed Oxide Fuel Fabrication Facility
MIFT	MOX Irradiation, Feedstock, and Transportation
MOX	mixed oxide
MT	metric ton
NAS	National Academy of Sciences
NEPA	National Environmental Policy Act
NNSA	National Nuclear Security Administration
NRC	Nuclear Regulatory Commission
OPC	other project cost
ORNL	Oak Ridge National Laboratory
PDCF	Pit Disassembly and Conversion Facility
PMDA	Plutonium Management and Disposition Agreement
PWG	Plutonium Disposition Working Group
PWR	pressurized-water reactor
QA	quality assurance
RCRA	Resource Conservation and Recovery Act
Red Team	Plutonium Disposition Red Team
SEIS	Supplemental Environmental Impact Statement
SFS	spent fuel standard
SMP	Sellafield MOX Plant
SNM	special nuclear material
SRS	Savannah River Site
TEC	total estimated cost
TRU	transuranic

WIPP	Waste Isolation Pilot Plant
WSB	Waste Solidification Building

Executive Summary

The Plutonium Management and Disposition Agreement (PMDA) calls for the United States and Russia to each dispose of 34 metric tons (MT) of excess weapon-grade plutonium by irradiating it as mixed oxide fuel (MOX), or by any other method that may be agreed by the Parties in writing. The MOX disposition pathway is a realization of the spent fuel standard (SFS) as envisaged in the 1994 National Academy of Sciences (NAS) review that recognized the value of physical, chemical, and radiological barriers to future use of the material in nuclear weapons whether by state or non-state actors.

The decision to pursue the MOX pathway using light water reactors in combination with immobilization using a can-in-canister approach was adopted by the United States Department of Energy (DOE) after review of 37 different pathways for disposition in 1997. Since that time, the situation has evolved in a number of significant ways:

- Nonproliferation policy has been increasingly focused on potential threats from non-state actors, which increases the sense of urgency for timely disposition and potentially offers greater flexibility in the final form of the material to prevent future use;
- The cost of the MOX approach has increased dramatically compared to early estimates;
- A disposition alternative not available in the nineties has been successfully demonstrated in support of the closure of Rocky Flats and other projects—downblending or dilution of PuO_2 with adulterating material and disposal in the Waste Isolation Pilot Plant (WIPP).

The Dilute and Dispose option can be thought of as substituting geologic disposal for the self-protecting radiation field and physical protection of spent fuel casks, and the dilution with adulterants as the chemical barrier. The Scoping Comment Summary from the Draft Surplus Plutonium Disposition Supplemental Environmental Impact Statement (SEIS) noted: "DOE believes that the alternatives, including the WIPP Alternative, analyzed in this Surplus Plutonium Disposition SEIS provide protection from theft, diversion, or future reuse in nuclear weapons akin to that afforded by the Spent Fuel Standard." The review team concurs with this assessment and believes that the Dilute and Dispose approach meets the requirements for permanent disposition, but recognizes that this assertion will ultimately be subject to agreement with the Russians, and that the decision will be as much political as technical.

The primary focus of the Red Team was a comparison of the MOX approach to a Dilute and Dispose option (and some variants of each), in light of recently published cost comparisons. As discussed in the Introduction to this document, consideration was given to other options such as fast reactor Pu metal fuel or borehole disposal, but these options have large uncertainties in siting, licensing, cost, technology demonstration, and other factors, so the Red Team concluded early that they did not offer a suitable basis for near term decisions about the future of the program. Were fast reactors to become part of the overall U.S. nuclear energy strategy (as they are in Russia), or if a successful research and development program on borehole disposal led to siting of a disposal facility, these options could become more viable in the future.

Analyses of the MOX and Dilute and Dispose options have been carried out at various times, by various parties, with differing degrees of access to relevant information, and with varying assumptions about conditions over the long duration of the program. The Red Team's analysis focused on annual funding levels (during both construction and operations), risks to successful completion, and opportunities for improvements over time that could accelerate the program and save money. For comparison purposes, the Red Team describes a relatively optimistic view of the MOX approach [adjusted somewhat to account for a dispute in the present status of the MOX Fuel Fabrication Facility (MFFF) project], and compares it to a relatively conservative version of the Dilute and Dispose alternative.

The Red Team concluded that if the MOX pathway is to be successful, then annual funding for the whole program (MFFF plus other activities that produce feed material and support fuel licensing and reactor availability) would have to increase from the current ~$400M per year to ~$700M-$800M per year over the next 2-3 years, and then remain at $700M-$800M per year until all 34 MT are dispositioned (all in FY15 dollars). To be successful, the overall effort would need to be clearly driven with a strong mandate to integrate decision making across the sites and across DOE programs and organizations. At this funding level, operations would only commence after as much as 15 more years of construction and ~3 years of commissioning.

The Dilute and Dispose option could be executed at approximately the current $400M annual program funding level over roughly the same timeframe as the MOX approach. Faster progress could be made if, during the 2-3 year period while MFFF construction and associated unneeded program elements are discontinued and demobilized, an appropriate, modest increase in funding over current levels could be used to support the initiation of oxide production and small-scale dilution operations, as well as the relatively small capital efforts needed to expand into full-scale production. The Red Team also noted that the Dilute and Dispose option would have headroom within an annual program operating cost of about $400M (FY15 dollars) available for process optimization, which could increase annual throughput and decrease life cycle costs (LCCs) by reducing the overall program duration. Several optimization variations to the Dilute and Dispose approach are discussed in the body of this document.

During the course of the review, the Red Team noted that both the MOX and Dilute and Dispose options rely on the availability of national assets for their execution, namely WIPP, H-Canyon at the Savannah River Site (SRS), and PF-4 at Los Alamos National Laboratory (LANL). WIPP will be required to either accept waste from MOX operations, and/or will be used as the final repository for diluted material. Were it to become unavailable due to budget, capacity, or operational reasons the program would be compromised. This dependency is not unique to Pu disposition, and reflects the fact that WIPP is a critical asset for DOE's Environmental Management (EM) program, the National Nuclear Security Administration (NNSA) for Pu disposition, and to all the operating sites relying on WIPP to deal with legacy issues that are impediments to mission, as well as for direct support to on-going missions through the disposal of newly-generated transuranic (TRU) waste.

For this reason it is imperative that WIPP be used as efficiently as possible, and the Red Team encourages DOE to work with the State of New Mexico to implement efficiency improvements regardless of the Pu disposition path forward. The Red Team offers for consideration two techniques for disposal efficiency related to Pu disposition which may obviate any perceived need to amend the WIPP Land Withdrawal Act of 1992 (LWA) specifically to support this program. However, given the tremendous value of a TRU waste repository to both DOE and the State of New Mexico, it may eventually become desirable to explore expansion of WIPP's capacity beyond the current LWA limit regardless of Pu Disposition Program needs.

Similarly H-Canyon is critical to both potential disposition pathways since HB-Line is needed to process material currently at SRS. Recent EM budget pressures have called into question the future availability of H-Canyon beyond FY16. This is critical not just to EM (the SRS material is owned by EM) but NNSA since the weapon grade component of that material is part of the 34 MT PMDA inventory. In addition to EM and NNSA, H-Canyon is also essential to the Office of Science and the Office of Nuclear Energy since it is the only facility capable of reprocessing highly enriched uranium (HEU) spent fuel. While it is appropriate to seek out incremental programmatic funding to support specific facility improvements that might be needed to support a particular mission activity, it does not make sense to piecemeal the funding of operations at a nuclear facility. A more viable model is to recognize the stewardship role played by EM on behalf of the broader DOE missions and adequately fund the base operating cost of the facility in the EM budget.

In summary, the Red Team concluded:

- The MOX approach to Pu disposition is reasonably viable at about $700M-$800M per year (FY15 dollars) until all of the excess weapon-grade Pu is dispositioned, provided executive leadership at DOE-Headquarters with cross-cutting authority is established to champion the program, and project management issues noted by the Red Team as well as those identified in the earlier Root Cause Analysis (1) are addressed.
- The MOX approach would satisfy the SFS in the PMDA, but would not achieve agreed timeframes for the disposition of excess plutonium.
- Aerospace over-estimated the MFFF construction duration under funding-constrained circumstances, and hence the LCC of the MOX approach in those scenarios.
- Aerospace correctly concluded that even the best case scenario for the remaining MOX approach would be more expensive and riskier than the worst case scenario for the Dilute and Dispose approach, assuming that the latter approach is sufficient for compliance with the PMDA and is efficiently enabled in cooperation with the State of New Mexico.
- There are no obvious silver bullets to reduce the LCC of the MOX approach.
- As soon as the new MOX facilities go hot, DOE is committed to long-term surveillance and maintenance costs and has adopted a complex new decontamination and decommissioning liability, regardless of whether the Pu Disposition Program is ever completed using the MOX approach.
- The Dilute and Dispose approach is viable at about $400M per year (FY15 dollars), over a similar duration as the MOX approach.
- Unlike the MOX approach, the Dilute and Dispose approach offers opportunities for introduction of efficiencies which could reduce life cycle duration and cost, many of which could be implemented after the program is underway.
- DOE should consider a “sterilization” approach to excess Pu disposition in parallel with startup of a Dilute and Dispose strategy as a means of reducing Program LCC.
- Contrary to conclusions in the High Bridge report, risks associated with the Dilute and Dispose option are far lower than the MOX approach, since both the technology and the disposition process associated with Dilute and Dispose are far simpler.
- The Dilute and Dispose approach would utilize existing facilities, and consequently creates essentially no incremental post-program liability.
- Perceived fundamental barriers to the Dilute and Dispose approach, namely WIPP capacity limits and PMDA compliance, are not viewed as insurmountable by the Red Team, but should be retired as early in the planning phase for this option as possible. The combination of evolving international circumstances and the fact that the U.S. has already accommodated a Russian national interest in a previous PMDA modification causes the Red Team to believe that the federal government has a reasonable position with which to enter PMDA negotiations. Ensuring

adequate WIPP capacity (and/or enhancing disposal efficiency) would require high level, transparent, and cooperative discussions with the State of New Mexico, but the Red Team believes that the constructive on-going engagement with the State of New Mexico regarding WIPP restart bodes well for such discussions.

- Regardless of the DOE chosen path forward, it is vitally important to make a decision as soon as possible and secure consistent funding to prevent further degradation of the Pu Disposition Program.

Introduction

At the request of U.S. Secretary of Energy Ernest Moniz by memorandum dated June 25, 2015 (see Appendix A), a Plutonium Disposition Red Team (Red Team) was established by Dr. Thomas Mason, Director of Oak Ridge National Laboratory (ORNL), to assess options for the disposition of 34 MT of surplus weapon-grade plutonium. Dr. Mason assembled 18 experts, including both current and former employees of Savannah River National Laboratory, LANL, Idaho National Laboratory, Sandia National Laboratory, ORNL, the United Kingdom National Nuclear Laboratory, the Nuclear Regulatory Commission (NRC), and the Tennessee Valley Authority, as well as private nuclear industry and capital project management experts. Their purpose was to examine costs and other factors of the MOX fuel production approach and the Dilute and Dispose approach to Pu disposition, as well as any other meritorious approaches deemed feasible and cost effective. Red Team members are listed in Appendix B, with brief biographical sketches provided in Appendix C. The Red Team was assisted by subject matter experts from the institutions represented on the team and engaged in the Pu Disposition Program, as well as from DOE.

Specifically, the Secretary requested that the Red Team:

1. Evaluate and reconcile previous cost estimates;
2. Analyze ways to modify the MOX fuel approach to reduce costs; and
3. Examine how different risk assumptions can impact total lifecycle costs.

The Secretary specified use of the same comparison criteria that were used by the Plutonium Disposition Working Group (PWG) in their previous assessment of options: (2)

- Schedule to begin and complete disposition;
- Technical viability;
- Ability to meet international commitments; and
- Regulatory and other issues.

This Red Team report is organized in accordance with the June 25 charge memorandum. Section 1 discusses the team's conclusions with respect to the apparent contradictions in recent assessments of LCC. Section 2 describes the current MOX-based approach to Pu disposition, and assesses this option against the four criteria. In direct answer to Charge #2 (above), Section 2 concludes with a discussion of potential adjustments (opportunities) which could make the annual outlay and LCC for the MOX approach more palatable. Section 3 provides a description of the Dilute and Dispose alternative, evaluates it against the four criteria, and offers several techniques for improving upon the basic model. Section 4 then provides a comparative analysis, with the goal of helping DOE executives make a final decision on the path forward.

The Red Team has also chosen to take some "executive license" with specifics of the charge memorandum. Consequently, this introductory section is immediately followed with a preamble titled, "Executive Considerations."

Due to the initial deadline of August 10 for delivery of a Red Team report to the Secretary, the kick-off meeting was held immediately after the charge memo was signed, by videoconference on Friday, June

26. After an initial week of background reading and information gathering via Program-sponsored presentations, the group travelled first to the WIPP for tours and interactive presentations and discussions, and then to LANL for similar discussions and tours of their pit conversion and oxide production scope of work. During this week at LANL, the U.S. Government Accountability Office answered a Red Team invitation and provided their views on the progress and cost of the MOX approach. Week three was spent sharing key “takeaways” and lessons learned to date, participating in additional background presentations by teleconference, and preparing lines of inquiry for a visit to the SRS the following week. The first three days of week four were spent in tours and briefings at SRS, including private discussions with both contractor and federal project and program leadership, as well as Aerospace and High Bridge representatives. During this time, a valuable perspective on the genesis of the PMDA agreement with the Russians was obtained from Dr. Siegfried Hecker by teleconference. The last day and a half of productive time that week were spent developing a consensus on key points, drafting an annotated report outline, and initiating report writing. An initial review draft was distributed for Red Team review and comment on Wednesday, August 5, and a final draft was submitted to the Secretary’s office the week of August 10, less than eight weeks after the kick-off meeting.

How to Use this Report

This Red Team report does not provide a bottoms-up estimate of any Pu disposition option. It should therefore not serve as a basis to judge absolute costs. Clearly, any path forward selected by DOE will require the development of a new bottoms-up baseline cost and schedule estimate at both an integrated program level and for any major capital components, as well as contractual action to align a new acquisition strategy and incentive structure with the chosen path forward. Both DOE and the contractors have acknowledged this. Instead, it is the Red Team’s intent that this document serve to clarify existing information to assist DOE with the urgent matter of making a final decision on the path forward. The Red Team has also offered some insight in this report on potentially advantageous execution strategies.

Screening of Alternatives

An early consensus was struck within the Red Team on the ability to screen out most alternative approaches to Pu disposition based on the available background reading. A significant amount of work has been done in the past to screen alternatives, beginning with the 1994 NAS review which identified MOX fuel fabrication and immobilization as the most promising alternatives, given the goal of achieving a SFS. (3) The NAS study was followed by a 1997 DOE review (4) of 37 disposition options which recommended a combination of MOX fuel production and “can-in-can” immobilization, consistent with NAS recommendations. This hybrid strategy was adopted in September 2000 as the U.S. approach to Pu disposition in the initial Plutonium Management and Disposition Agreement (PMDA) with Russia. (5)

A subsequent review in the early 2000s eliminated the immobilization approach due in part to cost concerns, largely caused by the need to make the Defense Waste Processing Facility a more secure facility. It also became evident that there would not be enough high-level waste at SRS to serve as encapsulating material for all of the solidified plutonium inner cans that were targeted for immobilization (i.e., the “non-MOXable” fraction of the excess plutonium inventory). DOE considered augmenting SRS immobilization efforts with operations at Hanford, but this was judged to be highly impractical. The policy change to eliminate immobilization and rely exclusively on MOX was incorporated into the 2010 modification of the PMDA, along with a change to facilitate Russian disposition of MOX as fast reactor fuel.

In 2013 due to cost concerns that emerged as a result of the MOX Services' baseline change proposal (BCP), DOE re-opened the consideration of Pu disposition alternatives, culminating in the 2014 PWG report. While the Red Team initially reconsidered all five of the alternatives in the PWG report, no rationale was found to overturn DOE's logic with respect to elimination of the can-in-can immobilization alternative. Consequently, the Red Team dropped this alternative from further consideration. The Red Team also dropped deep borehole disposal and the Advanced Disposition Reactor (ADR) options from further consideration. The deep borehole option is considered to be essentially equivalent to the Dilute and Dispose option, but lacks the proof-of-principle that its sister option enjoys, and suffers from significant uncertainty related to siting (although it could be used later to augment Dilute and Dispose with an additional disposal outlet if such issues are resolved). The ADR option involves a capital investment similar in magnitude to the MFFF but with all of the risks associated with first-of-a kind new reactor construction (e.g., liquid metal fast reactor), and this complex nuclear facility construction has not even been proposed yet for a Critical Decision (CD)-0. Choosing the ADR option would be akin to choosing to do the MOX approach all over again, but without a directly relevant and easily accessible reference facility/operation (such as exists for MOX in France) to provide a leg up on experience and design.

Consequently, the remainder of this Red Team report focuses exclusively on the MOX approach and the Dilute and Dispose option, and enhancements thereof.

Scope of Consideration

It is easy to get confused by nomenclature associated with the MOX approach. For purposes of this review, the Red Team is concerned with the entire Pu Disposition Program scope, not just the MFFF or some other subset. Figure 1 is intended to help clarify the nomenclature used consistently throughout this report to describe the MOX Program. The sum total of the scope illustrated in Figure 1 is called the MOX approach, or the MOX Program throughout this report. The color-coded boxes represent various components of the MOX Irradiation, Feedstock, and Transportation (MIFT) portion of that program, and the black and white boxes are the major capital acquisitions called the Waste Solidification Building (WSB) and the MFFF project.

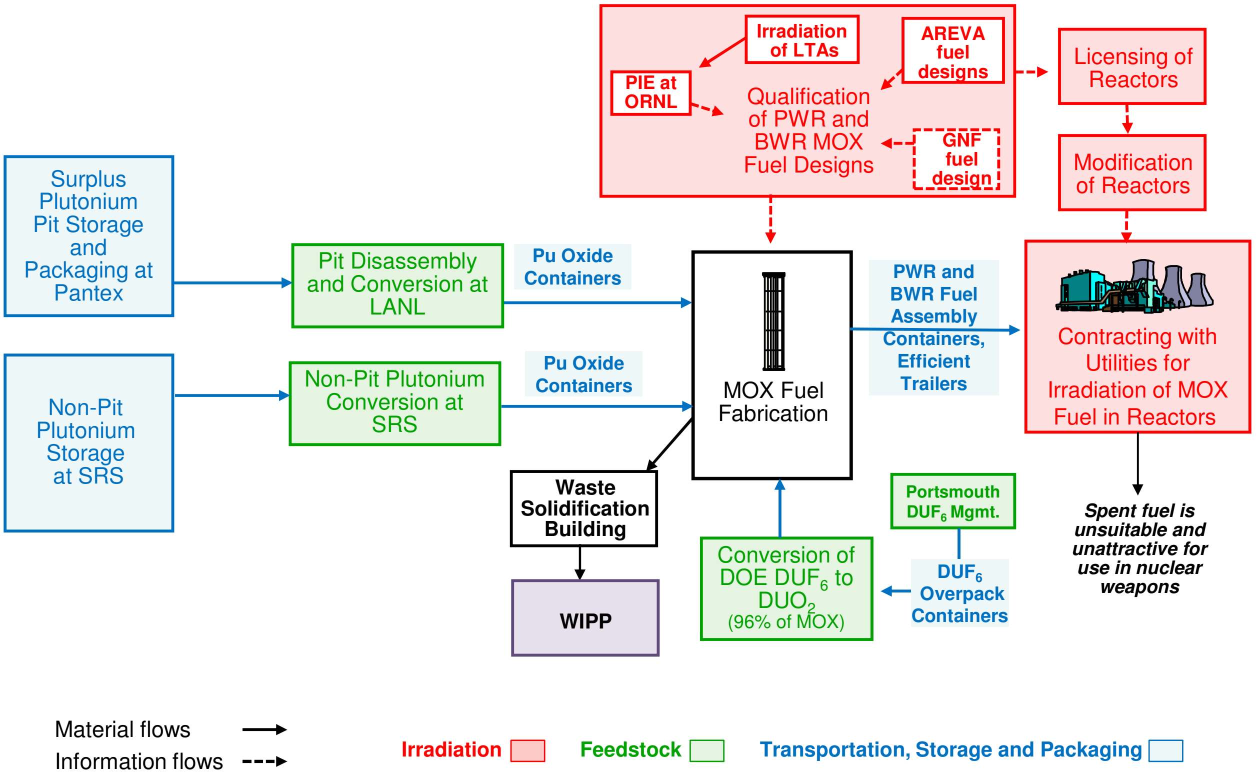

Figure 1. Definition of MOX Program Elements

Executive Considerations

The Urgent Need for a Path-forward Decision

The current lack of sustained funding for the MFFF project illustrated in Table 1, which shows planned (based on the MOX Services 2012 BCP) versus actual funding, has created an environment of intense uncertainty, ultimately manifesting itself through project inefficiencies and strained relationships between DOE and the contractor. This uncertainty has in-turn led to a lack of workforce confidence in program stability, resulting in low levels of staff retention (exacerbated by loss of the most qualified workers), and low morale in the remaining workforce. A high turnover rate was noted by the Red Team, and the project is reportedly viewed regionally as a training ground for nearby nuclear and other major construction projects with better outlooks. This situation results in eroded performance which worsens the lack of confidence from Program sponsors and congressional committees, creating a feedback loop that leads to rapid Program degeneration. The downward performance spiral is accompanied by an upward cost escalation spiral that would eventually make DOE's path-forward decision for them, but only after a great deal of money has been wasted. Project surety would instead lead directly to increased staff retention, resulting in reduced recruitment and training costs, increased ownership, and enhanced overall project performance. Should the MOX option be chosen for continuation, it is vital to create and sustain an adequate and stable funding profile. Indeed, consistent support will be vital for any path forward.

Table 1. Comparison of planned budgetary needs to actual appropriations

		TEC ($K)	OPC ($K)	Total ($K)
FY13	Plan	388,802	180,699	569,501
	Actual	400,990	40,003	440,993
FY14	Plan	582,488	47,144	626,632
	Actual	402,742	40,000	442,742
FY15	Plan	583,500	48,066	631,566
	Actual	335,000	10,000	345,000
TEC – total estimated cost OPC – other project cost				

MFFF project funding shortfalls are not the only financial difficulty facing the Pu Disposition Program. The project performance and funding difficulties with the MFFF have at times obscured the fact it is but one element of the larger Pu Disposition Program which, in addition to building and operating MFFF, must produce the feedstock and facilitate fuel usage in civilian power reactors (as shown in Figure 1). The additional scope, known as MIFT, has not been able to realize funding levels sufficient to support eventual MFFF operations and final Pu disposition. In addition to impacting the LCC of the MOX approach, inadequate MIFT funding threatens certain fundamental Pu disposition strategies, such as the creation of an oxide reserve so that oxide production at LANL (and/or SRS) never constrains the rate of Pu disposition.

Program/Project Management and Contract Reform

The Red Team saw an opportunity to realize meaningful cost savings through improved governance of the Pu Disposition Program. While the Federal Program Manager's Senior Technical Advisor is clearly engaged and knowledgeable, overall Federal Ownership of the Pu Disposition Program should reside with a senior career executive who has the overall responsibility and authority for the Pu Disposition Program, including integration across the various sites and across the various Programs and organization at DOE-Headquarters. This executive should have the authority to convene, coordinate (using a systems integration approach), and hold accountable all parties associated with the Pu Disposition Program (regardless of organization), including the major capital projects, and should establish joint ownership and governance expectations for both Federal and Contractor leadership. Indeed, multiple contractors involved in the current MOX approach expressed a desire for immediate reformulation of a centrally coordinated, integrating steering committee involving all executing parties. If a decision is made to pursue the Dilute and Dispose option, this need for multi-site, multi-program coordination at the DOE-HQ level will remain acute.

At the local level, the Red Team observed an antagonistic relationship between the local NNSA Federal Project Director's office and the MOX Services organization. As previously discussed, some of this would be a natural outcome of difficult, downward spiraling circumstances, but the Red Team noted that some of it may be arising from a genuine dispute regarding the degree of completion of the MFFF project (a perception likely to be exacerbated by the difficult work environment). It is difficult to judge how much work is actually accomplished when funding is only slightly more than the annual hotel load (level-of-effort fixed costs), since construction logic and productivity are so negatively affected by drastic funding reductions. The Federal Project Director's office has indicated that recent unit rates for commodity installation in the MFFF are higher than the contractor's BCP predicted because the BCP estimate relied on experience with easy procurements implemented by the contractor to grab earned value on the MFFF project, and that contractor unit rates used to produce an updated estimate to complete (ETC) do not reflect recent experience and anticipated re-work. The Red Team observed that many of the commodities are not in a stage of installation at which peak unit rate performance would be expected—peak performance can usually be expected in the 20-80% stage of installation on bulk commodities, with significantly lower productivity at the two extremes (ramping up and finishing up). Consequently, extrapolation at this time based on performance to date is problematic. Regardless, such disputes are manifested in a fundamental disagreement on the true ETC for the MFFF project. The Red Team asserts that a true ETC cannot be developed and authenticated until it can be based on a sound schedule that in turn is based on firm funding level commitments at a reasonable and sustained level through project completion.

Ultimately, the federal staff will need to take a more balanced approach to oversight and adopt an advocacy-based culture that avoids antagonistic engagement. Simultaneously, the contractor staff will need to demonstrate a stronger culture of performance under which commitments big and small are routinely delivered on time, transparently, and in accordance with expectations. Developing and maintaining a positive and success-oriented culture of trust between the NNSA project office and the MOX Services contractor should be a priority of the responsible NNSA leadership and the MOX Services governing Board, but these cultural changes can only be enabled through consistent, adequate funding of the chosen path for Pu disposition.

Contractual enhancements may also enable a reduction of burdensome oversight and indirect costs associated with this kind of counterproductive relationship between DOE and the contractor. In particular, the need to update performance expectations defined within the MOX Services prime contract (MFFF design, build, operate) was expressed by both the responsible DOE field element and MOX Services contractor executives. Current performance metrics (based largely upon standard project management metrics, such as the present application of earned value) have incentivized the wrong behaviors and have inflated the cost of governance and oversight. It was also not clear that the suggestions in the independent root cause analysis of the project had been implemented by either the contractor or NNSA. Implementing project management reforms, providing for incentive fees (based upon jointly negotiated performance outcomes) and ultimately reducing the amount of daily oversight and transactional interactions between the DOE field element and the MOX Services contractor could result in meaningful cost savings.

WIPP as a National Asset

> ***In announcing the agreement with DOE to spend $73M on improvements in transuranic waste transportation after the recent events at WIPP, New Mexico Governor Susana Martinez described LANL and WIPP as "critical assets to our nation's security, our state's economy, and the communities in which they operate."***
>
> \- NY Times, August 8, 2015

Opened in 1999 after 25 years of development and evaluation, the WIPP is the only disposal option for TRU waste from national defense activities, and should therefore be considered a strategic national asset worthy of extraordinary attention and protection measures. WIPP currently has a legislated capacity limit of 176,000 cubic meters and to date has emplaced about 91,000 cubic meters. 66,000 cubic meters of the remaining 85,000 cubic meters is already subscribed by known TRU waste generators, leaving about 19,000 cubic meters for support of future TRU waste generators such as the Pu Disposition Program.

The Red Team noted that TRU waste projections, upon which the unsubscribed (19,000 cubic meters) capacity of WIPP is based, are derived from EM waste generators across the complex. Significant uncertainty in the remaining WIPP capacity may exist, but if so, this uncertainty has little to do with the methodology or thoroughness of waste projections. Rather, it is derived from a potentially incomplete portrayal of future waste generating activities. To date, WIPP has been largely viewed as a repository for the disposal of legacy defense waste remediated by the EM. But if an operating large-scale actinide processing facility, or a legacy facility not formally incorporated into the EM baseline is not included, the TRU waste that will eventually be generated during decommissioning and demolition is not counted in waste projections. Likewise, the U.S. will not cease all TRU waste generation once legacy waste is disposed by EM, and it is not clear that the life cycle of newly-generated TRU waste from around the complex has been taken into account in the calculation of unsubscribed capacity at WIPP. Without substantial changes to container packing efficiency and/or volume accounting techniques at WIPP, the disposal of just 13 MT of the 34 MT U.S. obligation via the Dilute and Dispose approach discussed later in this document would reportedly consume as much as 68% of the remaining unsubscribed capacity.

It is imperative that WIPP be used as efficiently as possible. The Department should ensure that waste placed in WIPP be as densely packed as practical to minimize volumetric use as well as shipping. Recognizing that not all waste is in forms that are amenable to dense packing, DOE should also work with the State of New Mexico to account for the true waste volume placed at WIPP as accurately as possible (i.e., using actual waste volume, as opposed to container volume). Executed properly, these two steps should be sufficient to ensure enough capacity at WIPP to support 34 MT of surplus Pu disposition via the Dilute and Dispose technique, should DOE choose this option. However, given the tremendous value of a TRU waste repository, it may eventually become desirable to explore expansion of WIPP's capacity beyond the current LWA limit regardless of how much volume is utilized by the Pu Disposition Program. It is worth noting that most current Pu Disposition Program facilities have physical constraints that limit expansion, whereas WIPP is effectively not geographically limited—any restrictions are primarily regulatory in nature.

Stable Nuclear Infrastructure Funding

H-Canyon is critical to both potential disposition pathways in which HB-Line is needed to process material currently at SRS. Recent EM budget pressures have called into question the future availability of H-Canyon beyond FY16. This asset is critical not just to EM (the SRS material is owned by EM), but NNSA as well since the weapons grade component of that material is part of the 34 MT PMDA inventory. In addition to EM and NNSA, H-Canyon is also essential to the Office of Science and the Office of Nuclear Energy since it is the only facility capable of reprocessing HEU spent fuel. Similar issues could potentially be found at LANL with reliable funding of PF-4 and associated infrastructure, but in that case the importance of PF-4 to NNSA missions is well accepted.

While it is appropriate to seek out incremental programmatic funding to support specific facility improvements that might be needed to support a particular mission, it does not make sense to piecemeal the funding of base operations at a nuclear facility. A more viable model is to recognize the stewardship role played by EM on behalf of the broader DOE missions and adequately fund the base operating cost of H-Canyon in the EM budget. Failure to do so will undermine Pu disposition no matter which solution is adopted (as well as other programs). Although developed for scientific facilities, the

Cooperative Stewardship model described in the National Academy report of the same name is directly applicable to this case. (6)

Plutonium Management and Disposition Agreement

In 1994, the existence of surplus weapons plutonium arising from U. S. and Russian disarmament activities was described as a "…clear and present danger…" to international security by the NAS. (3) Accordingly, both nations initiated plutonium disposition programs under the umbrella of the bilateral PMDA.

To provide a framework for guiding the selection of disposition alternatives, the NAS Committee on International Security and Arms Control (CISAC) proposed the SFS as well as a process for evaluating alternatives versus the standard. The SFS "…holds that the final plutonium form produced by a disposition option should be approximately as resistant to acquisition, processing, and use in nuclear weapons as is the plutonium in typical spent fuel from once through operation in a commercial light-water reactor." Further, the CISAC stated: "Judgements about compliance with the spent fuel standard should depend only on the intrinsic properties of the final plutonium form, not on the extent of engineered and institutional protections."

However, in the twenty-plus years since the SFS was put forward by the NAS, there have been important changes, including:

- Uncertainties surrounding the breakup of the Soviet Union and associated concerns regarding special nuclear material (SNM) security have abated.
- The nature of the external threat has changed. There is increasing concern today over threats from proliferator nations and subnational actors and less concern associated with host nations. Associated interpretations of material attractiveness have also evolved.
- The view of the importance of some barriers has changed, including for example, the self-protective nature of high-level waste.
- Physical security has improved, especially since September 11, 2001.
- The presumption of a high-level waste repository available in the U. S. within a foreseeable future has shifted.

The Red Team believes that the SFS barriers (i.e., physical, chemical, and radiological) represent a valuable template for evaluating disposition options. However, the Red Team believes that it is now appropriate to credit engineering and institutional measures, such as physical security, disposal site characteristics, and safeguards as essentially equivalent to the barriers provided by SFS. This broader view would, for example, recognize the protective attributes of WIPP, and perhaps at a later date, accommodate efficiency improvements in the Dilute and Dispose option.

In fact, the DOE has already taken steps in this direction. Surplus plutonium oxide materials from Rocky Flats and Hanford have already been disposed as TRU waste in WIPP. Also, in the Surplus Plutonium Disposition Supplemental Environmental Impact Statement Scoping Comment Summary, DOE stated: "DOE believes that the alternatives, including the WIPP Alternative, analyzed in this Supplemental EIS provide protection from theft, diversion, or future reuse in nuclear weapons akin to that afforded by the Spent Fuel Standard."

The Red Team agrees that this DOE view is appropriate for today's circumstances and clears the way for consideration of options that could provide for more timely disposition, which is beneficial from both the nonproliferation and cost perspective. The Red Team believes that the strong U.S. commitment to disarmament could be maintained through a more timely disposition of excess Pu, so long as the chosen technique results in a material form that is akin to the SFS (e.g., using a Dilute and Dispose approach). In combination with a reminder that the PMDA was already modified to accommodate a Russian national energy interest, this philosophy should provide a sound basis for renegotiation of SFS-related PMDA provisions, as needed.

1. Evaluation of Previous Cost Assessments

The Red Team reviewed each of the estimates performed since the 2012 contractor BCP to evaluate estimate approach, assumptions, risks and conclusions. During this process, the Review Team had the following observations:

- All of the MFFF estimates were based on the contractor BCP and subsequent independent cost estimate developed by the U.S. Army Corps of Engineers (COE) for DOE. No other full scope bottoms-up estimates were performed.
- Differences are generally variations in the assumptions and estimating methodologies used to adjust the contractor or other derived estimate.
- The approach and magnitude applied to risks varied significantly between estimate approaches.
- There was not uniform access to detailed basis of estimate information for all components of the Pu Disposition Program.

Additionally, the Red Team noted that many of the cost-estimating best practices recommended by the U.S. Government Accountability Office were not consistently followed in essentially all of these estimates. The resulting variations demonstrated by these estimates have resulted in valid criticisms of the absolute accuracy of each of the individual estimates, including multiple instances of comparisons that were not "apples to apples." Both DOE and the contractors acknowledge the need for a new "bottoms-up" integrated Pu Disposition Program baseline once the path forward is resolved.

The recent cost estimates for the MOX option were derived in the following way:

- The contractor (MOX Services) submitted a MFFF BCP in December 2012.
- DOE requested an Independent Cost Estimate (ICE) conducted by the COE that was completed in 2013. The result was an estimate higher than the BCP.
- The PWG made adjustments to the COE ICE in 2014 to reflect some slightly differing assumptions related to assessments of the most recent status, provided a separate MIFT estimate.
- The Aerospace report used the cost estimates produced by the PWG for Option One (MOX) and Option Four (Downblend) and applied the results of an assessment of programmatic risks and resultant cost impacts to establish a total program LCC estimate with an 85% confidence level for each of the two options, without crediting any MOX progress since the 2012 BCP.
- The High Bridge report challenged the assumptions of the Aerospace report. Using the PWG costs as a starting point, they applied their own risk assumptions to determine a different set of LCC estimates.

The basic approach used and results produced by each of three recent studies are summarized below. In each of the subsections, the Red Team has summarily assessed each of the cost reports, offering opinions on the validity and utility of each study's conclusions. The Red Team attempted to assimilate our observations into an executive level understanding of the relative costs of the two most viable options (the MOX approach and the Dilute and Dispose alternative).

A time-limited independent evaluation of the relative costs performed by the Red Team served primarily to reinforce Red Team conclusions derived from four weeks of background reading, presentations, interviews, and tours. For the independent evaluation, the Red Team used the current MOX Services ETC for discreet work ($1.5B). It is recognized that this value has not been validated–by either the Federal project team or the Red Team–and may not be all-inclusive and fully representative of the remaining work on the project. However, by adding an appropriate contingency allowance, the Red Team believes this value can be considered approximately representative of the remaining project costs, especially since more of a best or optimum case for MFFF completion was our intent for comparison purposes. The Red Team's overall cost comparison is provided in Section 4.2.

1.1 Plutonium Disposition Working Group Report

In April 2014 the PWG established by the NNSA published a report that assessed five primary options for disposition of weapon-grade plutonium to meet international commitments. Programmatic LCC estimates were developed for each of the options, to the extent that information was available. The primary purpose of the LCC estimates was to facilitate comparison of alternatives, rather than to ensure an accurate prediction of true and total program costs over the projected life of each option.

The PWG estimates of LCCs were based on an assumed funding constraint of $500 million per year for capital expenditures, with no constraints on operating period expenditures. For reasons discussed in the Introduction, only two of the options evaluated by the PWG were evaluated and considered by this Review Team (PWG's Option 1, referred to as the MOX approach in this report, and PWG's Option 4, called Downblend and Dispose in the PWG report but referred to as the Dilute and Dispose option in this report). The PWG LCC estimates for these remaining two options are shown in Table 2.

Table 2. PWG Estimate Summary ($billions)

Cost Element	Option 1: MOX Fuel	Option 4: Dilute and Dispose
Capital Project(s)	6.46	0.29
Operating Costs	10.26	3.00
Other Program Costs	8.40	5.49
Total Life Cycle To-Go Cost	**25.12**	**8.78**

The Red Team finds that the PWG did a credible job of identifying and capturing the costs for all key program elements, established an overall program schedule based on the degree of program integration available at the time, and provided a valid basis for a relative comparison of programmatic options, at least on a gross/conceptual scale. However, there were some vulnerabilities in the report which may have contributed to the perception of the need for an independent assessment of the PWG's conclusions. For example, overall programmatic risks were not fully identified and analyzed, and by establishing LCC point estimates instead of ranges, as well as point estimates of annual funding needs, the variability and uncertainty of these estimates can be obscured. Also, the estimation of LCC in real-year dollars can be confusing and potentially misleading due to the compounding impact of escalation allowances (uncertain as they are) over the length of schedule portrayed for the program, which exacerbated this communication issue.

1.2 Aerospace Report

Congress directed NNSA to task a Federally Funded Research and Development Center to conduct an independent review of the PWG report. In December 2014, The Aerospace Corporation (Aerospace) was approached by NNSA to perform this review. Aerospace was asked to assess and validate the PWG report's analysis and findings, and independently verify LCC estimates for the construction and operation of the MOX facility (PWG's Option 1) and the option to Dilute and Dispose of the material in a repository (PWG's Option 4).

The Aerospace assessment was conducted in early 2015 and included a review of the previous PWG options evaluation report, tours at SRS and LANL, and discussions with relevant DOE, NNSA, MOX Services, and Savannah River Nuclear Solutions personnel. Aerospace organized and executed their evaluation in accordance with sound systems engineering principles, analyzed the previous cost and schedule estimates for both options, and performed independent risk assessments for each option with a focus on broad programmatic issues.

Aerospace issued their report in April 2015 with the following primary conclusions (paraphrased), reporting the values shown in Table 3:

1. The PWG cost and schedule estimates were performed in reasonable accord with accepted best practices.
2. Programmatic risks were generally underestimated for both options.
3. The Dilute and Dispose option is lower cost than the MOX option.
4. The MOX option is essentially not viable at anticipated capital funding levels (i.e., $350M/yr - $500M/yr).

Table 3. Aerospace Estimate Summary ($billions – FY14/RY)

Cost Element	Option 1: MOX Fuel	Option 4: Dilute and Dispose
PWG LCC Estimate	18.6 / 25.1	8.2 / 10.3
Assessment of Changes	2.7 / 5.6	1.9 / 2.9
$500M Cap		
Assessment of Cost Risks	5.9 / 16.8	3.0 / 4.0
Total Life Cycle To-Go Cost w/ $500M cap	**27.2 / 47.5**	**13.1 / 17.2**
$375M Cap		
Assessment of Cost Risks	8.5 / 79.7	3.0 / 4.0
Total Life Cycle To-Go Cost w/ $375M cap	**29.8 / 110.4**	**13.1 / 17.2**

The Red Team's assessment of the Aerospace report generally concurred with the first three conclusions, but disagreed with the fourth conclusion listed above since their analysis was not able to factor in modifications to project planning and execution in response to reduced funding levels. The strengths and weaknesses in the Aerospace report upon which the Red Team's judgments were based are discussed in more detail below.

The Red Team considered a key strength of the Aerospace report to be its assessment and evaluation of the overall Plutonium Disposition Program from a systems engineering approach. Each of the relevant program components necessary to support the Pu disposition options was clearly outlined, the key program component interdependencies were defined, and the risks and opportunities pertaining to each option were logically and systematically developed with an emphasis on broader programmatic considerations that are often given insufficient attention. The Aerospace effort added value by providing a useful comparative architecture for the two different options on a relative basis. Of specific benefit was the "S" curve LCC comparison provided in Figure 10 of the Aerospace report. This figure provided an efficient comparative summary of the base and risk-adjusted LCCs of the two options without imposing additional capital funding constraints. The clear and compelling conclusion illustrated in this figure is that the Dilute and Dispose option will result in lower LCCs than the MOX facility option under all credible scenarios—a conclusion with which the Red Team agrees. This reflects the Red Team's observation that to a significant degree, the Dilute and Dispose option is a subset of the MOX approach.

The key weakness in the Aerospace report was its methodology for quantitatively evaluating the LCCs for the MOX option under the capital funding constraints. The Aerospace methodology did not use the discrete to-go MOX facility project costs and actual MOX facility "hotel loads" (fixed costs) as the basis for establishing the duration to reach CD-4. Rather, Aerospace used a more coarse approach, consistent with instructions from DOE and based on information available to them from the PWG report, that resulted in unrealistic extensions of the MOX facility construction duration. Specifically, the Aerospace report determined durations to reach CD-4 of 30 years at a capital funding level of $500M/yr and 86 years at a capital funding level of $350M/yr. These conclusions are artifacts of the Aerospace analytic approach and assume no action on the part of the Department or the contractor to modify plans to reflect reduced funding levels. For example, even at a low annual funding of $350M, approximately $100M goes toward discrete work (although the Red Team is well aware that MOX Services is unlikely to get $100M in earned value for $100M in discrete work expenditures under current execution circumstances). With a discrete work estimate to go of about $1.5B, the project is done in 15 years using simple math and ignoring the obvious inefficiencies related to underfunding and the likelihood that work will become more difficult and risky as the end of the project approaches. Even with back-end loaded risk and inefficient execution it is difficult to imagine 86 years to go on construction, let alone the 30 years Aerospace asserted at a much higher capital funding level of $500M/yr—both scenarios basically assume that DOE and Congress would be willing to tolerate ineffective project management indefinitely.

As previously discussed under Executive Considerations, the Red Team used the current MOX Services ETC for discreet work ($1.5B) in the above discussion, and in our independent cost comparison, with a reasonable allowance for uncertainty in work remaining. It is recognized that this value has not been validated–by either the Federal project team or the Red Team–and may not be all-inclusive and fully representative of the remaining work on the project. However, the Red Team believes this value can be used as approximately representative of the remaining project costs since it was the Red Team's intent to compare a reasonably optimistic view of the MOX approach with a reasonably pessimistic view of the Dilute and Dispose approach for illustrative purposes in Section 4.2.

A similar impact was noted from the inflation of predicted operating costs. As can be seen from Figure 2, removing excess contingency from the MFFF operating cost estimates to bring them into better alignment with the MOX Services original estimate (~$330M/yr, FY14 dollars) and benchmarks at the reference plant (MELOX ~$250M/yr, FY14 dollars) and the British Sellafield MOX Plant (~$200M/yr, FY14 dollars) reduces the overall LCC estimate for the MOX option between $2B and $10B. Correction of the overly protracted construction and commissioning durations and implementation of a less conservative escalation rate would decrease the LCC estimate for the MOX option even further. These examples highlight the problem with accurately estimating LCCs for multiple decade programs. Uncertainties in key input assumptions can significantly skew the results due to the dominance of escalation. This problem becomes particularly acute when funding constraints or limitations are imposed, especially when funding does not escalate but cost does. The Red Team concludes that the quantitative approach taken by Aerospace significantly overestimated the duration of the MOX facility to reach CD-4, thereby artificially inflating the LCC cost impacts of potential funding constraints. The net result was that conclusions regarding the viability of the MOX approach drawn by Aerospace could be mitigated by decisive Departmental action and consistent Congressional funding at a more appropriate level.

In summary, it is the Red Team's position that the Aerospace report provides valuable insights to support relative comparisons between the MOX option and the Dilute and Dispose option, including identification of potential programmatic risks that warrant management attention and mitigation strategies. But the specific conclusions of Aerospace regarding the viability of the MOX option under the funding constraints analyzed are based on an avoidable scenario, and arise from limitations in their quantitative analysis caused in part by the lack of a detailed, resource-loaded schedule constrained by an appropriate funding cap. In Section 4.2 of this report, the Red Team concludes that the MOX approach to Pu disposition could be completed within a reasonable timeframe for less than $1B per year. However, the most fundamental Aerospace conclusion, illustrated in their "S curve" figure, remains intact: The worst case scenario for the Dilute and Dispose option is significantly less expensive and comes with lower technical and operational risk than the best case scenario for the MOX approach.

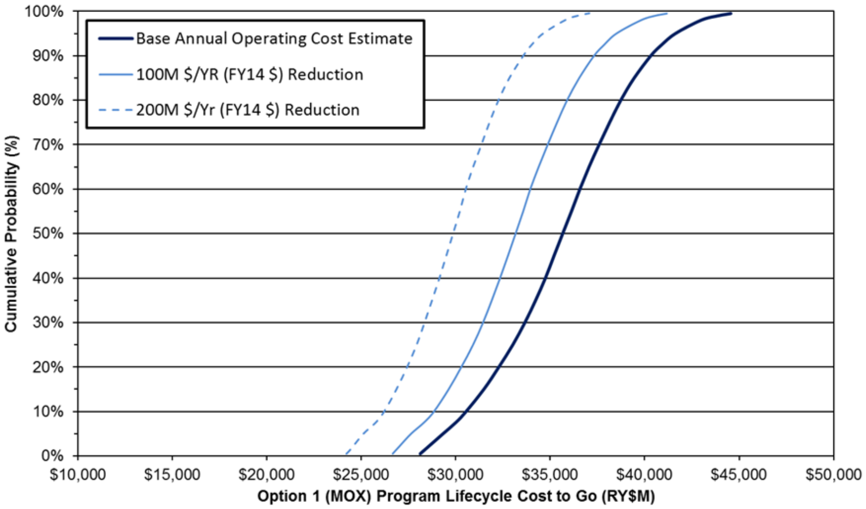

Figure 2. Impact of Arbitrary $100M and $200M Reductions in Ops Costs on MOX Program Life Cycle Costs

1.3 High Bridge Report

The Board of Governors of MOX Services retained the services of High Bridge Associates, Inc. (High Bridge) to conduct an independent review of the Aerospace report. In their report, published June 29, 2015, High Bridge concluded that Aerospace's identification and analysis of risk issues and contingency impacts identified for the MOX and Dilute and Dispose options was flawed. Specifically, they stated the MOX risk elements and resulting impacts appear to be overstated and inconsistent, while Dilute and Disposal risk elements are "clearly understated."

The results of the High Bridge assessment are presented in Table 4. The Red Team was not able to track the Aerospace costs shown in Table 4 to the Aerospace estimate results (as summarized previously in Table 3).

Table 4. High Bridge Estimate Summary ($FY14 billions)

Cost Element	Option 1 MOX Fuel	Option 4 Downblend and Dispose
Unescalated Base Cost (with contingency)	24.3	13.0
Aerospace Evaluation Risks/Contingency	7.4	2.3
High Bridge Evaluation Risks/Contingency	3.7	9.3
Differences	-3.7	7.0
Adjusted LCC ($B FY14)	**20.6**	**20.0**

The Red Team determined that there was merit to a few of the High Bridge criticisms. Indeed, some of High Bridge's assertions are similar to Red Team observations discussed in the previous section. However, many of the High Bridge conclusions seemed counterintuitive and overstated, causing enough concern to warrant a conference call with the High Bridge Assessment Team on Wednesday, July 29, 2015. The results of this call reinforced many of the Red Team's concerns, but it is important to note that High Bridge indicated they were refining their analyses in a more detailed report. This revised version of the High Bridge report was not available for evaluation during the Red Team's data gathering period.

The High Bridge report asserted that there are discrete risks in the Option 4 (Dilute and Dispose) approach that were ignored or under-valued by Aerospace with respect to potential impact. Examples included required amendments to licenses, permits, and even modification of the LWA. High Bridge also believed that Aerospace applied risks to Option 1 (MOX) that were over stated, and that Aerospace did not properly assess the impact of insufficient funding on completion of Option 1. The High Bridge report concluded that funding levels assumed by Aerospace were too low for MFFF to allow efficient completion, and funding needs expressed by Aerospace are too low for what Option 4 would need to accomplish the required work. Even though the High Bridge report did have some valid questions about Aerospace's dilute and dispose risks, a major concern of the Red Team was that some of the identified risks in the High Bridge report were not evenly applied to both projects, particularly for facilities/processes that are relied upon for both Pu disposal options. During the course of the discussion, High Bridge agreed this situation needed to be addressed in their final report.

The Red Team was also concerned with the application of a project risk profile to Option 4 commensurate with the application of DOE Order 413.3B for a major new nuclear facility acquisition. Option 4 primarily involves the use of existing facilities, some of which have been used in conversion or dilution before, including the disposition of plutonium at WIPP. The Red Team believes it is inappropriate to equate Option 4 to a complicated greenfield project that is at CD-0, and then reflect that kind of a risk profile in a calculation of LCCs. However, the High Bridge report did correctly identify that the shutdown costs of MFFF need to be part of the Dilute and Dispose option's cost profile.

During the teleconference, High Bridge strongly emphasized the challenge of going from CD-0 to CD-4 on the Dilute and Dispose option in just three years, even though the capital scope amounts to the relatively simple installation of two gloveboxes in an existing facility. While the Red Team agrees that three years would be an aggressive schedule, High Bridge's criticism failed to acknowledge an existing, capable glovebox which could be operational in a matter of months. Once International Atomic Energy Agency (IAEA) inspection is integrated into this single box operation, DOE could begin taking credit for progress toward disposition of the agreed 34 MT. In the meantime, DOE could use the existing glovebox to reduce the risk of fines and penalties from the State of South Carolina for failing to make any progress at all toward Pu disposition.

Similarly, the Red Team does not concur with High Bridge's concerns related to the degree of risk to the Dilute and Dispose option associated with WIPP and the PMDA. Given the importance of getting WIPP re-opened to the greater DOE nuclear enterprise and the previously discussed history of PMDA modifications negotiated to date, the Red Team believes that it is reasonable to assume that resumption of operations at WIPP and its designation as the repository for all 34 MT, as well as a successful negotiated adjustment to the PMDA, could be achieved within a reasonable time frame. Any associated risks would be manifested mainly in delayed startup of the Dilute and Dispose approach. During a delayed startup, DOE could be spending the bulk of its annual Program funding on MOX contractual closeout, and could spend the remainder on oxide production and/or the creation of certifiable TRU waste for eventual disposal at WIPP utilizing up to 500 kg/yr of plutonium at SRS, regardless of whether the plutonium counts toward the 34 MT commitment. With 19,000 cubic meters of unsubscribed capacity, SRS could ship at this rate for a long time if necessary, once WIPP is reopened and until either existing volume-based capacity limits are increased, or one of the variants to Dilute and Dispose obviates the need for early expansion of the volume limitation.

Another issue is the fact that the High Bridge report incorrectly took MIFT-related risks out of the MOX Program estimate. Even though there might be slight variances in those costs depending on the option chosen, many MIFT costs apply to both Pu disposition options and such risks should be treated consistently. If anything, the MIFT risks are lower in the Dilute and Dispose case due to relaxed specifications on the quality of plutonium oxide, and elimination of the fuel qualification program.

In any event, the High Bridge analysis fails to recognize that the majority of scope related to the Dilute and Dispose alternative is a subset of the MOX approach to Pu disposition. Under any credible scenario, therefore, Dilute and Dispose cannot be as costly or as complex as the MOX approach. Thus, and for reasons discussed above, the Red Team does not agree that the risks and their impacts and the resultant

LCCs of the two options are nearly identical as the initial High Bridge report asserts (as shown in Table 4).

2. Evaluation of the MOX Approach to Pu Disposition

2.1 The Baseline Approach to MOX-based Pu Disposition

2.1.1 Description of the MOX approach

The baseline MOX approach has been thoroughly described elsewhere. This section provides only a brief description of the scope and status in order to avoid redundancy. The major elements are depicted in Figure 3, and discussed below.

- **Feed Preparation** from pits consists of pit disassembly, physical separation and conversion of plutonium metal to oxide. Pit disassembly occurs at LANL, and oxide production of material from pits is performed at LANL.
- **Feed preparation from non-pit material:** Material residing in K Area at SRS will be processed in H-Canyon (HB-Line) at SRS. Aqueous polishing (AP) is performed on all oxide feed for purposes of achieving the acceptance criteria for the feed stream entering MOX fuel production.
- **The MOX Fuel Fabrication Facility (MFFF)** consists of a complex of 16 support facilities and the MFFF Process building. To date 12 of the 16 support facilities have been completed. The Process building is a 500,000 square foot, seismically qualified, steel reinforced facility. The facility is based on a proven French design, modified to achieve modern U.S. standards and to accommodate the different feedstock, and will be licensed by the NRC. The main processes in the MFFF Process building:
    - Aqueous polishing
    - Analytical chemistry
    - Fuel fabrication
    - Shipping and receiving
    - Direct metal oxidation (proposed)

- **Qualification of fuel design, and contracting, licensing and modification of reactors to take MOX fuel:** The MOX plant will generate mixed oxide fuel to be used in commercial light water reactors. The plant is being designed with capability to make fuel for both pressurized-water reactors (PWRs) and boiling-water reactors (BWRs), and has built-in flexibility to accommodate some future reactors such as AP-1000, and likely some small modular reactor fuel designs. The baseline plan assumes that CB&I AREVA, the sales agent for MOX Services and NNSA, will enter into contracts with utilities to supply fuel to seven reactors. NNSA has evaluated the potential modifications needed to both PWR and BWR reactors to support up to 40% of the core being MOX fuel (the remainder would be uranium fuel). Modifications are needed to the reactivity controls in PWRs to support loadings greater than 20% MOX assemblies and are estimated at about $20M per reactor in capital cost plus about $2M per year thereafter. There are no significant modifications needed to BWRs. Reactor operators would need to prepare and submit license amendment requests to NRC, support NRC's review, and obtain NRC approval prior to loading MOX fuel. Lead test assemblies may be required for MOX fuel in BWRs. Fuel suppliers will need to obtain NRC approval of MOX fuel codes, and transport packages would need certification.

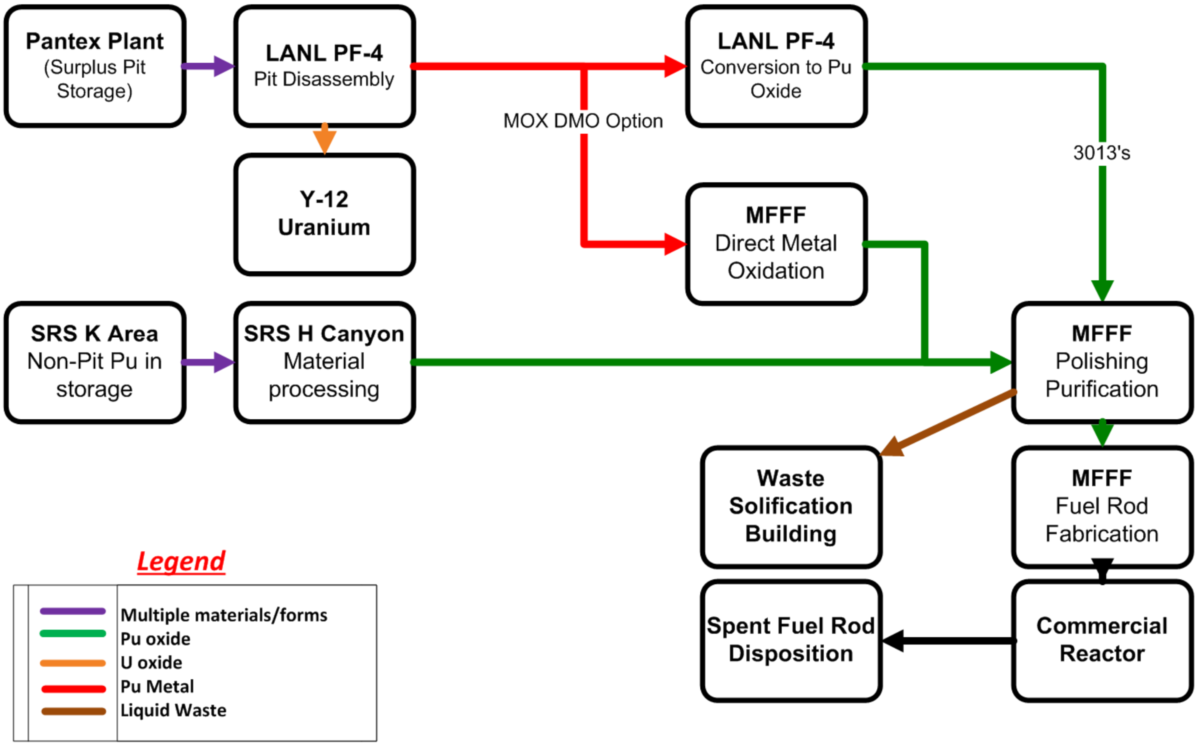

Figure 3. Basic Flow Diagram for the MOX Approach

- **The Waste Solidification Building (WSB):** A separate capital project to design/build a facility to treat and dispose of liquid wastes from the cancelled Pit Disassembly and Conversion Facility (PDCF) and MOX facilities. WSB construction is essentially complete, and the facility is in standby awaiting operation. Since the PDCF has been cancelled at SRS, this facility has excess capacity, and absent pursuit of the MOX approach, may never be used.

MOX program planning and throughput is based on seven PWRs loading up to 40% of their reactor cores with MOX fuel assemblies. MOX assemblies will contain on average 18.2 kg of plutonium (the assembly weighs about 450 kg). U.S. PWRs typically operate on 18 month refueling cycles. It is assumed that MOX assemblies will be used in the reactor for two cycles generating electricity. That means that at steady state a PWR reactor may have about 72 assemblies containing MOX fuel, and that during each refueling cycle 36 MOX assemblies will be replaced during refueling. This results in roughly 435 kg plutonium per reactor being dispositioned annually, or approximately 3000 kg (3 MT) per year from seven reactors.

The MFFF project itself (bullet 3, above) is reported by MOX Services to be about 65% complete. The Red Team acknowledges that local DOE project oversight personnel, including the Federal Project

Director, dispute this number due in part to inadequate specification of construction sequencing and potential significant re-work. The Red Team noted that MOX Services is mitigating some of the risk of re-work through an extensive testing program aimed at critical systems and components, much of which has been completed. In keeping with an optimistic approach for comparison purposes, the Red Team used the 65% complete number and the associated ETC of $1.5B for discrete work (as previously discussed) for purposes of comparing this approach to other alternatives in this report. MOX Services claims to be completing approximately 3-5% of its remaining discrete work on the MFFF annually at the severely restricted funding level – a productivity level that is also challenged by the local DOE oversight office.

The current reported status for the MFFF by functional area as reported by MOX Services was:

- Engineering overall design at 94% complete with design for construction at 98% complete. The primary to-go engineering scope was electrical and controls/instrumentation design
- Procurement:
    - Complex gloveboxes: 86% awarded, 51% delivered
    - Other engineered equipment: 76% awarded, 40% delivered
    - Bulk material: 69% awarded/delivered
    - Subcontract value remaining to go: $675M
- Construction:
    - Civil 93% complete
    - HVAC duct 20% complete
    - Piping 10% complete
    - Glovebox and associated process equipment 27%
    - Cable tray and conduit 5% complete
    - Cable pull 1% complete

All other components of the MOX-based Pu Disposition Program have been either suspended, or are funded at a capability maintenance level due to severe funding restrictions initiated in FY14. All fuel qualification efforts, for example, were suspended in 2013. The Red Team notes that at some point, fuel qualification and licensing will become critical path, since it is normally a 10-year process.

2.1.2 Technical Viability of the MOX Approach

The technical methodology associated with the MOX approach to plutonium disposition is derived from the approach implemented at facilities in Europe and is relatively mature, although the French MELOX reference facility uses reactor fuel grade plutonium as feed and has a significantly higher throughput. The specific technologies include preparation of plutonium oxide through disassembly and conversion of plutonium pits, aqueous processing for removal of impurities (such as Ga, U, and Am) from plutonium dioxide feedstock, materials processing associated with pellet preparation and fabrication of the fuel rods, and use of the MOX fuel in light water reactors. There is an associated set of operations including waste management and disposition, transportation, and material control and accountability.

The initial step in disposition is the generation of oxide materials. For certain elements of the inventory, plutonium metal is converted to oxide. This has been demonstrated; NNSA has demonstrated plutonium oxide production by disassembling pits and converting them into plutonium oxide at LANL, and has established operations at H-Canyon and HB-Line which are capable of producing oxide from non-pit plutonium. The "reference facility" for AP is the AREVA facility in La Hague, where the UP3 line has been operating since 1995 for reprocessing of used commercial uranium fuel. The chemistry involves dissolution in nitric acid, actinide purification through liquid-liquid extraction, and recovery of plutonium through precipitation, with subsequent calcining. Plutonium purification in the AP portion of the MFFF involves less complex chemical separations than those used in fuel reprocessing, and simpler processing conditions (e.g., reduced dose). Process equipment has been designed to mimic that which is already in use in the reference facility, and key process equipment such as pulsed columns have been tested with surrogate materials.

The feedstock for MOX is more heterogeneous than the reference facility, with the need to accommodate variable purity and refractory oxide materials (including those with high chloride content). Process units have been designed to address electrolytic dissolution and dechlorination, although these units do not have long-term process experience. Fuel fabrication, on the other hand, is more directly comparable to that conducted at the MELOX facility at Marcoule. Process steps include production of powder (mixing and homogenizing), production of pellets (pelletizing, sintering, and final shaping), and rod assembly (loading, welding, inspection). There is a degree of complexity associated with process automation, although the majority of the process units have seen little modification from those in the reference facility.

The final stage of MOX disposition is irradiation of the MOX fuel in domestic commercial nuclear power reactors, including existing PWRs and BWRs. MOX fuel has been in commercial use since the 1980s (mostly in PWRs). Domestic demonstration has been made of the technology; four MOX fuel lead test assemblies manufactured from U.S. weapon-grade plutonium and fabricated at the Cadarache plant in 2005 and were irradiated on a trial basis at the Catawba plant for two 18-month operating cycles in 2005. Although this test had problems, the issues were associated with assembly design rather than fuel pellet concerns, and issues have been or are being addressed for assemblies holding uranium fuel as well as future MOX fuel.

Based on the demonstration of analogous (or closely related) processes at scale, the technology associated with the MOX approach is judged to be viable. However, the Red Team noted several concerns. First, the conservative approach to meeting NRC requirements has resulted in an extremely robust facility (manifest, in part, in high capital construction costs exceeding European benchmarks), and very tight controls. MOX Services reported 8,000 active items relied on for safety (IROFS) and 7,000 passive IROFS within the MFFF, all with attendant quality assurance (QA) and/or monitoring and reporting requirements. To the extent that these (especially the active ones) are analogous to Technical Safety Requirements within a DOE nuclear facility, each of these IROFS (especially the active ones) potentially represents a threat to continuous operation. They also drive the large analytical chemistry load expected to accompany MFFF operations. One-third of the 75,000 analytical procedures expected annually during operations are derived from IROFS requirements.

The second risk is excessive automation. The Red Team notes that excessive automation, inability to perform corrective maintenance on failed systems within gloveboxes, and inadequate buffer storage between process steps were causes of disappointing throughput rates at the Sellafield MOX Plant (SMP) in the United Kingdom (designed for a fuel output of 120 MT/yr, but only achieved 5 MT/yr). It appears that the MFFF design has addressed lessons learned from the SMP and incorporated maintenance capability and buffer storage to mitigate these risks. However, automated systems integration challenges in the facility add schedule risk to commissioning and startup, and could pose an ongoing risk to future operations and maintenance.

The third risk is the availability of reactors and utility agreements to support the planned 3 MT throughput. The Red Team notes that this would require the active engagement of seven reactors at the time of MOX production, but believes that these arrangements are ultimately achievable.

2.1.3 Ability to Meet International Commitments

The irradiation of MOX fuel prepared with weapon-grade plutonium in LWRs constitutes the U.S. commitment under the PMDA, although the project is behind the agreed-upon schedule. Thus, even though the technical approach is consistent with provisions of the PMDA, the agreement may nevertheless need to be renegotiated to accommodate new schedules and throughput rates, particularly if the deviation grows.

2.1.4 Regulatory and Other Issues

The NRC licensing requirements are not viewed by the Red Team as a high risk to the MOX approach, except to the extent that under-funding could eventually cause fuel qualification and licensing to become critical path. There are two different licensing activities for the MOX option: licensing of the MFFF (handled by NRC's Nuclear Materials Safety and Safeguards division) and licensing of the use of the MOX fuel in existing reactors (handled by NRC's Nuclear Regulatory Regulation division).

There are no significant issues currently identified regarding the licensing of the MFFF. The NRC issued a Construction Authorization in March 2005 for the MFFF. MOX Services submitted a license application in September 2006. The NRC published the Final Safety Evaluation Report in December 2010. The NRC should issue a license subject to MOX Services complying with the Principal Structures, Systems, and Component requirements. The NRC currently has a resident inspector on site at MFFF and supplemental personnel from Region II and NRC headquarters as needed. From the Red Team perspective, there is an appropriate relationship between the NRC and MOX Services. The NRC requirements are well defined and there is a similar facility in operation in France providing confidence in operability of the MFFF within a regulated environment. The NRC staff has visited MELOX and has had discussions with the French regulators. Therefore, there should be no major surprises from either the regulator or from the operations by MOX Services.

There could be an issue of dual regulation that would need to be resolved between NNSA and NRC. The NRC is responsible for granting the license, but if NNSA adds additional requirements and MOX Services makes them a license commitment, these additional requirements then become NRC license requirements. This is most apparent in the area of security. The NRC currently licenses Category 1 facilities and has processes, procedures, and requirements for satisfying these requirements. If additional requirements are put in place by NNSA and are not part of the NRC license, the chance for confusion and even conflict increases. One set of regulatory requirements and one regulator results in the best safety and security.

If DOE chooses to continue with the MOX approach, it is important that the MOX Program leadership establish sufficient priority and funding to address long-lead elements associated with the actual use of the MOX fuel in licensed nuclear reactors. This means that continued, sustained progress occurs at NRC for approval of the MOX fuel, including NRC review of MOX Services topical reports and funding MOX Services efforts to address NRC questions. In addition, the specific licensed reactors that might use the MOX fuel need to ensure they acquire the necessary NRC approvals in a timely manner. The NRC needs advanced planning for the necessary actions regarding the MOX Program. This includes the proper staffing for license reviews and inspections of the facilities needed for the construction, operations, and nuclear reactor use. The NRC budget process occurs well in advance of the time needed for actual staffing. NNSA needs to be mindful of NRC's logistical and budgetary requirements and give sufficient notice of their needs. Absent this, fuel qualification and licensing may not only become critical path, there may also be a ramp-up time associated with the replacement of lost resources and knowledge.

2.2 Potential Enhancements for Cost Reduction

2.2.1 Staffing

In a review of the MOX services hotel load scope and staffing levels for FY 2014, the ratio of non-manual to manual labor was found to be slightly higher than 1:1. This non-manual staffing level seemed excessive given the levels during previous fiscal years prior to the partial suspension of the project. When reviewed with the MOX Services team, the contractor stated that the non-manual level of effort portion of the hotel load has not been optimized, and in fact, resources were maintained at a higher level to retain talent in anticipation of ramping the project back to a full funding level. Reductions could be made in the management and oversight levels commensurate with the lower direct craft levels. This creates an opportunity to reduce these non-manual headcount levels in a $350M a year funding level scenario from $14M/month to $11-12M/month or lower, thus creating the opportunity for a larger percentage of direct work in each fiscal year. While this is a non-trivial reduction in current costs, the cost to ramp down and then ramp back up should be considered. This situation further illustrates the need for a funding decision related to the MFFF.

Perhaps more importantly, a low ratio of support to direct labor should be the goal at any funding level, and DOE could help enable this through a different approach to oversight. As an NRC-regulated construction project, and with a properly structured contract, the local DOE project oversight office (approximately 30 personnel, expected to increase to 50 if the project is fully funded) could focus almost exclusively on contract compliance. While contractual oversight is appropriate and necessary, it could be carefully scheduled in cooperation with the contractor, relatively rare and episodic, and aimed primarily at fee-bearing aspects of the prime contract. The large number of assessments conducted by local DOE staff, combined with the layers of oversight conducted by the sponsoring program and headquarters, can drive excessively large support organizations within the contractor, and even steer their attention away from project support to client support. The Red Team was surprised, for example, that MOX Services currently carries a project controls staff in excess of 200 people. In addition, projected staffing levels for MFFF operations have been benchmarked against the Reference Case and the absolute numbers appear disproportionately high. Opportunities certainly exist for revision and reduction in future MFFF operations staffing levels, which may include out-sourcing.

2.2.2 MOX Fuel Use Revenue and Risk Mitigation

Costs and risks associated with MOX fuel use include the transport packages, development of depleted uranium feed (which makes up 96% of a MOX assembly), shipment, increased security, licensing of vendor fuel codes and license amendments for reactors. Some of these activities have long lead times, such as validation of vendor fuel codes. NRC review and approval of topical reports is a precursor to utilities submitting license amendment requests, and so forth.

The maximum possible value associated with MOX fuel is the value of the displaced uranium fuel, or 36 assemblies every reload. Current prices for uranium and enrichment, the key components in nuclear fuel cost, are near historic low levels. The cost of a uranium fuel assembly in today's dollars is approximately $1M, or $36M per reload. Over the life of the Pu Disposition Program, that would result in approximately $1.8B of potential revenue. From a utility perspective, the risks to MOX fuel use are large and will potentially require a substantial price discount, perhaps to the point of being "free" in the beginning, to incentivize the utility to make modifications to their reactor and go through NRC license amendments, to use fuel that is less optimum than their current fuel. To the extent that such incentives become necessary, they subtract from the total potential revenue of $1.8B. However, the net value should be subtracted from the LCCs of the MOX approach when comparing point estimates of LCCs to other alternatives (which, as previously discussed, can be misleading). The Red Team believes it is unrealistic to assume a net value of more than $1B for the 34 MT of surplus plutonium.

The Red Team noted that some utilities operate in regulated power markets where public utility commissions decide on what qualifies to go into the electricity rate base. In those utilities, fuel costs are usually passed directly to customers and it may be unlikely that a regulated utility would bear the risk of MOX fuel, even if it is free. This puts at risk the assumption of seven available reactors to support the movement of material through the MFFF facility fast enough to support the facility's designed throughput rate. However, the Red Team believes it may be possible to accomplish the irradiation mission with fewer than seven reactors, as some reactors are capable of 100% MOX loadings (e.g., Combustion Engineering Reactor designs, AP-1000), and/or by irradiating some MOX assemblies for one cycle only, increasing the number of new MOX assemblies loaded above 36 per cycle.

Furthermore, utilities will demand that MOX fuel meet strict QA requirements and delivery guarantees, the same as fresh fuel. It is the Red Team's understanding that no vendor has ever failed to supply fuel and thus caused a delay in reactor startup. To address the risk of potential delay in the supply of in-spec MOX fuel, NNSA has created a large backup supply of low enriched uranium fuel, consisting of 170 MT of uranium at 4.95% enrichment. This provides substantial risk mitigation to fuel supply interruption, and thus facilitates the eventual development of a sufficient customer base. In summary, the Red Team believes the risk that an insufficient number of reactors will be available for the MOX fuel has been overstated. It was always unrealistic to expect utilities to effectively "sign up" so far in advance, and with sufficient incentives, the Red Team is convinced that there would be an adequate number of buyers and reactors available. Until the MFFF is delivering licensed fuel to an operating reactor, DOE would be proceeding with the MOX approach at risk since that will be a necessary condition to secure final agreements for a full suite of reactors.

2.2.3 Scope Reduction

In addition to the measures described above relating to optimization of the baseline approach and reduction of LCC, the Red Team asked the project team to identify potential modifications to scope that could result in cost savings to the overall MOX project. It is clear that a number of improvements have been made over the duration of the project to date, including simplification of processes, and elimination of redundant systems or select excess capacity. Several additional options were considered. Most involved savings in future operational costs, rather than reduction in the scope and costs of capital construction, and most of the associated impacts were small to moderate. These are less mature concepts, and have a high degree of uncertainty in potential savings; for some it is not even possible to quantify cost reduction at this stage. These are presented below in the interest of identifying options that may be appropriate for further study, and in direct answer to Red Team Charge #2. The Red Team notes, however, that their combined budgetary impact is not large and is not likely to factor into a decision on whether to proceed with the MOX approach.

2.2.3.1 Consolidation of IROFS

As discussed in Section 2.1.2, the decision to perform a qualitative safety assessment during design development is considered to have provided a short-term cost and schedule benefit during early design efforts, but appears to have generated a capital and expense burden through over designation of the safety features (the IROFS). Quantitative risk assessment may have led to at least 1,500 fewer such designations. The MOX Services project team has already identified a small potential savings of $11M capital at this late date in construction, and $0.7M in annual operating expenses, related to a reasonable reduction in the number of IROFS. The risk reduction value described in Section 2.1.2 related to the avoidance of operational upsets may be far higher.

2.2.3.2 Modification of Laboratory Operations

The laboratory defined in the scope of the MFFF serves to provide physical and chemical analyses of samples from both the AP and MOX Process areas of the facility, with specifications established by production and compliance requirements. It was reported that laboratory unit operations may be sized with some redundancy to support operations during peak load times, and/or as a safeguard against equipment failures. Although significant progress has been made in the procurement of equipment, installation and procedure development is at a low level of completion. In addition, there is some risk that equipment will become outdated as the MFFF is completed, requiring additional investment. Opportunities for better integration were discussed to take advantage of other laboratories (notably, existing SRS analytical laboratories) by subcontracting a range of scope for these operations. This carries the opportunity of modest construction and operational cost savings (in the range of millions to tens of millions of dollars), with associated variable degrees of risk reduction. The viability of these options may be more likely when combined with a reduction in IROFS.

2.2.3.3 Simplifying or Eliminating AP Operations

One planned deviation from demonstrated MOX technology is the use of lower-purity feedstocks at MFFF (Alternate Feedstocks, or AFS). Although all feeds (both high- and low-purity) are planned to be processed in the AP area, lower-purity feed results in lower throughput due to the need to employ dechlorination to eliminate impurities that could impact processing and product quality. Modest cost savings may result from the substitution of additional high-purity feed for certain AFS material. The Red Team is convinced that should DOE decide to employ this risk reduction, there may be other sources of material to make up for the loss of AFS feed.

The option of curtailing AP operations altogether was also discussed. One option would be to process some or all of the low-purity feed and conduct final purification steps in H-Canyon/HB-Line. This could require an extension of operations in HB-Line in some scenarios, beyond the predicted life of the EM mission there. Although high-purity feeds do not contain the same range of impurities, they retain other constituents (^{241}Am, Ga) that either increase dose or interfere with fuel performance or fabrication. Alternative technologies may be available to address removal of these constituents, obviating the need for AP operations altogether (as well as associated waste management costs since WSB volume is dominated by effluent from AP). Possible benefits of this range of options would be cost reductions associated with capital completion (perhaps small) and elimination of costs associated with operation of the AP area and the WSB. However, risks also exist; given the potential for impact of impurities on fuel performance, the implementation of new technologies (to remove volatile Ga, for example) could lead to schedule delay including the requirement for a new lead test assembly evaluation. These technologies have not been demonstrated at scale, and performance characteristics are not available to judge cost or impact on product performance or worker dose. For this reason, it is not possible at this time to judge costs and benefits; further study of these options would be required.

If DOE chooses to pursue this opportunity, it will be important to assess implications to the NRC license and fuel quality to define an efficient path forward and maximize potential savings.

3. Dilute and Dispose, and Similar Options

For purposes of considering alternatives that have not already been screened out as impractical, the Red Team articulated a guiding principle to use as a framework for examining alternative approaches:

> "Develop an alternative disposition pathway that can be executed at an affordable cost, with an acceptable schedule and risk profile, using an approach that has a reasonable probability of achieving Russian concurrence on a revised PMDA."

Having screened out all previously considered alternatives to MOX other than Dilute and Dispose, the Red Team attempted a systematic approach to developing practical variations to this remaining alternative using this guiding principle. A broad definition of the possible approaches is shown in Figure 4 with five different levels of options possible (A through E). The options span a spectrum from the minimum condition (do nothing), up to and including the current approach, with the baseline MOX approach shown as option E for the sake of comparison. Based on sponsor input and collected information, the first filter that the Red Team applied towards the range of remaining options was the desire to minimize the proliferation risk associated with disposition. Options A and B from Figure 4 were eliminated from further consideration since the disposition form is an intact pit that fails to provide adequate protection against proliferation. So the remaining option categories were C) the sterilization option, D) the Dilute and Dispose option, and E) the MOX approach. The MOX approach was evaluated previously in this document, and the sterilization approach will be discussed later, in Section 3.2. Section 3.1 evaluates alternative category D (Dilute and Dispose) from Figure 4. For purposes of this report, the downblending option as described in the PWG report is considered a "base" concept for the Red Team's Dilute and Dispose option (alternative D), takes the path of D2 in Figure 4, and is the subject of Section 3.1.1. Opportunities to improve upon that base approach, including the path represented by D1 in Figure 4, are addressed in Section 3.1.2.

3.1 The Dilute and Dispose Option

3.1.1 The Base Case (D2 from Figure 4)

3.1.1.1 Description of the Basic Dilute and Dispose Option

This option would involve the dilution of 34 MT of excess plutonium oxide material with inert materials at SRS, packaging the diluted material into approved shipping containers, and transporting the shipping containers to WIPP where they would be placed in the underground panels for permanent disposal. The D2 base option shows pits being shipped from Pantex to LANL where they would be disassembled, the plutonium metal converted to plutonium oxide as in the MOX option (except to a lower acceptance standard than MOX feedstock), and the plutonium oxide transported to SRS for dilution prior to disposition to WIPP. The system diagram for this option is given in Figure 5.

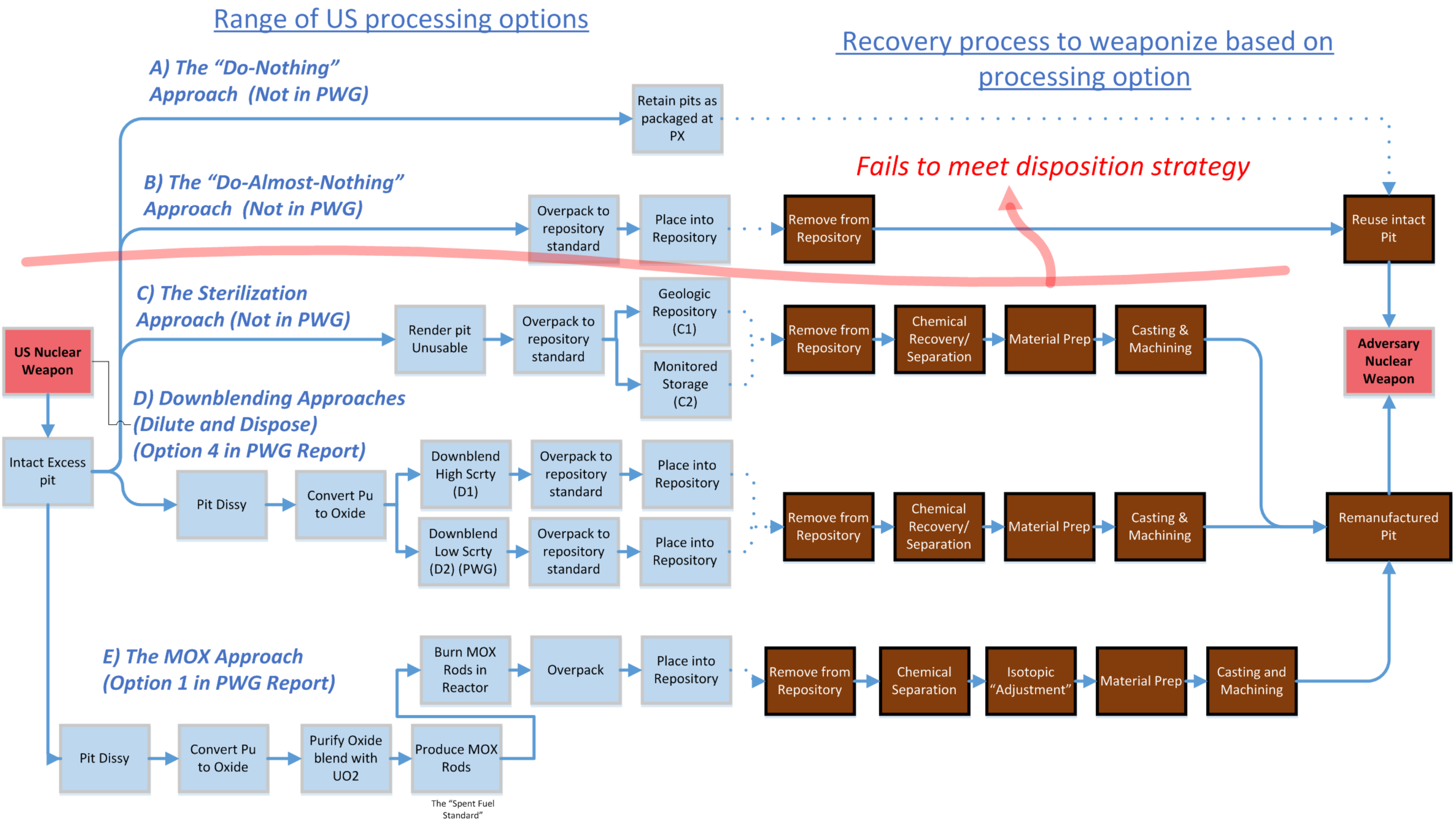

Figure 4. Remaining Practical Approaches to Pu Disposition

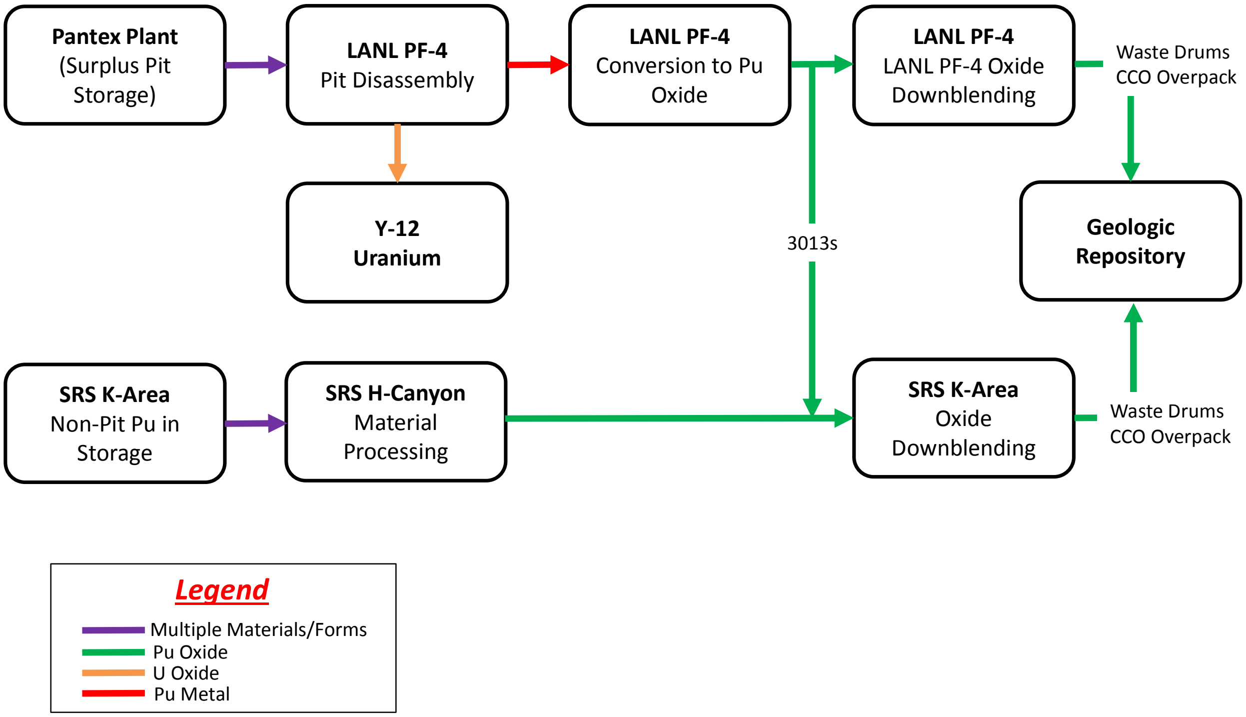

Figure 5. Basic Flow Diagram for the Dilute and Dispose Approach: This figure shows the major material flows for the base Dilute and Dispose approach as well as one variant, described later. Under this variant, LANL also dilutes material as a second production site, working in parallel with SRS.

The plutonium oxide would be diluted with an adulterant mixture that serves to reduce the attractiveness level of the plutonium oxide by yielding a mixture that: 1) has a reduced plutonium concentration; and 2) requires extensive processing to achieve a purified material. As such, the diluted plutonium oxide material would meet a Safeguards and Security Attractiveness Level D, and safeguards could be terminated on the material so that it could be disposed at the WIPP.

3.1.1.2 Technical Viability of Dilution and Disposal

To assess this option, the Red Team toured the SRS K-Area facility, the LANL PF-4 facility, and WIPP, and held multiple discussions with facility and Program personnel. Based on these inputs, and the fact that this approach for dispositioning excess plutonium oxide materials has already been used at several DOE sites in the past (the Rocky Flats Environmental Technology Site, the Hanford Site, and SRS), the Red Team judges that:

- The dilution of plutonium oxide with an inert adulterant is a low complexity technology;
- There are no real technical challenges to the successful implementation of this option, given the systems already in place to produce oxide for MFFF; and
- The primary risks with this approach would be regulatory and stakeholder issues.

As mentioned above, all of the dilution activities for the base version of this option would be done at SRS. Specifically, the dilution activities would occur in the K-Area Material Storage (KAMS) facility. Initially, the dilution activities would be conducted in the current KAMS glovebox, referred to as the K-Area Interim

Surveillance glovebox. The anticipated throughput of this glovebox is 400-500 kg of plutonium per year. To increase the throughput up to about 1,500 kilograms of plutonium per year, this option includes the installation of two additional gloveboxes into KAMS at an unofficial estimated cost of up to $240 million. That installation not only includes the two gloveboxes but also non-destructive assay equipment and changes to the KAMS documented safety analysis to allow for increased throughput, as well as support systems such as ventilation systems, fire suppression systems, staging rooms, electrical upgrades, and installation of several instrument and monitoring systems. The Red Team believes that the $240M estimate is conservative when compared to the much less expensive installation cost of the very similar, existing glovebox.

The diluted plutonium oxide material would be packaged in product cans, removed from the glovebox in bag-out sleeves, and packaged into a slip-lid can. That can-bag-can configuration would be loaded into a Criticality Control Overpack (CCO) that will be used to ship material to WIPP in a TRUPACT II. The average plutonium loading of the CCO is anticipated to be about 300 grams.

The disposition of the 34 MT of plutonium in this manner will be subject to international observation and remote monitoring by the IAEA. Therefore, some equipment would need to be installed in KAMS to support the IAEA activities. It should be noted that KAMS already has some SNM under international safeguards, so facility operators are familiar with the IAEA requirements.

The SRS activities for this option also include the conversion of a fraction of AFS metal to oxide using the H-Canyon for dissolution of the metal, with the purification, oxalate precipitation, and oxide conversion in the HB-Line. These activities are anticipated to be completed in 2022-2024 and are also required for the MOX Program to provide feed for the MFFF.

The Red Team toured the KAMS on July 28, 2015. Based on that tour, the Red Team judges that:

- There is sufficient footprint in KAMS facility available for dilution activities and associated storage and staging; and
- The previous experience in repurposing the KAMS facility for other purposes gives confidence in the viability of this approach.

The LANL activities for this option would essentially be the same as for the MOX Program. Specifically:

- All pit disassembly and oxidation of pit material would be done at LANL; and
- All oxidized plutonium pit material would be sent to SRS for dilution under the base approach.

However, there are three scope changes to the LANL activities relative to the MOX program, all of which effectively reduce the relative cost and risk of feed production for the Dilute and Dispose option as compared to MOX:

- No analysis of the product plutonium oxide would be necessary to show that the material meets the MOX feed specifications;
- Major elements of the LANL program (e.g., most QA and quality control requirements) intended to produce “certified” oxide would not be necessary since oxide production specifications would only be driven by transportation requirements and the WIPP waste acceptance criteria; and

- The milling/blending operation would be eliminated and other process equipment would be simplified throughout the manufacturing flowsheet.

With respect to facility modifications and/or equipment, there is an apparent synergy between existing equipment that would be removed and new equipment that would need to be added for capacity. After the tour of the PF-4 facility at LANL on July 16, 2015, the Red Team judges that:

- LANL has the technical capability needed to prepare plutonium oxide from pit plutonium metal, and has in fact demonstrated this capability at a pilot scale, producing oxide with a more demanding specification than would be needed for the Dilute and Dispose option;
- There is sufficient space available in the PF-4 facility to perform this scope without undue interference from existing and planned missions. While PF-4 is used for other missions and customers, and risk exists that other missions could impact Dilute and Dispose operations, the Red Team judges the probability of that occurring as low and concludes that the impacts of interruption are more severe to the MOX approach than to the Dilute and Dispose option.; and
- Resumption of operations will be a factor in PF-4 planning through 2016 for either the MOX approach or the Dilute and Dispose approach.

In this option all diluted plutonium oxide materials would be sent to WIPP for disposition. As previously discussed, WIPP has already received and disposed of such materials in the past. Thus, the receipt of similarly diluted materials is not expected to pose technical problems; but there are regulatory issues that would need to be addressed to allow the disposition of all 34 MT of plutonium (see Section 3.1.1.4). To accommodate the number of CCO packages anticipated for this option, at least one additional panel would need to be mined at a cost of about $8-10 million/panel, but it is not clear that this would be an NNSA cost. The scope of this option would also include the termination of the MFFF project; in fact this represents the largest cost element for the Dilute and Dispose option. The Red Team has assumed based on input from MOX Services that between $200M and $350M per year will be needed over the first three years to fund the MFFF project termination if the Dilute and Dispose option is selected for future execution.

In summary, the Dilute and Dispose approach uses simple, robust technological elements to produce a product suitable for disposal at WIPP. All of the processes necessary to produce, pack and ship diluted plutonium have been demonstrated in a production environment at multiple sites. The process requires no unique machine tools, gages or instruments that are not already a part of the process for making oxide and disposing of waste for the MOX approach. It also utilizes transportation techniques that are well established and proven. Stated another way, all of the technology required to produce a blended can of oxide is a subset of the technology required to produce certified oxide for the MOX approach. Thus, the technology is assessed to be mature having been demonstrated in a production environment.

These same processes will need to be scaled up to achieve a higher throughput capacity, but this scaling involves essentially no unique technical risk as it represents replication of existing equipment and relatively simple footprint expansion within existing facilities. In an effort to reduce dose, some of these processes may eventually be automated in the future, but initial operations are perfectly suited to manual activities to produce suitable product. Perhaps the greatest technical risk during full-scale operations will be the standard challenge of managing tightly controlled material movement logistics within a high security nuclear facility. Ultimately, the rate of oxide production at LANL is expected to control the maximum rate of diluted plutonium drums sent to WIPP each year.

Regardless, there is a stark contrast in the required technology for the MOX approach versus the Dilute and Dispose approach. Each involves the usual supporting technology required for safe and secure plutonium operations such as a complex facility ventilation system, airlocks, nuclear material control and accountability, etc., but the technology comparison is between the highly automated process equipment in a newly constructed, highly controlled MFFF on the cutting edge of integrated manufacturing technology, versus the simple mixing and measuring technology of the Dilute and Dispose approach.

3.1.1.3 Ability to Meet International Commitments

While the NAS report adopted a SFS as discussed at the beginning of this report, and the irradiation component of the PMDA requires spent MOX fuel to no longer be weapon-grade (i.e, the ^{240}Pu to ^{239}Pu ratio should be greater than 10%), it was also clear in the NAS report that similar chemical, physical, and radiological barriers to proliferation should be acceptable as well. Consistent with this, the Russians agreed in the original PMDA to allow the U.S. to use immobilization for a portion of the inventory, which involves no isotopic dilution but achieves all three of the barriers discussed by NAS. As pointed out in the PWG report, the Dilute and Dispose option would implement two of these three barriers (chemical and physical).

Much has been, and will continue to be, said about the risk of unacceptability of this option from the standpoint of meeting the letter and intent of the PMDA. However, as discussed in Executive Considerations, the Red Team believes that based on the history of modifications negotiated to date under the framework of the PMDA it is reasonable to conclude that a new modification could be successfully negotiated on the basis of a Dilute and Dispose approach, provided a strong U.S. commitment is maintained with regard to timely disposition. The Red Team conclusion is supported by the following considerations:

- Article III of the PMDA allows for modification to the disposition approach if agreed in writing.
- The U.S. has previously accommodated Russian national interests in an amendment to the PMDA.
- International circumstances have changed, such that it now appears appropriate to credit engineering and institutional measures, such as physical security, disposal site characteristics, and safeguards, as essentially equivalent to the barriers provided by SFS. Indeed, the Surplus Pu Disposition SEIS Scoping Comment Summary stated that Dilute and Dispose is “akin” to the SFS, which implies that the U.S. has already made a “sufficiently equivalent” determination.
- Regardless of any path forward, PMDA negotiations must be renewed with the Russians. In the case of the MOX approach, it is already too late to achieve the agreed timeline for disposition of the 34 MT. Based on interviews conducted by the Red Team, the Russians may consider the agreement abrogated on this basis alone, but will nevertheless proceed with Pu disposition as part of their overall nuclear energy strategy (although they may hold weapons grade material aside and use recycled reactor grade MOX). Regardless, the proliferation risk of Russian held material has changed substantially since the PMDA was first negotiated, as previously discussed. This leaves room for negotiation, assuming that overall relations allow cooperative exchange.
- The U.S. has already successfully disposed of non-MOXable weapons grade Pu at WIPP via a Dilute and Dispose approach, although none of this material can count toward the 34 MT commitment since it was not independently verified by the IAEA. DOE has determined that the blending technique utilized for this material achieves the reduction of attractiveness required to eliminate safeguards as discussed in DOE Order 474.2. Thus, the U.S. will have a reasonable position to enter into negotiations of the PMDA.

It is the Red Team's opinion that the federal government has a reasonable position with which to enter PMDA negotiations when a negotiating process emerges as a natural outcome of a final decision on the path forward. In any event, the Red Team offers a brief alternative approach in Appendix D to address concerns that the Dilute and Dispose option inadequately complies with the PMDA.

3.1.1.4 Regulatory and Other Issues

Most of the regulatory issues identified for this option by the Red Team involve WIPP. Of first concern is the timely resumption of WIPP operations, which have been suspended since the two February 2014 incidents (vehicle fire and radioactive material release). As previously discussed, WIPP is the only repository for TRU waste, and as such is a critical asset both for completion of the EM mission (cleanup of the nation's nuclear weapons production legacy), and for continued support of DOE's weapons and other programs. Thus, an inability to resume operations at WIPP is not considered by the Red Team to be a credible risk to the Dilute and Dispose option. WIPP is simply too important to the nation. As reaffirmed in her NY Times quote on August 8, New Mexico Governor Susana Martinez believes WIPP and LANL are "*critical assets to our nation's security, our state's economy, and the communities in which they operate.*"

Rather, the protracted resumption of operations at WIPP poses a risk to the assumed startup date for the Dilute and Dispose option. A conservative assumption for the full-scale resumption of WIPP operations would be five years. During the first three years of this assumed WIPP recovery period, DOE would need to spend a significant fraction of the expected available annual funding (as much as 75%, assuming annual budgets remain at current levels) on MFFF cessation anyway, and could spend the rest on development of a detailed baseline program plan and funding-capped pursuit of the relatively small capital investments at LANL and SRS needed to support an optimized version of the Dilute and Dispose option. As the relatively small capital projects are completed, DOE could ramp up oxide production capacity and produce a feedstock backlog to ensure that LANL does not become an unacceptable production limiter. The primary impact due to delayed start, therefore, would be escalation of present-day dollars, but the Red Team asserts that an accurate baseline plan for Dilution and Disposal would involve a relatively long ramp up period anyway, which would prevent WIPP restart from appearing as the critical path.

Second, the WIPP LWA restricts the total TRU waste volume to 176,000 cubic meters, and to date, 91,000 cubic meters have already been emplaced. Of the remaining 85,000 cubic meters, only about 19,000 cubic meters are considered "unsubscribed", and as previously discussed, the Red Team believes this number may be over-estimated (depending of course, on value judgements related to disposal priority). The base Dilute and Dispose option would require a considerably larger volume allowance, perhaps as much as 34,000 cubic meters. Unless some of the subscribed capacity is re-directed toward support of the Pu Disposition Program, an increase in the volume allowance would require action by the U.S. Congress. But the Red Team posits that the eventual expansion of WIPP capacity will be necessary anyway from the emerging recognition of other TRU waste sources that are not included in the current DOE-EM baseline, irrespective of the needs of the Plutonium Disposition Program, although any such expansion would be subject to cooperation and regulation from the State of New Mexico regardless of the source of waste.

In any event, well over half of the entire duration of a Dilute and Dispose operation could be completed before facility expansion would be needed. This leaves adequate time to address the national imperative for additional capacity at WIPP (subject to concurrence from the State of New Mexico) without it becoming a critical path item on the Dilute and Dispose schedule, and there are opportunities for mitigating the residual risk discussed below in Section 3.1.2. Similar to the WIPP restart risk, the Red Team does not consider WIPP expansion to be a catastrophic risk to the base Dilute and Dispose approach, even ignoring the potential enhancements (discussed below) which may obviate the need for any legislative or regulatory action to expand WIPP specifically to support a Dilute and Dispose approach. The Red Team notes that long-term WIPP operation and available capacity is also a requirement for the MOX Fuel approach since the WSB would generate TRU Waste as a consequence of MFFF Operations.

A third regulatory risk relates to the Resource Conservation and Recovery Act (RCRA) Permit for hazardous wastes from the New Mexico Environment Department under which WIPP operates. Based on discussions with personnel at WIPP during the July 13, 2015 visit, large-scale support of the Pu Disposition Program would require one or more Class III permit modifications, which are subject to public involvement. Although such revisions to the permit have been made in the past rather routinely, the recent incidents at WIPP may stimulate heightened public interest, and non-governmental organizations may mobilize in an attempt to prevent the large-scale disposal of excess weapon-grade plutonium at WIPP. Ultimately, any such permit modifications would be subject to State of New Mexico approval and regulation.

The updating of National Environmental Policy Act (NEPA) documentation to support this alternative will present a similar opportunity for public input. The current NEPA action governing the plutonium oxide dilution effort at SRS is an Interim Action which allows for a limited amount of material to be diluted and sent to the WIPP. The Surplus Plutonium Disposition SEIS allows for a larger amount of plutonium oxide to be diluted and shipped to WIPP, but the Record of Decision for that NEPA action has not been issued. To cover the full scope of diluting 34 MT plutonium oxide and shipping it to the WIPP for disposition would require additional NEPA review.

3.1.2 Potential Enhancements to the Base Dilute and Dispose Option

The Red Team spent considerable time evaluating the Dilute and Dispose option as an alternative means for Pu Disposition. This involved trips to LANL, WIPP, and SRS locations in order to walk the spaces intended for use in this option. During the course of this effort, several possible enhancements were identified that offered potential improvements to the base approach. These enhancements included the broad goals of:

- Possible cost and schedule savings;
- Improvements to reduce execution, regulatory and security risks;
- Changes in the approach to simplify logistics; and
- Changes in the approach to facilitate successful negotiations on any necessary PMDA modification.

While all of the following opportunities are expected to be technically feasible, none are needed to initiate the Dilute and Dispose process and the removal of plutonium from current locations. These enhancements can be developed and added in parallel with ongoing operations. It is important to note that the Dilute and Dispose option can be started early at a lower throughput during the modification process to install new gloveboxes in the baseline case. It is during this transition period that the following enhancement opportunities could be developed and implemented.

3.1.2.1 Increased Pu Loading Per Container

Increasing the plutonium amount per container would have a direct impact on LCCs of the Dilute and Dispose option because of the reduction in processing time, and the reduction in drums, shipments, and other logistics associated with the campaign. This opportunity would incur increases in cost from enhanced security requirements consistent with the approach in the PWG report variant to the Option 4 Downblending approach, as depicted as path D1 on Figure 4. One possible benefit of this approach is the volume reduction needed for the final disposal in WIPP. It may be possible to increase loading to a level that negates the need LWA changes to accept the waste from 34 MT of surplus plutonium.

3.1.2.2 Accurate Volume Accounting at WIPP

The Red Team was surprised to learn that the WIPP RCRA permit requires that the volume considered utilized at WIPP is based on the volume of the external container rather than the volume of the TRU waste within. Thus, it is estimated that 30-50% of the 176,000 cubic meters at WIPP may eventually be consumed by empty space within outer containers. In the limited time available for this study, the Red Team identified no basis for this accounting method in worker or environmental protection or regulatory compliance. Likewise, the total volume restriction that appears in both the RCRA permit and the LWA is not rooted in WIPP's performance assessment. As discussed in our Executive Considerations, the treatment of WIPP as a valuable national asset requires addressing these limitations in cooperation with the State of New Mexico. In combination with enhanced Pu loading discussed in Section 3.1.2.1, proper waste volume accounting may obviate the need for any changes to the LWA.

3.1.2.3 LANL and SRS Cooperative Hybrid

This approach would help optimize Office of Secure Transport, TRUPACTs, and other logistical resources by performing some Dilute and Dispose scope at both LANL and SRS, in an optimized configuration yet to be determined through detailed study. This approach may have LANL perform some dilution and direct shipments to WIPP as an add-on to the LANL oxide production scope. This approach would increase the number of glovebox lines at LANL for oxide blending, but the small number required would be readily available since they are basic gloveboxes that do not require customization. WIPP-compliant characterization and TRUPACT loading and shipping equipment are already available to support existing operations.

An optimized approach also may also require modifications to the scope at SRS. Increasing the amount of metal to be converted to oxide at SRS is one option, either using a process similar to existing processing of AFS material or through the installation of muffle furnaces at KAMS. Another option is the use of HB-Line for dilution to supplement operations in KAMS and potentially at LANL. During the lifecycle of H-Canyon operations for EM's spent nuclear fuel processing at SRS, the support infrastructure (HVAC, etc.) remains viable for HB-Line Phase 1 and/or Phase 3 gloveboxes to be used to augment Pu dilution within H area security constraints. HB-Line Phase 1 was used in 2012/2013 to dilute the initial EM plutonium for WIPP.

The H-Canyon life expectancy is dependent on EM funding and decisions on duration of Spent Fuel processing missions. Currently, H-Canyon is expected to remain operational into FY24, although recent EM budget constraints have called this into question. The cost to extend this Phase 1 operation until 2024 is expected to be bounded by the annual cost for AFS-2 processing because of the less demanding sample analyses and operations to meet WIPP criteria compared to MFFF specifications. After that, there will be serious issues regarding the responsibility for funding infrastructure.

An optimized hybrid approach to oxide production and blending would increase overall throughput and reliability through a parallel processing approach. Cost savings relative to the base approach would be manifested in terms of reduced LCC. Also, the risk of one site losing operational status would be partially mitigated by the presence of duplicative capability and complimentary capacity. The Red Team notes that initial investments into hybrid capability might have a higher return at LANL in the event of severe funding restrictions, since pit conversion must occur there anyway.

3.1.2.4 Use of a Planned Future Glovebox in KAMS for Dilution

This opportunity would utilize a new glovebox that is anticipated (pending NEPA) for processing in KAMS. This glovebox is expected to include furnace capability and could augment metal conversion to oxide as well as dilution. Physical modifications are not expected to be significant to replace minor hardware elements in the glovebox to allow bulk dilution. The glovebox is being installed for a different program, and is expected to only be utilized for this purpose for 2-3 years.

3.1.2.5 Addition of More Gloveboxes in KAMS

Determining the optimum number of glovebox lines to be added to KAMS may result in more than the two currently envisioned in the base Dilute and Dispose approach in order to reduce project duration and LCC. However, the utility of such an investment requires an understanding of limiting conditions, which is likely to be oxide production at LANL, where limited capital investment may have a greater benefit. If the addition of more than two gloveboxes at KAMS makes sense, the Red Team notes that such an addition of scope should be made early in the design phase to take advantage of economies of scale. Installation of new gloveboxes may be difficult once the supporting infrastructure is installed, and especially after the existing gloveboxes become contaminated. Contracting strategies that incentivize building additional glovebox lines within a defined total project cost may be effective, given that a large fraction of the capital cost will likely be devoted to design and safety analysis as opposed to procurement.

3.1.2.6 Alternative Downblending Technologies

Other potential approaches exist which would require technology maturation to blend the Pu for disposal in different ways to achieve different objectives. Appendix D offers a description of one such approach related to specific risk mitigation. There are others which could be analyzed within a value engineering context. In addition, automation of portions of the Dilute and Dispose option could be explored to minimize labor and personnel exposure and to accelerate portions of the overall flowsheet. All such options are viewed as continuing improvement techniques and opportunity challenges for the management team of the Dilute and Dispose approach, and should only be pursued if a business case can be made for return on investment.

3.2 The Sterilization Approach (Option C on Figure 4)

As presently defined, the Dilute and Dispose approach was intended to meet the established requirements for shipping and disposal. Although far more efficient than the MOX approach, these requirements result in limitations that cause considerable expense, lengthen the time for program execution, and require frequent transportation of nuclear material. Option C from Figure 4 illustrates a potentially simpler option. Under this option, two major changes occur relative to the “base” Dilute and Dispose option. First, instead of transporting pits to LANL for disassembly and the plutonium to either SRS or LANL for processing, the pits would be processed at Pantex to “sterilize” them to the extent necessary to achieve disposition. Second, instead of transportation to a geologic repository, the sterilized pits would remain at Pantex under monitored storage (Variant C1 in Figure 4). Variant C2 would have the sterilized pits transported to WIPP for permanent disposal, thus achieving equivalency to the Dilute and Dispose alternative.

A sterilization approach (particularly if enhanced by monitored storage at Pantex in lieu of WIPP disposal) could result in the following improvements relative to the dilute and dispose option:

- Using this approach would dramatically improve the processing rate to convert starting material into a “dispositionable” product;
- Would reduce nuclear material shipments by 90% ;
- The end product could be monitored to ensure that theft and diversion does not occur;
- The packages prepared for monitored storage could be monitored in-situ, and could always be transported to a geologic repository at a later date;
- Eliminates the non-value added work associated with complete pit processing.

However, there are also significant challenges to this approach:

- The sterilization approach, although viewed by the Red Team as essentially equivalent to Dilute and Dispose (under variant C2), may not be viewed by the Russian Federation as sufficiently compliant with the PMDA;
- Under Variant C1, Pantex storage capacity may be insufficient to support this approach absent a capital investment;
- Under Variant C2, the acceptability of this material form as a waste that can be transported and disposed at WIPP is not clear. At a minimum, it may require exemptions to obtain safeguards termination, and there may be challenges related to compliance with WIPP waste acceptance criteria.

The pursuit of this option would require a separate feasibility study and detailed planning. As discussed for the Dilute and Dispose optimization opportunities listed in Section 3.1.2, this alternative could be implemented after the dilution and disposal approach is underway, as a means of truncating LCC.

4. Comparative Analysis

This section provides a summary-level comparative examination for purposes of aiding DOE in a path forward decision. Section 4.1 summarizes the attributes of the two options relative to the criteria utilized by the Red Team, and Section 4.2 provides conclusions from the Red Team on relative cost and risk.

4.1 Attribute Comparison Summary

The various attributes of the retained options (technical viability, ability to meet international commitments, and regulatory and other issues) are discussed in detail in previous sections, and briefly summarized in the table below. While it may appear from Table 5 that the Red Team considers the two options to be roughly equivalent overall when assessed against the criteria specified in the Charge memo from the Secretary, the Red Team has concluded that the nature of the risks associated with the two options puts the MOX approach at greater risk of cost growth throughout its life cycle. Since the technology for Dilute and Dispose is so much simpler, and the overall disposition process so much less complex, the most significant risks associated with this approach could be retired early, as issues associated with WIPP restart and potential expansion and the PMDA are strategized and addressed during a protracted planning phase, while small-scale Pu dilution proceeds using the existing glovebox, NNSA is installing two additional gloveboxes, and the MOX approach is being discontinued.

Table 5. Attribute Comparison Summary

	MOX Option		Dilute and Dispose Option	
Attribute	**Rating**	**Issues**	**Rating**	**Issues**
Technical viability	↑	• Uses proven technology • Accommodates diverse feedstock • Conservative approach to meet NRC requirements led to very tight controls that could threaten throughput • Operational and facility availability risk associated with automation • Relatively high operations risk • Very complex program to manage with multiple entities, locations, and contractual interfaces • Execution relies on five high-hazard processing facilities after MFFF and WSB are added	↑↑↑	• Uses proven technology • Amenable to diverse feedstock • Straightforward process • No complex equipment involved so maintenance and replacement would be relatively easy • Pu disposition can begin at a low throughput within a matter of months, but will only count toward the 34 MT obligation after IAEA inspection has been integrated. • Multiple opportunities for efficiency improvement • Detailed program baseline needed • Program complexity is moderate with low technology risk • Execution relies on three high-hazard processing facilities
Ability to meet international commitments	↑	• Meets the U.S. SFS commitment under the PMDA • Does not meet PMDA timeline	↓	• Does not meet the letter of the PMDA • PMDA allows for modification to approach if agreed to in writing • PMDA will need to renew negotiations anyway as the timeline will not be met • Surplus Plutonium Disposition SEIS notes Dilute and Dispose is “akin” to the spent fuel standard
Regulatory and other issues	↑	• No significant issues identified with NRC licensing of the MFFF • Potential issue with dual regulation if NNSA adds requirements to the NRC requirements for licensing • Consistent funding to assure continued NRC engagement/progress for long-lead items such as fuel qualification, and avoidance of a downward performance spiral • Could result in a protracted removal of Pu from the State of SC, and a higher potential for associated fines and penalties	↓	• WIPP issues – o restart will occur but may be in the five-year time frame but dilute/dispose program activities could be initiated at a low level of effort o NM Environment Dept RCRA Permit modifications would be needed; permit revisions have been obtained before but public interest may be heightened after the February 2014 incidents • LWA may need to be revised to increase volume of TRU waste allowed in WIPP • NEPA actions are needed to allow for the 34 MT to be dispositioned at WIPP
Cost effectiveness	↓↓↓	• See Section 4.2	↑↑	• See Section 4.2

4.2 Cost Comparison Summary

In order to facilitate a decision by DOE, the Red Team has chosen to compare a relatively conservative version of the Dilute and Dispose option to a relatively optimistic view of the MOX approach. Based on interviews and presentations, analysis of existing assessments, and our own cursory evaluation, the Red Team determined that the MOX approach for plutonium disposition could be viably executed within a reasonable timeframe provided that annual funding in the range of $700M-$800M (FY15 dollars) is consistently granted for near-term completion of the MFFF capital project and the simultaneous development of feed production and fuel qualification (through approximately 2025), and then sustained for the longer term operational feed and fuel production activities (perhaps into the mid 2040s). The Department would need to take decisive action on the overall program management and integration and the MFFF contracting strategy to successfully execute this approach. Given the relatively advanced state of design, equipment procurement, and construction achieved to date, the Red Team did not identify any facility scope changes/reductions or process modifications that would appreciably decrease the project costs without introducing technical or regulatory risks as substantial offsets. There are no obvious “silver bullets” for LCC reduction, but if DOE decides to proceed with the MOX approach, the replacement of impure feedstocks and the introduction of new technology for Ga removal could enable the elimination of the AP operations and the associated waste management, and substantially reduce the analytical load. This may be an opportunity worthy of additional investigation in light of the potentially significant reduction in operating costs.

The Red Team concluded that the conservative base case for the Dilute and Dispose option can be viably executed with only a modest increase in current annual funding levels (a sustained average funding of approximately $400M/yr) over a total timeframe that is similar to the MOX option, particularly if this average funding level is boosted slightly in the early years to enable progress in the Dilute and Dispose approach in parallel with MOX contract closure. Unlike the MOX option, there are multiple opportunities to significantly reduce the life cycle duration and cost of the base Dilute and Dispose approach, some of which could be implemented as in-process improvements after the program has started. These include:

- Design of an optimized feed production scenario that matches the rate at which diluted material is expected to be produced.
- Establishing duplicate oxide production and/or dilution capability as both a risk mitigation and a throughput enhancer, with emphasis on investment at LANL first since all pit material must go to LANL for disassembly.
- Optimizing the production rate (i.e., establishing a “right-sized” production capability between SRS and LANL) for diluted material based on an understanding of fixed limiting conditions, such as the maximum number of incremental shipments that WIPP can handle per week.
- Enhancing the Pu loading per shipped container.
- Shifting from a dilution approach to a sterilization approach, providing it proves feasible.

However the latent $1B economic value of MOX fuel would not be realized under the Dilute and Dispose option.

The Red Team agrees with the overall Aerospace conclusion that the worst case Dilute and Dispose option will never be as expensive as even the best case MOX-based approach, but disagrees with the assertion that the MOX approach becomes essentially unviable with the imposition of a capital cap of $500M/yr or less. The Red Team also agrees with Aerospace that the capital and operational risks are substantially higher for the MOX approach, and with the High Bridge conclusion that the programmatic risks associated with Dilute and Dispose are higher at this early stage than expressed in the Aerospace report. While the Red Team recognizes that planning for the Dilute and Dispose approach has just begun, and that MOX suffers from a high degree of familiarity when it comes to characterizing risk, High Bridge nonetheless overstated the capital and operational risks of the Dilute and Dispose option by equating it to a complicated nuclear construction project at pre-CD-0. The Dilute and Dispose option utilizes far simpler technology relative to the MOX option and can be performed in modifications to existing facilities that require relatively small capital investments.

Furthermore, the Red Team finds that the program risks related to the Dilute and Dispose approach, typically characterized as delayed restart, and/or insufficient space and permission for disposal at WIPP, as well as inconsistency with the PMDA, are not insurmountable given historical precedence (i.e., they are not technical risks associated with the dilution process itself). The Red Team believes that these issues can be solved within a timeframe that need not be on the critical path for the Dilute and Dispose approach. On the contrary, with 19,000 cubic meters of unsubscribed space, there is adequate time to solve the space issue through a combination of means which may not even have to include modification of the LWA, and with perhaps five front end years of MOX demobilization, capital improvements at LANL and SRS, and ramp up of feedstock production, there is sufficient time to engage the Russians and establish IAEA verification. Regardless of any federal action to amend either the LWA or the PMDA, a cooperative negotiation with the State of New Mexico would need to be pursued, and the State would have to conclude that support of this disposition pathway is in the best interests of the citizens of New Mexico.

In short, DOE could accomplish a MOX approach to Pu disposition for about $700M-$800M/yr that involves a high level of technical complexity and risk, but would eventually meet the agreed SFS provisions of the PMDA. Or, DOE could sustain current program funding levels and implement the relatively simple Dilute and Dispose approach with reasonable confidence that the political and regulatory risks could be successfully managed. The Red Team believes that the Dilute and Dispose approach has as many opportunities for base improvement as it does true capital and operational risks, but that this option has been tarnished by a perception of catastrophic risks which the Red Team believes can be successfully mitigated in cooperation with the State of New Mexico.

DOE and Congress will have to decide whether the incremental annual cost of the MOX approach, with its attendant construction and operations risks, is ultimately worth the perceived external benefits this approach offers the U.S. both domestically, and internationally. The Red Team did not attempt to characterize these external benefits, but imagines they include at least:

- Preservation of jobs and lower regional unemployment
- Overall economic impact to the region
- Domestic credibility of the nuclear industry
- Bolstering of the domestic nuclear industrial base
- International credibility in non-proliferation and the broader nuclear arena
- An important training ground for nuclear workers
- Institutional knowledge in nuclear materials handling and processing
- Revenue arising from MOX fuel sales on the order of up to $1B

It should be noted that some of these benefits can be attained using the Dilute and Dispose option as well, albeit to a lesser degree.

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Appendix A

Red Team Charge Letter

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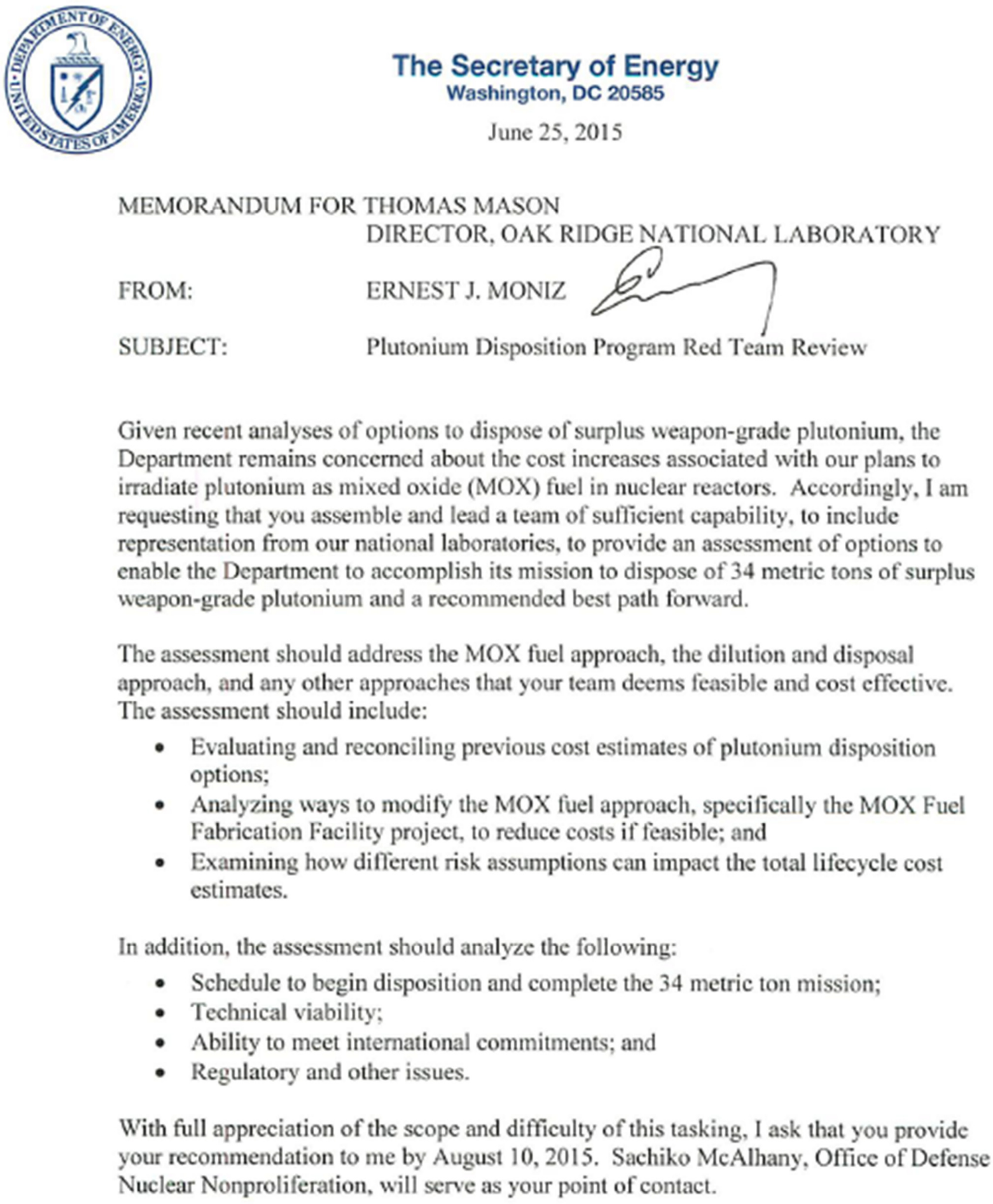

The Secretary of Energy
Washington, DC 20585

June 25, 2015

MEMORANDUM FOR THOMAS MASON
DIRECTOR, OAK RIDGE NATIONAL LABORATORY

FROM: ERNEST J. MONIZ

SUBJECT: Plutonium Disposition Program Red Team Review

Given recent analyses of options to dispose of surplus weapon-grade plutonium, the Department remains concerned about the cost increases associated with our plans to irradiate plutonium as mixed oxide (MOX) fuel in nuclear reactors. Accordingly, I am requesting that you assemble and lead a team of sufficient capability, to include representation from our national laboratories, to provide an assessment of options to enable the Department to accomplish its mission to dispose of 34 metric tons of surplus weapon-grade plutonium and a recommended best path forward.

The assessment should address the MOX fuel approach, the dilution and disposal approach, and any other approaches that your team deems feasible and cost effective. The assessment should include:

- Evaluating and reconciling previous cost estimates of plutonium disposition options;
- Analyzing ways to modify the MOX fuel approach, specifically the MOX Fuel Fabrication Facility project, to reduce costs if feasible; and
- Examining how different risk assumptions can impact the total lifecycle cost estimates.

In addition, the assessment should analyze the following:

- Schedule to begin disposition and complete the 34 metric ton mission;
- Technical viability;
- Ability to meet international commitments; and
- Regulatory and other issues.

With full appreciation of the scope and difficulty of this tasking, I ask that you provide your recommendation to me by August 10, 2015. Sachiko McAlhany, Office of Defense Nuclear Nonproliferation, will serve as your point of contact.

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Appendix B

Participants and Subject Matter Experts

Participants
David Amerine, Consultant
William Bates, Savannah River National Laboratory
Kelly Beierschmitt, Idaho National Laboratory
Carol Burns, Los Alamos National Laboratory
Thomas D. Burns, Parsons Government Services
Jeremy Edwards, National Nuclear Laboratory
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Glenda Sharp, Oak Ridge National Laboratory

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Appendix C

Biographies of Red Team Members

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David Amerine
Consultant

David Amerine has 45 years of experience in the nuclear industry. He began his career in the U.S. Navy, after graduating from the United States Naval Academy and obtained a Master's in Management Science from the Naval Post Graduate School while in the Navy. After leaving the Navy, he joined Westinghouse at the Department of Energy (DOE) Hanford Site. There he worked as a shift operations manager and then as the refueling manager for the initial core load of the Fast Flux Test Facility, the nation's prototype breeder reactor.

Mr. Amerine furthered his career in the commercial nuclear power industry throughout the 1980s; first as the Nuclear Steam Supply System vendor, Combustion Engineering, Site Manager at the Palo Verde Nuclear Generating Station during startup of that three-reactor plant and then as Assistant Vice President Nuclear at Davis-Besse Nuclear Power Station. There he led special, interdisciplinary task forces for complex problem resolutions involving engineering and operations during recovery period at that facility back in the late 1980s.

Davis-Besse was the first of eight nuclear plants where he was part of the leadership team or the leader brought in to restore stakeholder confidence in management and/or operations. In the DOE Nuclear Complex these endeavor recoveries included the Replacement Tritium Facility, the Defense Waste Processing Facility, and the Salt Waste Processing Facility projects. In addition to Davis-Besse in the commercial nuclear industry, in 1997 he was brought in as the Vice President of Engineering and Services at the Millstone Nuclear Power Station where he was instrumental in leading recovery actions following the facility being shut down by the Nuclear Regulatory Commission. His responsibilities included establishing robust Safety Conscious Work Environments programs.

In 2000, Mr. Amerine assumed the role of Executive Vice President of Washington Government, a $2.5 billion business unit of Washington Group International (WGI). In this role, Mr. Amerine was responsible for integrated safety management, conduct of operations, startup test programs, and synergies between the diverse operating companies and divisions that made up WGI Government. Mr. Amerine was then selected as the Executive Vice President and Deputy General Manager, CH2M Hill Nuclear Business Group, where he supported the President in managing day-to-day operation of the group, which included six major DOE sites, three site offices, and numerous individual contracts in the international nuclear industry. He was charged with improving conduct of operations and project management, expenditures and staffing oversight, goal setting, performance monitoring, and special initiatives leadership.

Mr. Amerine came to B&W in 2009 where he was subsequently selected as President of Nuclear Fuel Services (NFS) in early 2010 after the NRC had shut down that facility which was vital to the security of the United States since it is the sole producer of fuel for the nuclear Navy. He led the restoration of confidence of the various stakeholders, including the NRC and Naval Reactors. The plant was restored to full operation under Mr. Amerine's leadership. He retired from NFS in 2011.

William (Bill) Bates
Deputy Associate Director, Nuclear Materials Management,
Savannah River National Laboratory

Bill Bates has over 28 years of nuclear experience starting in Reactor Technology and Engineering as the system engineer for exhaust filtration and control rod drive systems. His increasing responsibilities included Engineering Management for Reactor Instrumentation and Controls. In the mid-1990s, Bill took the role of Engineering Manager in High Level Waste Systems Engineering responsible for all technical aspects of the H Area Tank Farm at the Savannah River Site (SRS). In 2000, he transitioned to Operations Management. His Operations Facility Management roles have included Deputy Facility Manager for K Area (KAMS),
L Area (Spent Fuel Program) and the Receiving Basin for Offsite Fuels and Facility Manager for K Area (KAMS) during the DOE Plutonium Consolidation Campaign. As Facility Manager, he led the deinventory of all unirradiated Highly Enriched Uranium (HEU) ingots and fresh SRS reactor Mk-22 HEU fuel assemblies from K Area, which were part of the NNSA's Blended Low-Enriched Uranium program feedstock. From 2006 through 2008, he served as the Manager for K Area Business Programs, Project Controls, and Quality Assurance. He returned to Operations Management in late 2008 as the Deputy Director and later Director for Nuclear Materials Storage, which included all of the Pu and Spent Fuel Programs in K Area and L Area. While in this role, he was recognized by the NNSA Administrator for his contributions to Pu Consolidation from the Lawrence Livermore National Laboratory and the Los Alamos National Laboratory. During his management tenure in K Area, he oversaw operations and nuclear materials management as well as numerous Category I secure vault and facility expansion projects, which have provided increased capacity and capability for consolidation and safe special nuclear material interim storage. In 2011, he took the role of Deputy Associate Laboratory Director for Nuclear Materials Management Programs in the Savannah River National Laboratory responsible for Program Management for ongoing receipt, storage and disposition missions in K, L, and H areas as well as integration and optimization of the SRS nuclear facilities to support new and emergent nuclear missions for DOE and other federal programs. He has a Bachelor's of Science degree in Electrical Engineering from Lehigh University and is a member of the Institute of Nuclear Materials Management and the Citizens for Nuclear Technology Awareness.

Kelly Beierschmitt
Deputy Director, Idaho National Laboratory

Dr. Kelly Beierschmitt is currently the Deputy Laboratory Director for Nuclear and Laboratory Operations at Idaho National Laboratory (INL). He has over 30 years of experience in engineering, nuclear and materials-related R&D, production, and operations management. Kelly reports to the INL Laboratory Director and is responsible for institutional leadership in nuclear operations and nuclear support programs and projects. He is responsible for providing strategic leadership, direction, and integration for all nuclear and laboratory operations at the INL including Materials and Fuels Complex, which is INL's center for fuel fabrication and post irradiation testing; and Advanced Test Reactor Complex, designated as a National Scientific User Facility and is available to universities and industry for conducting in-core experiments vital to nuclear energy technology and materials development. He is also responsible for providing strategic leadership and direction to the Transient Reactor Test Facility, specifically built to conduct transient reactor tests where the test material is subjected to neutron pulses that can simulate conditions ranging from mild upsets to severe reactor accidents. Kelly is also responsible for providing strategic direction to effect revitalization of the INL physical infrastructure and help advance research and development through management of key infrastructure components supporting Laboratory missions.

Prior to joining INL, Kelly was the Oak Ridge National Laboratory Associate Laboratory Director (ALD) of the Neutron Sciences Directorate responsible for the Spallation Neutron Source (SNS), the world's most powerful pulsed neutron source. This responsibility included leading a community of scientists dedicated to the study of the structure and dynamics of quantum condensed matter, biology and soft matter, chemistry and engineered materials through the application of neutron scattering techniques and supporting over 3,000 users annually. He was also responsible for the operation of the High Flux Isotope Reactor, an 85 megawatt research reactor dedicated to neutron scattering, materials irradiation, and isotope production. During his time as ALD, he successfully oversaw the power up-ramp to 1.2 megawatts of proton energy on the target; and he updated the scientific strategy for the SNS supported by the scientific community to identify those research priorities leading to a full build-out of instruments on existing beam-lines, and the need for a second target station. During this period, Kelly served extensively on international advisory boards including support to ISIS at the Rutherford Appleton Laboratory; the European Spallation Source in England; the Open Pool Australian Lightwater Reactor in Australia; and Japan Proton Accelerator Research Complex in Japan.

Carol Burns
Deputy Principal Associate Director, Science, Technology, and Engineering
Los Alamos National Laboratory

Dr. Carol Burns currently serves as Deputy Principal Associate Director for Science, Technology, and Engineering (PADSTE) at Los Alamos National Laboratory (LANL). The PADSTE organization has line management responsibility for ~2500 employees and is responsible for integrating strategy for science, technology and engineering at the laboratory.

Carol received her B.A. in Chemistry from Rice University, and her Ph.D. in Chemistry as a Hertz Foundation Fellow at the University of California at Berkeley. She came to LANL as a J. Robert Oppenheimer Postdoctoral Fellow, and has been employed at the Laboratory since that time, serving in a variety of line and program management positions, and conducting work across all mission areas of the Department of Energy. She served as a Senior Policy Advisor in the Office of Science and Technology Policy in 2003-4, where she provided technical and policy assistance on national and homeland security science and technology issues involving defense infrastructure and threat preparedness.

Carol was awarded the LANL Fellows Publication Prize in 2002, and was named a Laboratory Fellow in 2003. She is a Fellow of the American Association for the Advancement of Science. She is a recognized expert in actinide and radiochemistry, with more than 100 peer-reviewed publications and invited book chapters, and has served on a number of editorial boards, review boards, and advisory groups, including DOE advisory panels and National Academy studies on management of transuranic and mixed waste, isotope production, the nuclear energy fuel cycle, and workforce needs in nuclear science and radiochemistry.

Tom Burns
Vice President – Project Management and Engineering for Parsons Government Services

Dr. Thomas D. Burns, Jr. is currently the Vice President/Deputy Project Manager/Director of Engineering for Parsons' Salt Waste Processing Facility (SWPF) design-build-operate project. The SWPF project is a multi-billion dollar first-of-a-kind radio-chemical processing plant for stabilizing more than 100 million gallons of legacy waste from plutonium and tritium production at the Savannah River Site (SRS).

As the Deputy Project Manager/Director of Engineering for SWPF, Dr. Burns has been responsible for a technical workforce of more than 850 personnel supporting all aspects of technology development, design engineering, nuclear safety, procurement, construction, commissioning, and operations. Dr. Burns is recognized as an excellent technical leader in the DOE complex who has been uniquely successful in resolving difficult technology/design challenges and complicated oversight/regulatory issues ranging from complex structural design qualification to large-scale air-pulse-agitator mixing performance validation testing.

Prior to joining Parsons, Dr. Burns served as both an Executive Engineer with MPR Associates providing consulting support services to DOE and commercial nuclear industry clients and as a Senior Technical Staff member for the Defense Nuclear Facilities Safety Board (DNFSB). During his tenure with the DNFSB, Dr. Burns served as a field representative at both SRS and Los Alamos National Laboratory with responsibilities including strategic assessments of nuclear weapons programs and nuclear material processing activities as well as process and operational oversight of nuclear material separations and metallurgy, nuclear materials testing, nuclear waste disposition, tritium processing, and all associated safety-basis activities.

Prior to joining the DNFSB staff, Dr. Burns has served as a research associate at both national and international laboratories including, Oak Ridge National Laboratory, Idaho National Engineering Laboratory, and the Commissariat a l'Energie Atomique at Cadarche, France.

Dr. Burns is a graduate of the University of Virginia, having received his undergraduate, Masters and Doctoral degrees in Nuclear Engineering.

Jeremy Edwards
Technical Manager for Nuclear Security, CBRN and Resilience
National Nuclear Laboratory

With nearly 20 years experience working with the UK National Nuclear Laboratory, and its forerunner organizations, Jeremy brings knowledge and awareness of the UK civil nuclear programme, complemented by specific technical skills. These include the development and use of optioneering and evaluation processes for complex projects, including the long-term liabilities associated with contaminated land. These skills were additionally utilized to inform decisions relating to abatement solutions for effluent discharge, the decommissioning (and subsequent recovery) of redundant sea discharge pipelines, and site-wide aerial discharges. Jeremy supported the production of an IAEA TecDoc (No. 1279) on the 'Non-technical factors impacting on the decision making process for environmental remediation'.

He subsequently led a team delivering environmental safety assessment to major operational and capital build projects supporting the UK civil nuclear programme on a diverse range of projects and technical issues across the UK civil nuclear estate; and engineering project delivery.

Since 2006, Jeremy has managed the development and delivery of a nuclear security and threat reduction capability within National Nuclear Laboratory. Included within this scope is the security of nuclear and radiological materials, nuclear safeguards and non-proliferation; coupled with CBRN preparedness, and resilience. Activities include capacity building of both UK and international partners, technical assessments, development of capability and approaches. Jeremy led NNL delivery of a European Commission funded redirection of former weapon scientists programme; and presently supports other similar global initiatives. He is currently supporting IAEA in the Coordinated Research Programme for development of Nuclear Security Assessment Methodologies (NuSAM), within which he is a Case Study chair. In addition to externally funded projects, Jeremy manages the internally funded research programme across the Laboratory in this area.

Jeremy led the preparations for the UK/National Nuclear Laboratory successfully hosting the European Safeguards Research and Development Association (ESARDA) symposium in Manchester; and more recently, he has undertaken a review of plutonium R&D skills required to meet the current UK programme requirements.

Christopher O. Gruber
Independent Consultant — Program/Project Management, Cost Estimating, Project Control, and Risk Management/Assessment

Mr. Gruber is presently an independent consultant with over 40 years of progressively more responsible experience in all facets of cost engineering, cost management, and project management and control related to the construction, operation and decommissioning of complex capital projects. This experience was gained while employed by engineering and consulting organizations prior to working as an independent consultant, which he has been doing for more than 15 years. Mr. Gruber's experience includes performing independent reviews, independent cost estimates and validations of projects for the U.S. Department of Energy (DOE), the U. S. Army Corps of Engineers, the International Atomic Energy Agency, and various private sector companies, including several in the electric utility, chemical and process industries. Mr. Gruber has over 40 years' experience with commercial nuclear construction, operations and decommissioning projects, as well as over 25 years of experience with DOE/NNSA projects and programs, including project reviews (internal and external) of many major system acquisition projects, reviews of processes and capabilities, training, preparation of government cost estimates, program planning, project planning and execution as well as policy and guidance development and review. Mr. Gruber has led and/or coordinated risk assessments for both DOE/NNSA and commercial owners, was a key contributor for development of updated DOE Guides for Cost Estimating and Risk Management, and was the lead developer for new DOE project manager training courses in both areas.

Mr. Gruber has an undergraduate degree in Business Economics and an MBA in Finance. He is a past Officer and Board Member of the Association for Advancement of Cost Engineering, International (AACEI) and member of AACEI Decision and Risk Management Committee. He was a Certified Cost Consultant by AACEI from 1985 through 2011 (currently not active) and a Certified PMI® Project Management Professional from 2003 through 2011 (currently not active).

In addition to being a member of the team that did a recent Root Cause Analysis of the cost increases on the Mixed Oxide Fuel Fabrication Facility and Waste Solidification Building projects, Mr. Gruber previously served as a member of an NNSA Peer Review team assessing performance of the project and contractor team for the Mixed Oxide Fuel Fabrication Facility (MFFF) Project, completed a management assessment of the MFFF project for a new Federal Project Director, and provided an assessment of the likely cost of the MFFF project under various funding scenarios, based on recent baseline change proposal by the project contractor and the U.S. Army Corps of Engineers independent cost estimate.

Paul Howarth
Managing Director, National Nuclear Laboratory

Paul Howarth, Managing Director of the UK National Nuclear Laboratory (NNL), has led NNL through its transformation to a Government Owned Government Operated organisation, key to the UK's nuclear energy programmes.

He is an Executive Director of Battelle Energy UK and a visiting professor at the University of Manchester, where in 2006, he co-founded the Dalton Nuclear Institute. In December 2014 Paul joined the NPL Board as a Non-Executive Director.

Paul held various senior roles at BNFL, worked on the Japanese nuclear programme and on industrial applications of plasma technology. He sits on various R&D Committees and on the Board of the Association of Independent Research & Technology Organisations (AIRTO).

Paul holds degrees in Physics and Astrophysics and Business Administration. He gained his Ph.D. under Culham's fusion programme, is a Fellow of the Institute of Physics and the Nuclear Institute and was elected to the Royal Academy of Engineering in 2014.

Thomas O. Hunter
Sandia National Laboratories (retired)

Dr. Thomas (Tom) O. Hunter retired in July 2010 as President and Laboratories Director of Sandia National Laboratories. Sandia, with principal sites in Albuquerque, NM, and Livermore, CA, is a multi-program laboratory operated by Sandia Corporation for the U.S. Department of Energy's National Nuclear Security Administration. Dr. Hunter joined Sandia in 1967 and became president in April 2005. His responsibilities included managing the Laboratories' $2.3 billion annual budget and approximately 10,000 employees. In that role, he was personally involved in support of national security issues that required engaging leaders in the executive branch of government and in the U.S. Congress. Further, he was charged with providing assurance of essential elements of the U.S. nuclear deterrent and advising on matters such as energy, nuclear nonproliferation, and the nation's R&D agenda.

In May, 2010, DOE Secretary Steven Chu appointed Dr. Hunter as lead of the federal government's scientific team that worked with BP officials to develop and analyze solutions to the BP oil spill. Early in 2011, Dr. Hunter was appointed Chairman of the Department of Interior's Ocean Energy Safety Advisory Committee. A committee charged with identifying future technology needs for offshore oil and gas development

Dr. Hunter is a member of the Engineering Advisory Board for the University of Florida and Council on Foreign Relations. He is chairman of the National Academy of Sciences Advisory Board for the Gulf Research Program. Recently he was a member of the American Nuclear Society and served on the U.S. Strategic Command's Strategic Advisory Group. He has served on various review groups for the Federal government and with other DOE laboratories, guest lecturer at Massachusetts Institute of Technology on nuclear waste management, and as an adjunct professor at the University of New Mexico. Since retirement Dr. Hunter has been a member of the PCAST panel for the report "Transformation and Opportunity: The Future of the US Research Enterprise". He served as a board member for the Energy Policy Initiative for the Bipartisan Policy Center. He currently chairs the advisory committee for the University of Florida College Of Engineering Leadership Institute. He is the author of numerous technical papers and presentations. He is a recipient of the 2007 New Mexico Distinguished Public Service Award.

Dr. Hunter has served on many advisory boards for universities and government entities and is the author of numerous technical papers and presentations. Dr. Hunter earned a B.S. in mechanical engineering from the University of Florida, an M.S. in mechanical engineering from the University of New Mexico, an M.S. in nuclear engineering from the University of Wisconsin, and a Ph.D. in nuclear engineering from the University of Wisconsin. He was recognized as a distinguished alumnus by both the University of Florida and the University of Wisconsin.

Stephen I. Johnson
U.S. Navy (retired)

Rear Admiral Stephen I. Johnson's 30 year naval career included service in four nuclear submarines, including Engineer Officer in USS Ethan Allen (SSBN-608) (Blue) and Command of USS City of Corpus Christi (SSN-705). Additionally he served ashore as an instructor at the Navy Nuclear Power School, Engineer Officer for Submarine Squadron Seven, as a Requirements Officer on the Navy Staff, and as the Director for Fleet Liaison and Commanding Officer training at the Division of Naval Reactors, Naval Sea Systems Command (NAVSEA-08).

As an acquisition professional, Admiral Johnson served as Major Program Manager for the Submarine Electronic Systems program (PMS-401), directing the acquisition of the Navy's first non-hull-penetrating periscope imaging system and the combat and sensor systems for the Virginia Class submarine. After selection to Flag rank, he served as Commander, Naval Information Systems Management Center; Director, Combat Support Information and Technology Systems (Space and Naval Warfare Systems Command, PD-15); and Director for Year 2000 Remediation on the staff of the Chief of Naval Operations (OP-06Y), responsible for remediation of the Year 2000 faulty-date-logic problem across the Naval enterprise.

Subsequent from retirement from active duty, Admiral Johnson has provided industry and academia with strategic planning, senior program management, and subject matter expert services. He has served as a technology advisor to the William J. von Liebig Center for Entrepreneurism and Technology Advancement at the Erwin and Joan Jacobs School of Engineering, University of California, San Diego; as a business advisor to the Entrepreneurial Management Center, San Diego State University; and a business advisor and executive coach to entrepreneurs-in-residence at the George Dean Johnson School of Business, University of South Carolina, Upstate (Spartanburg SC). Admiral Johnson is a Chair and Executive Coach for Vistage International, the world's leading CEO membership organization, mentoring business leaders to become better leaders, make better decisions, and get better results.

Admiral Johnson has received numerous awards throughout his career including Legion of Merit (5 Awards), Meritorious Service Medal (2 Awards), Navy Commendation Medal (2 Awards), Vistage Chair Excellence Award (4 Awards), and numerous unit awards.

Dale Klein
Associate Vice Chancellor for Research, University of Texas

Dr. Dale Klein has been associated with the University of Texas since 1977 in a variety of administrative and academic positions as well as a professor of mechanical engineering (nuclear program). He served as a presidential appointee to the Nuclear, Chemical & Biological Defense Programs at the Pentagon from 2001 to 2006 and was a Commissioner of the U.S. Nuclear Regulatory Commission from 2006 to 2010 where he served as Chairman from 2006 to 2009.

Dr. Dale Klein returned in 2010 as a professor of mechanical engineering (nuclear program) and as the associate director of the Energy Institute at the University of Texas at Austin. In 2011 he became the Associate Vice Chancellor for Research at the University of Texas System. He also serves on the Board of the Southern Company and Pinnacle West / Arizona Public Service. Dr. Klein currently serves as the Chairman of the Nuclear Reform Monitoring Committee for the Tokyo Electric Power Company. In addition, he serves on the Committee for Nuclear Power advising the United Arab Emirates on their nuclear program.

Brett Kniss
Principal Associate Director, Weapons Program
Los Alamos National Laboratory

Mr. Kniss is a 32 year veteran in the NNSA complex with a background in weapons manufacturing, plutonium operations and nuclear facility planning. His early career was associated with nuclear weapons manufacturing at Pantex, Kansas City and Rocky Flats as a design agency representative at the production plants during the peak years of the cold war. For the past 20 years, Mr. Kniss has been associated with the plutonium facility TA55 at Los Alamos. Initially a staff member at TA55 in the early 1990s, he progressed through roles as project leader, program manager and is currently a program director. Over the past 2 decades he has been in line management, project execution, project management and strategic planning associated with the mission planning for Defense programs, Nuclear Non-Proliferation, plutonium science and nuclear weapon certification activities. He is currently the program director for plutonium strategy in the Weapons Associate Director's office at Los Alamos and is the program architect behind the plutonium facility strategy as well as the Los Alamos representative on the Livermore red team for the annual assessment process. Mr. Kniss functions primarily as a systems engineer balancing program requirements with facility resources through the Integrated Nuclear Planning process with a wide variety of customers and stakeholders. Mr. Kniss is frequently used as a resource to assist with planning and solution development for the acquisition, sizing and cost of line item nuclear facilities supporting plutonium programs. Mr. Kniss holds a B.S. in Civil Engineering, and a M.S. in Mechanical Engineering.

John W. Krueger
Isotope Production Manager
Oak Ridge National Laboratory

John W. Krueger (B.Sc. in Chemical Engineering, University of Nebraska – Lincoln; M.S. in Environmental Engineering and Science, Stanford University) serves as Isotope Production Manager at Oak Ridge National Laboratory (ORNL). Mr. Krueger started at ORNL in 2009 and was assigned under the Intergovernmental Personnel Act to serve as the DOE Federal Project Director for the U-233 Disposition Project for two years, an assignment for which he received two Secretarial Achievement awards. Now as Isotope Production Manager, Mr. Krueger coordinates stable and radioisotope production operations at ORNL in accordance with the DOE's Isotope Program priorities, and manages the Pu-238 Supply Project under DOE's Radioisotope Power Systems Program, in support of NASA's planetary and deep space science agenda.

Mr. Krueger's previous Oak Ridge experience includes serving as Senior Program Director for the environmental cleanup and waste management program at Y-12, and as President and CEO of a private company formerly responsible for most of the waste operations in Oak Ridge and Paducah.

Prior to moving to Tennessee, Mr. Krueger served as Waste Management Program Manager at the DOE Mound Facility in Ohio where he was responsible for on-going waste management and legacy waste disposition. During his Mound tenure, he was promoted to Deputy Site Manager and was responsible for leadership of the site closure project.

Krueger has also served as Vice President and Pacific Coast Division Manager for a major environmental consulting firm, and as a Project Leader for environmental restoration projects and Section Leader for solid radioactive waste operations at Los Alamos National Laboratory. He began his career in 1986 as Compliance Agreement Project Coordinator, working directly for DOE at the Rocky Flats Plant in Colorado.

Thomas E. Mason
Laboratory Director
Oak Ridge National Laboratory

Thomas E. Mason (B.S. in physics, Dalhousie University; Ph.D. in condensed matter sciences, McMaster University) is director of Oak Ridge National Laboratory (ORNL). Thom joined ORNL in 1998 as Scientific Director for the Spallation Neutron Source (SNS) project. He was named Associate Laboratory Director (ALD) for SNS in 2001 and ALD for Neutron Sciences in 2006.

Before joining ORNL, Thom was a faculty member in the Department of Physics at the University of Toronto. From 1992 to 1993, he was a Senior Scientist at Risø National Laboratory. He held a Natural Sciences and Engineering Research Council of Canada postdoctoral fellowship at AT&T Bell Laboratories from 1990 until 1992.

Thom's research background is in the application of neutron scattering techniques to novel magnetic materials and superconductors using a variety of facilities in North America and Europe. As Director of the U.S. Department of Energy's largest science and technology laboratory he has an interest in advancing materials, neutron, nuclear, and computational science to drive innovation and technical solutions relevant to energy and global security. He is a Fellow of the AAAS, APS, and NSSA.

Robert (Bob) Merriman
Consultant

Dr. Merriman works as a consultant in areas of uranium processing, energy, environment and national security.

His work in the nuclear fuel cycle and uranium processing fields has included roles as an individual researcher as well as in: R&D management; engineering; design and construction project management; and plant operations. He has spent most of his career in the areas of uranium enrichment, uranium processing and radiochemical process engineering and is familiar with the cross-section of the associated technologies, processes and equipment. He has worked on and managed the development and deployment of a variety of specialized production and separation processes associated with various steps in the nuclear fuel cycle, including fuel reprocessing, waste management, uranium processing, and isotope separation. Bob has held a variety of technical and managerial roles in these activities, including serving as the Senior Vice President, Martin Marietta Energy Systems (MMES) (COO for all MMES activities in Oak Ridge (ORNL, Y-12, K-25 & Central Services), Paducah, KY and Portsmouth, OH) and as Associate Laboratory Director, ORNL.

Bob holds BE (Vanderbilt), MS and PhD (University of Tennessee) degrees, all in chemical engineering. He also completed the executive management program at the University of Pittsburg.

He is a recipient of the DOE’s E. O. Lawrence Award and the Robert E. Wilson Award, presented by the Nuclear Engineering Division of the American Institute of Chemical Engineering, for his work in the nuclear fuel cycle.

Bob was also a member of the Nuclear Intelligence Panel, serving three CIA directors.

Terry A. Michalske
Executive Vice President and Director
Savannah River National Laboratory
Savannah River Nuclear Solutions, LLC

Dr. Terry A. Michalske is Savannah River Nuclear Solutions (SRNS), LLC, Executive Vice President and Director of the U.S. Department of Energy's (DOE) Savannah River National Laboratory (SRNL). In this position, he is responsible for the management, operations and strategic directions of the laboratory. Currently, the laboratory has approximately 900 employees and conducts research and development for a diversified portfolio of federal agencies supporting national missions in environmental management, national security and clean energy. As the DOE Environmental Management Laboratory, SRNL provides scientific and technological strategic direction and program support for the nation's legacy waste cleanup program.

Dr. Michalske has more than 30 years of experience in the fields of materials science, nanotechnology, biotechnology, energy science and national security systems. Among his various positions prior to joining SRNL, Dr. Michalske has served as founding Director for the DOE Center for Integrated Nanotechnologies, Director for the DOE Combustion Research Facility, Chairman of the Board of Directors for the Joint BioEnergy Institute, and Director of Energy and Security Systems at Sandia National Laboratories.

In addition to his current duties as SRNL Laboratory Director, Dr. Michalske serves as a Trustee of Alfred University, a Board of Directors member for EngenuitySC and the South Carolina Research Authority, Chairman of the National Laboratory Directors Council, and sits on the Secretary of Energy's Laboratory Policy Council.

He serves as the Forum on Energy Editorial Advisory Board Co-Chair, and a member of the University of South Carolina–Aiken Engineering Advisory Board and the Georgia Regents University James M. Hull College of Business Advisory Board.

Dr. Michalske has testified before the U.S. Senate and House of Representatives, and the state legislatures of California, New Mexico and South Carolina on topics including nanotechnology, energy security and environmental cleanup. He is a Fellow of the American Ceramic Society and the American Vacuum Society.

Dr. Michalske holds seven patents, has authored 90 journal publications, and has been a collaborator on several books. He is a member of several technical societies, panels and advisory boards and has chaired numerous technical workshops and symposia. Dr. Michalske's research awards include the Orton Lecture Award; an R&D 100 award (Interfacial Force Microscope); the Woldemar A. Weyl International Glass Science Award from the International Congress on Glass; and the Ross Coffin Purdy Award from the American Ceramic Society. He was a two-time winner of the DOE/BES Materials Science Award for Outstanding Technological Accomplishment.

Alice Murray
Deputy Associate Laboratory Director
Savannah River National Laboratory

Dr. Murray is the Deputy Associate Laboratory Director for the Science and Technology at the Savannah River National Laboratory (SRNL). However, she is serving as the Acting ALD for Science and Technology until that position is filled. Dr. Murray had been engaged as a researcher, manager, and technical consultant for 28 years in the area of research and development for nuclear material processes at the Rocky Flats Plant (RFP) and the SRNL. Currently she is serving as the Plutonium Process Engineer for the Mobile Plutonium Facility and SRS representative to the Department of Homeland Security's Plutonium Experts Panel.

Her professional activities include member of the American Chemical Society (ACS) (1988 – present); Treasurer of the ACS Division of Nuclear Chemistry and Technology since 2011; RFP and SRNL representative to the Actinide Separations Conference Board 1993 – 1996 and 2003 – present, respectively; SRNL representative on Advisory Board for the Nuclear Environmental Engineering and Science Program at Clemson University (2010- present) and on the Advisory Board for the Environmental Engineering and Earth Sciences Department at Clemson University (2013 – present)

Dr. Murray has a broad knowledge in both pyrochemical and aqueous plutonium recovery, and purification. At the Rocky Flats Plant, she was primarily involved with molten salt processes to remove americium from aged plutonium. She also was involved in other molten salt processing including direct oxide reduction and electrorefining. At the Savannah River National Laboratory, she began working on aqueous processing of plutonium and as manager of the Actinide Technology Section oversaw the development and deployment of several flowsheets for the dissolution of a myriad of plutonium oxide materials as well as anion exchange process development to purify plutonium and neptunium solutions with subsequent conversion to oxalate then to oxide.

Dr. Murray has participated in a wide range of DOE-Nuclear Weapons Complex activities including: Lead for the Pit Disassembly/Conversion Team for the Complex 21 Project (1992 – 1995), Manager of Nuclear Materials Focus Area Materials Processing Product Line (2000 – 2002), member of the Baseline Evaluation Team for plutonium purification/recovery processes for the Modern Pit Facility Project (2003), member of two Technical Assistance Teams to review processing options for stabilization of chloride-containing plutonium materials at the Rocky Flats Environmental Technology Site (2002) and at the Hanford Site (2003), and SRNL member of the Technology Readiness Assessment Team for Pit Disassembly and Conversion Project (2009-2011). She also served as SRS representative to the United States/United Kingdom Joint Working Group for Nuclear Materials Steering Committee (2002 – 2007).

Dan Stout
Senior Manager, Small Modular Reactors
Tennessee Valley Authority

Dan Stout is the Senior Manager, Small Modular Reactor (SMR) Technology for the Tennessee Valley Authority (TVA). He is responsible for nuclear project development including managing the scope, schedule, budget and business planning associated with licensing and potential deploying SMRs at TVA's Clinch River Site in Oak Ridge, TN.

Mr. Stout has over 30 years of experience in the nuclear energy sector. He joined TVA in April 2009 where he managed Federal Programs including tritium production, MOX fuel utilization and advanced modeling and simulation of light-water reactors until assuming responsibility for TVA's Small Modular Reactor program in 2012.

Prior to TVA, Mr. Stout served as Director, Nuclear Fuel Recycling at the Department of Energy where he was responsible for planning and policy development regarding nuclear fuel recycling. Prior to that, from 1991 to 2006, Mr. Stout worked in the uranium enrichment industry, predominantly at USEC Inc., with responsibility for R&D, engineering, and licensing of advanced uranium enrichment technologies and facilities.

From 1985-1991 Mr. Stout served in the U.S. Navy as a nuclear submarine officer. He also served in the Naval Reserves in the Naval Special Warfare community from 1991-2007, retiring as a Commander.

Mr. Stout graduated from the U.S. Naval Academy in 1985. He received his Master's Degree in Engineering Management from the National Technological University in 1997.

Tyrone Troutman
President and General Manager of Nuclear Power
Bechtel National, Inc.

Ty Troutman is general manager of Bechtel Nuclear, Security & Environmental's Nuclear Power business. He oversees a portfolio of commercial nuclear power projects throughout the U.S. and internationally.

A 31-year Bechtel veteran, Troutman has extensive experience in construction, operations, and management, serving as a leader on many critical projects. Most recently, he was the manager of functions for the Nuclear, Security & Environmental business. Prior to that role, he served as the manager of construction for the entire business unit providing functional management oversight for projects worldwide. Troutman has held vital positions for projects including the Waste Treatment and Immobilization plant in Hanford, Washington and Los Alamos National Laboratory in New Mexico.

Previous to Nuclear, Security & Environmental, Troutman worked in Bechtel Power and for Bechtel Construction on several nuclear projects including the Connecticut Yankee Power Station, Dresden Power Station and Beaver Valley Nuclear Power Station, holding various positions in design, subcontracts, field engineering, construction and project management.

He participated or led red team reviews and readiness reviews for several critical DOE and NNSA projects including WTP, UPF, K-25 and projects at Los Alamos and Lawrence Livermore Laboratories.

Troutman was elected a Bechtel principal vice president in 2013.

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Appendix D

Isotopic Dilution Variant

It is recognized that the SFS definition is a topic of relevance in the PMDA. Specifically, if achieving the ratio of Pu-240/Pu-239 greater than 0.1 in the final material form becomes a topic of interest, two options are worth consideration:

1. Allowance for the final product form or initial “disposition plutonium” requirements to be relaxed to allow a lower Pu-240/Pu-239 ratio in the final product, or removal of any isotopic specification.

or

2. Allowance for blending of separated fuel/reactor grade Pu with U.S. weapon-grade “disposition Pu” to achieve a Pu-240/Pu-239 ratio of >0.1 in Pu to be downblended.

In the second option, separated surplus U.S. fuel grade Pu and UK civilian separated reactor grade Pu could be used to blend with the 34 MT of U.S. weapon-grade Pu to increase the Pu-240/Pu-239 ratio. The quantity of U.S. fuel grade Pu is insufficient to achieve an overall ratio >0.1. Initial reviews of the UK stocks indicate that depending on the specific stocks, approximately 3-9 MT would be required to increase the U.S. Pu above a Pu-240/Pu-239 ratio of 0.1. It is recognized that any civilian Pu would require a Defense Determination prior to acceptance at WIPP. This approach would also involve international shipping, receipt, and processing of more bulk SNM, which would likely increase overall program cost. There may be potential cost-share models to offset these increases if UK funding is provided for the disposition costs for the fraction of the UK civilian Pu.

These approaches would require review related to Article II.6. of the PMDA, and the Annex on Monitoring and Inspections, section II items 11 and 15, to increase the allowable amount of blend stock to be mixed with weapons grade Pu.