High Bridge Associates, Inc.

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Comparison of Plutonium Disposition Alternatives: WIPP Diluted Plutonium Storage and MOX Fuel Irradiation

prepared for the
MOX Services Board of Governors

“Connecting Vision and Plans with Performance and Execution”
Executive Summary

High Bridge Associates, Inc. performed an assessment of technical parameters and estimated costs for the US DOE surplus plutonium disposition program for the WIPP and MOX alternatives. This included an analysis of the adequacy of the WIPP to accept significant quantities of surplus weapons plutonium in addition to those legacy transuranic (TRU) wastes already committed for storage in the repository. Specifically, we assessed the statutory basis, safety, science, technology, safeguards, nonproliferation, transportation, and cost impacts for storing 51.3 metric tons of surplus weapons plutonium at WIPP. It should be noted that the WIPP facility is a geological repository designed and permitted primarily for disposal of low concentration manufacturing residues of transuranic (TRU) wastes from the weapons complex. It is not permitted to store large quantities of concentrated weapons grade plutonium in WIPP. Weapons plutonium is isotopically identical to that of the TRU waste plutonium currently stored in WIPP (both are $^{239}\text{Pu}$). However, the weapons plutonium if stored at WIPP will be significantly more concentrated and will create a much more hazardous condition relative to criticality and safety.

Criticality Safety

The High Bridge team of nuclear experts identified a series of safety and regulatory concerns for the DOE/NNSA plan to store tons of plutonium not originally planned for emplacement in the WIPP repository. The most serious concern is that the plutonium packaging endorsed by the DOE will be crushed over time as the salt chambers in WIPP close up, creating a high likelihood of an uncontrolled criticality.

Criticality refers to a condition in which a nuclear chain reaction is possible. Unlike controlled criticality in a reactor, an uncontrolled criticality can behave in very erratic and unpredictable ways. This will result at a minimum in the release of large amounts of energy and the creation of a large inventory of radioactive fission products that would be available for release to the environment. The extremely high pressures created as the salt cavern closes in on the storage drums will force the plutonium closer together, creating the geometry of crushed storage drums which facilitates a critical chain reaction.

Storing 51.3 metric tons of plutonium in Criticality Control Overpacks (CCOs) endorsed by DOE would require 171,000 55-gallon drums. Our modeling indicates that a ~30% crushing of only a single stack of CCOs (21 drums containing about 8 kg of plutonium) could result in a criticality. We have found no evidence that DOE has analyzed this scenario. This scenario is not evaluated in the environmental impact statements that enabled WIPP to accept TRU waste, nor is it evaluated in any of the National Environmental Protection Act (NEPA) documentation for storage and disposition of weapons plutonium.

High Bridge also analyzed four other storage scenarios which reduced the concentration of plutonium, compared to the packaging identified by DOE, thus reducing or eliminating the likelihood of criticality. In each case, storage volume increased substantially from 1.5 to 3.5 times the limits contained in the WIPP Land Withdrawal Act of 1992 and considered in the Final Environmental Impact Statement.

Other Safety and Regulatory Issues

- Although approved for transportation, CCOs are not currently an acceptable waste package for WIPP. Previous analyses used to qualify WIPP do not consider the impact of the use of CCOs.
- The fissionable plutonium content in CCOs (29.2 kg/m$^3$) exceeds the maximum concentration limit of 7.3 kg/m$^3$ established by the American National Standards Institute to avoid criticality.
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- Large areas of the WIPP repository will significantly exceed EPA thermal heat load limits. This results in unanalyzed stresses in the geologic strata above the waste.

Safeguards and Security

Weapons-grade plutonium is stored under stringent safeguards intended to prevent theft or diversion. Because of the nature of transuranic materials now stored in WIPP, the facility operates under a much less stringent security program. Plutonium in CCOs is diluted but retains the same isotopic structure and therefore retains its value as a source of weapons material. Terminating safeguards for surplus weapons plutonium in CCOs during transportation to WIPP or after disposal at WIPP is unprecedented and may not be possible. If safeguards are not terminated, the additional security costs would further increase the cost of WIPP operations and require special methods to prevent human intrusion for 10,000 years or longer.

Violation of the U.S.–Russia Plutonium Management and Disposition Agreement (PMDA)

The PMDA specifically identifies the technical approaches for both countries to dispose of their surplus weapons-grade plutonium by irradiating it as mixed oxide (MOX) fuel in nuclear reactors. Once irradiated and converted to spent fuel, the plutonium can no longer be readily used for nuclear weapon purposes. Dilution and storage of this plutonium in a geologic repository such as WIPP has long been opposed by Russia, and a change to the basic disposition approach is likely to result in Russia halting its efforts to dispose of 34 MT of surplus weapons plutonium. If Russia were to reverse its long-standing opposition, Russian nonproliferation experts believe that, as a minimum, Russia would demand relief from the stringent nonproliferation conditions imposed by the PMDA – conditions which are essential to provide the United States with confidence that Russia is disposing of its weapons-grade plutonium in accordance with the terms and conditions of the PMDA.

Inadequacy of WIPP NEPA Environmental Documentation

The High Bridge analysis reveals that any scenario for storing large quantities of weapons-grade plutonium in WIPP would exceed its storage capacity. This would require changes to its statutory authorization as well as its environmental analyses and documentation, a time-consuming and risky process. The NEPA process would also need to be completed before a decision can be made to proceed. Disposal of weapons plutonium at WIPP could also jeopardize WIPP’s current Environmental Management and other DOE programmatic missions and its continued operation.

Comparative Costs of Diluted Plutonium Storage at WIPP vs. MOX Fuel Irradiation

The DOE/NNSA has stated that cost is the major driving force for the plutonium disposition program. It has frequently cited the Aerospace 2015 Assessment of MOX estimated costs of about $1 billion per year (nearly $47.5 billion for about 50 years) as the reason it has decided to follow the plutonium dilution storage path at WIPP with estimated costs of about $400 million per year ($13.1 billion for about 30 years). High Bridge evaluated these Aerospace cost assessments and has concluded that the estimates are based on significantly flawed and incorrect analyses. The Aerospace approach was driven by very narrow parameters that maximized the MOX Fuel Irradiation costs while minimizing the WIPP Dilution Storage costs. Additionally, many significant WIPP cost and schedule elements required to deal with greatly increased plutonium quantities and concentrations (a 243 fold increase over the WIPP design basis) were not analyzed by Aerospace. Most importantly, Aerospace never analyzed the costs associated with these
increased plutonium quantity and concentration levels from a nuclear criticality safety or FEIS regulatory compliance perspective.

As mentioned earlier, High Bridge performed a technical analysis that determined that the proposed disposal option will likely achieve a criticality during the period of regulatory concern. Therefore, five diluted plutonium storage scenarios for WIPP were evaluated based on reducing plutonium concentration levels to avoid criticality and ensure safety. The costs resulting from these scenarios were evaluated. High Bridge concludes that its scenario 5 is the most likely approach that will ensure safe and legal WIPP operations by avoiding nuclear criticality.

Based on these analyses, High Bridge concludes that the life cycle cost for the WIPP diluted storage option is $46.8 billion (not $13.1 billion as estimated by Aerospace) and that the life cycle cost for MOX Fuel Irradiation is $19.4 billion (not $47.5 billion as estimated by Aerospace). This High Bridge MOX estimate represents a cost of about $500 million a year to complete construction and less than $400 million a year for operations. The life cycle costs for completing the MOX program never approaches $1 billion/year.

The WIPP dilution storage option estimated cost of $46.8 billion is more than double the MOX fuel irradiation estimated cost of $19.4 billion. The WIPP dilution storage option estimated duration to dispose of the 51.3 MT of surplus plutonium is 55.3 years and more than double the MOX fuel irradiation estimated duration of about 25 years. None of the High Bridge analysis leading to its estimates have been recognized or evaluated by Aerospace.

About the High Bridge Team

High Bridge is a nuclear industry consulting firm with recognized expertise in providing independent technical and economic assessments of complex facilities and programs. It retained Studsvik Scandpower, an internationally recognized nuclear physics and criticality analysis firm, to assist with this review. High Bridge also retained a nationally recognized legal expert in National Environmental Policy Act (NEPA) compliance to validate our understanding of the existing or new NEPA documentation that could support a decision to store the additional excess weapons plutonium. Other team members included a retired Professor of Nuclear Science and Engineering from MIT; a retired Professor of Engineering and Computer Science from the University of Tennessee and a former Division Director of Research and Development for the Tennessee Valley Authority; and a former Chief Nuclear Engineer for Burns and Roe.

Complete Report that Follows

The Section 1 Overview provides an expanded discussion of analyses and conclusions along with selected graphics to show more insights for Executive Summary key conclusions. The body of the report for sections 3 to 9 provides the more detailed analyses of scientific, regulatory, and estimated cost issues that back up the Executive Summary and Overview. Section 10 References lists over 40 public domain information sources involving over 10,000 pages of data that served as the High Bridge research foundation and basis for this report.
1 Overview

Introduction

The DOE/NNSA has funded numerous studies to find an alternative to the current plan for plutonium disposition that was negotiated with the Russian Federation and signed as a formal agreement in 2000. The PMDA covers fabricating 34 metric tons of weapons grade plutonium into MOX Fuel for subsequent irradiation in nuclear reactors. Once irradiated and converted to spent fuel, the remaining plutonium can no longer be readily used for nuclear weapons purposes. Currently the MOX Fuel Fabrication Facility (MFFF) and supporting facilities are under construction at the Savannah River Site. The plant is approximately 68% complete with a cost to date of $5.2 billion. It is estimated that approximately $3.0 billion is required to complete the plant on an efficiently funded schedule with a completion date of 2022.

The DOE/NNSA is looking at alternatives since the cost of the MOX facility has increased significantly since it was first authorized. This cost increase is due to many factors including and not limited to major scope changes in the program and a lack of fully funding the project that has resulted in cost inefficiencies and extended schedule costs. In their studies, the DOE/NNSA concluded that the least expensive path forward is diluting the plutonium with other materials and disposing it at WIPP. This facility is a geological repository designed and permitted primarily for disposal of low concentration manufacturing residues of transuranic (TRU) wastes from the weapons complex. It is not permitted to store large quantities of concentrated weapons grade plutonium in WIPP. Weapons plutonium is isotopically identical to that of the TRU waste plutonium currently stored in WIPP (both are $^{239}$Pu). However, the weapons plutonium if stored at WIPP will be significantly more concentrated and will create a much more hazardous condition relative to criticality and safety.

In studies, DOE/NNSA made an assumption that WIPP could accept this highly concentrated weapons plutonium without difficulty. High Bridge finds no evidence that DOE rigorously analyzed this assumption in terms of safety, regulatory compliance, technical feasibility, or cost and schedule impacts. Examining other previous DOE/NNSA reports, High Bridge concludes that DOE/NNSA followed an approach that erroneously assumed that past environmental and safety analyses for low concentrations EM TRU waste would apply to the higher concentration of surplus weapons plutonium.

Purpose and Structure of Assessment

The purpose of this High Bridge study was to perform an assessment of technical parameters and estimated costs for the US DOE surplus plutonium disposition program alternatives for the WIPP and MOX alternatives. Additionally, High Bridge investigated in more detail if the WIPP repository can accept the storage of significant quantities of NNSA weapons plutonium in addition to the EM legacy TRU wastes destined for WIPP. Specifically, High Bridge assessed the statutory basis, safety, science, technology, safeguards, transportation, and cost impacts for storing 51.3 metric tons of surplus weapons plutonium.

High Bridge established 51.3 MT of surplus weapons plutonium as the total plutonium quantity that it evaluated for storage at WIPP based on publicly available DOE/NNSA information. This includes 4.2 MT of surplus weapons plutonium currently being packaged at SRS to be shipped to WIPP, 13.1 MT of plutonium under consideration for disposal, and the 34 MTs currently slated to go through the MOX Fuel Fabrication Facility (MFFF) as part of the Plutonium Management and Disposition Agreement (PMDA). The report identifies areas were the proposed action is outside of the current design basis and will be a violation of the current NEPA FEIS permit for operation. The main areas of concern are nuclear criticality,
radiological releases, safeguards security, thermal consequences, and cost impacts. It is not the intention of this report to be a definitive study of these issues, but rather an assessment of the magnitude of the potential impact of the disposal of up to 51.3 MTs of surplus weapons plutonium at WIPP.

This High Bridge report is structured as follows:

- The Executive Summary provides key conclusions regarding this complex program.
- Section 1 Overview – provides an expanded discussion of analyses and conclusions along with selected graphics to show more insights for Executive Summary key conclusions.
- Section 2 Introduction – discusses the High Bridge assessment methodology along with WIPP background and general information.
- Section 3 Criticality – provides analyses and quantification of safety issues considered in the current WIPP FEIS and the impacts created by introducing concentrated weapons plutonium.
- Section 4 Legal and Regulatory – defines current legal compliance parameters in the current WIPP FEIS and what would be violated if surplus weapons plutonium were stored at WIPP.
- Section 5 Radiological Releases – outlines governing regulatory parameters and assesses impacts resulting from nuclear criticality occurring with surplus plutonium stored at WIPP.
- Section 6 Safeguards – explains regulatory standards regarding transportation and storage of special nuclear like weapons plutonium and the security issues created if stored at WIPP.
- Section 7 Thermal Impacts – describes the repository thermal heat load compliance parameters in the WIPP current FEIS and the impacts of criticality energy release on these parameters.
- Section 8 US Russian Plutonium Disposition Program – discusses the PMDA agreement history, current compliance requirements, and impacts resulting from MOX cancelation and WIPP storage.
- Section 9 Economic Analysis – describes prior High Bridge assessments of WIPP and MOX estimated costs performed by Aerospace Corporation; assesses five WIPP technical impact scenarios to achieve safe and regulatory legal compliance for plutonium storage at WIPP; and provides an economic cost analysis of the five WIPP Diluted Plutonium Storage scenarios compared to the MOX Fuel Irradiation alternative.
- Section 10 References – lists and describes over 40 publically available information references used by High Bridge as the basis for this assessment analysis and conclusions.

Criticality

The TRU waste slated to be dispositioned in WIPP has an extremely low concentration of fissile isotopes. The extremely low concentration led to the WIPP FEIS/Sandia conclusion that achieving a sustained nuclear chain reaction was very unlikely, based on:

- A total of 21 MTs of fissile isotopes were distributed uniformly in 6.2 million ft³ of waste
- 150 MTs of $^{238}$U was also uniformly distributed in the waste reducing the reactivity of the fissile isotopes
- The total mass of $^{239}$Pu was 12.8 MTs
- The fissile concentration of actinides was approximately 12% making the formation of a critical aqueous solution impossible since it must be assumed that water intrusion will occur.
- The non-fissile waste materials present made it impossible to compact the fissile materials sufficiently to form a critical mass
However, the DOE/NNSA proposal to disposition surplus weapons plutonium in criticality control overpacks (CCOs) in WIPP violates all of the conditions that made criticality impossible in the design basis. At present, 52% of the legally allowed TRU waste has already been emplaced. As a result, the proposed disposition of surplus weapons plutonium at WIPP represents a significant increase in the concentration of actinide fissile isotopes because a far greater quantity will be placed in the remaining 48% of the allowable waste volume. Assuming that the original waste assessment was correct and the previous inventory remains proportional, the addition of 51.3 MTs of plutonium in the remaining space raises the average concentration of fissile isotopes (i.e. the enrichment) from 12% to 46%. This is shown diagrammatically in Exhibit 1-1.

Exhibit 1-1 – Change in Actinide Fissile Concentration if Surplus Weapons Plutonium is Dispositioned in WIPP

This increase in fissile concentration is significant and is far outside of the bounding analyses that support the NEPA documentation. None of the analyses supporting the NEPA documentation and the permit for WIPP’s operation have considered material with these fissile concentrations. Unlike the material from Rocky Flats, this material is more than twice the amount of fissile material that was analyzed in the supporting calculations for WIPP (21 MTs vs 51.3 MTs).

The SANDIA study (SAND99-2898) that supported the original conclusion that a criticality was impossible at WIPP were based on the assumption that it was impossible to compress the waste material enough to assemble a critical mass. The ANSI standard governing criticality assessments (ANSI/ANS-8.1-2014) is 7.3 kg/m³, the minimum concentration for criticality to be a concern. The SANDIA study suggested a lower concentration of 3 kg/m³ be used. Whereas the previous waste packaging for WIPP was comprised of difficult-to-compress materials, the CCO is essentially an empty 55-gallon drum with a criticality control container (CCC) secured in the center. Exhibit 1-2 shows the comparison of the Pipe Overpack Container (that is allowed by the WIPP WAC¹) and the CCO (that is not approved by the WIPP WAC). As can clearly be seen, it cannot be assumed that a CCO will not be crushed by the action of the salt overburden creeping into the waste storage rooms over an extended period of time.

¹ Waste Acceptance Criteria
At 380 grams per CCC, the density of fissile material inside the CCC is 29.2 kg/m³. The only reason a CCO is subcritical for shipping and handling purposes is that the distance between the CCCs is maintained by the intact drums. When the CCOs are crushed that separation is eliminated allowing the formation of a critical mass. Trace amounts of $^{239}$Pu in the surplus weapons plutonium provide free neutrons via spontaneous fissions and the presence of water in the repository set the minimum conditions necessary for an uncontrolled criticality to occur. A preliminary bounding analysis by Studsvik analysts has concluded that once these minimum conditions are achieved, the mass in a single stack (7x3) of CCOs stored in the repository is enough to go critical. The presence of over 50 MTs of surplus weapons plutonium emplaced in the repository in CCOs ensures that the criticality event would be wide-spread and significant in both output and duration.

In Sandia’s own study, they showed the likely impact of the crushing salt on their waste packages as shown in Exhibit 1-3 below.
Current WIPP operations call for the installation of either a 3,000 pound or a 4,200 pound supersack of magnesium oxide (MgO) on top of each waste stack before closure. This is done to absorb CO₂ produced by the decay of carbon-based materials in the waste forms, i.e., wood, paper, plastic, rubber, etc. Ironically, MgO is a weak nuclear moderator and a fairly efficient reflector of neutrons. This further enhances the physical conditions necessary for criticality.

In summary, the plan to place any amount of surplus weapons plutonium in WIPP in CCOs violates the WIPP WAC and constitutes an unacceptable risk of criticality. Given this risk and its potential consequences, High Bridge recommends that a detailed criticality and safety assessment be performed and made part of any NEPA documentation to inform decision-makers before this option is seriously considered or any surplus plutonium is shipped to WIPP.

Statutory and Regulatory

The DOE Waste Isolation Pilot Plant (WIPP) was created for disposition of transuranic (TRU) legacy wastes from U.S. nuclear weapons production. It has been developed as required by the United States Congress in the WIPP Land Withdrawal Act (Public Law 102-579, 1992).

DOE prepared a Supplemental Environmental Impact Statement (EIS) for approval in 1996 which was approved as the Final Supplemental EIS (FEIS DOE/EIS-0026 S-2) for the WIPP facility. Before significant changes can be made to the facility, its operation or its performance that could have a significant
environmental impact, a new FEIS or supplement to the FEIS for WIPP must be prepared by DOE to inform the decision-making process in accordance with the NEPA. In addition to providing updated information, including waste characterization and potential source terms, this new NEPA documentation needs to address whether WIPP itself could continue as the only facility available for TRU disposition. If the problems become insurmountable for the use of WIPP, a new facility would be required that will be designed to address the unique issues associated with the disposal of surplus weapons plutonium as TRU waste. A new facility could also be required if this material is dispositioned in WIPP resulting in WIPP’s statutory limit being reached, in which case WIPP would need to be either expanded or a new facility authorized to continue serving programmatic needs.

DOE/NNSA has prepared a supplemental FEIS for Surplus Plutonium Disposition that concludes that 13.1 MTs of Surplus Weapons Plutonium can be dispositioned at WIPP. It appears to rely on the experience from Rocky Flats where 180 kg of weapons grade plutonium was permitted to be dispositioned at WIPP. If all surplus weapons plutonium were to be disposed of at WIPP, it would involve the total current inventory of 51.3 MT. This represents over 250 times the amount from the POC shipments from Rocky Flats. In an attempt to comply with the WIPP statutory limited storage volume, the Criticality Control Overpack (CCO) for this plutonium was developed. The CCO contains 380 grams within a Criticality Control Container. (See Exhibit 1-2 above.) However, this container has not been approved for use in WIPP and is not included in the WIPP Waste Acceptance Criteria (WAC).

In order to use the CCO, an amendment to the WIPP WAC will be necessary. A decision to amend the WIPP WAC to accommodate the use of the CCO would require NEPA documentation at the appropriate level to inform decision-making. In light of the potential effects on WIPP performance if the CCO is used for surplus weapons plutonium, it appears to High Bridge that a new or supplement to the FEIS would be the appropriate level.

In the journal Nature\(^2\), Stanford University researchers questioned whether, over time, storage containers at WIPP could be crushed by the salt, causing a nuclear accident or leak. Also, the researchers questioned the safety of disposal of diluted Plutonium in “inert” material. The authors pointed out that plutonium has many chemical states and that there are very few truly inert materials in geological time, especially in the WIPP environment. Due to the long timeframe of Plutonium wastes (half-life of 24,000 years), it is likely that the regulatory time-period will be increased\(^3\). This coupled with the large increase in the quantity of plutonium that is planned to be disposed, increases the probability of human intrusion. They also point out that the lack of a revised safety analysis of this action could likely result in future failures.

**Safety, Science and Technology**

WIPP operates based on the scientific and technical assumptions embodied in the NEPA documentation supporting the decisions to construct and operate WIPP including the Original EIS, Supplemental EIS and all of the Supplement Analyses that have been performed for decision-making concerning WIPP. The proposed action to dispose of significant quantities of surplus weapons plutonium at WIPP is well beyond the design basis for WIPP and if undertaken without appropriate analysis and formal process, could result in the immediate need to revise the permit for WIPP operation and be subject to prolonged litigation.


\(^3\) A subtle point not made by the authors of that article is the fact that \(^{239}\text{Pu}\) decays to \(^{235}\text{U}\) that is just as hazardous albeit with a 704 million year half-life.
The major focus of the EPA regulations governing WIPP is the control of the releases of hazardous substances to the environment. Potential radiological releases are proportional to the inventory of radioactive isotopes available for release. WIPP was analyzed based on the presence of 21 MT of fissile isotopes uniformly distributed in the statutorily established limit of 175,564 m³ (0.12 kg/m³). Approximately 52% of the available legal volume limit of waste has been emplaced in WIPP. The disposal of 51.3 MTs of surplus weapons plutonium will increase this to 61.3 MT distributed in the remaining volume of 84,000 m³ (0.73 kg/m³). That is six times the concentration that was analyzed. Also, the crushing of the CCOs would result in a concentration of about 25 kg/m³ or over 200 times the concentration analyzed. Therefore, disposing of CCOs loaded to the design basis limit (380 g) represents an unanalyzed condition that must preclude the disposal of a single CCO until these issues are resolved.

A specific limit imposed by the EPA on the WIPP repository is the thermal heat load naturally produced by radioactive decay. The EPA limit for the thermal load from the decay heat in the waste form is 10,000 watts/acre. Based on the original design, the projected heat load was estimated to be 4,270 watts/acre. However, the heat load above an entire panel filled with surplus weapons plutonium would be over 11,000 watts/acre. The area above an individual room filled with surplus weapons plutonium would be approximately 40,000 watts/acre.

While the entire repository may be within the EPA limited heat load, large areas of the repository will not. This would result in unanalyzed stresses in the geologic strata above the waste. This, too, is an unanalyzed condition and would preclude the disposal of surplus weapons plutonium at WIPP until it has been analyzed and demonstrated acceptable.

**Safeguards**

Without the termination of safeguards, the surplus weapons plutonium cannot be reasonably transported to or disposed of in WIPP. DOE/NNSA routinely cites the Rocky Flats experience as the basis for claiming that the surplus weapons plutonium safeguards can be terminated. If rigorous safeguards would be necessary for either the transportation of this material or for WIPP, there would be significant cost and programmatic consequences that have not been considered. For the following reasons, the Rocky Flats Environmental and Technology Site (REFTS) experience is largely inapplicable and the termination of safeguards for these quantities and attractiveness category would be unprecedented.

- The surplus weapons plutonium is of a higher attractiveness category than the REFTS Pu
- The termination of safeguards for Rocky Flats material in WIPP was based partially on the small quantities involved - 180 kg out of 12,800 kgs
- As shown in Exhibit 1-4, the permitted license basis for WIPP covers 12,800 kg of $^{239}$Pu at a concentration of 0.12 kg/m³. The proposed increase in surplus weapons plutonium covers 51,300 kg of $^{239}$Pu at a concentration of 29.2 kg/m³. This four-fold increase in quantity and 250 fold increase in concentration results in an approximate 1,000 fold increase in attractiveness for diversion.
- The termination was based on the perceived difficulty in separating plutonium from the inerting agent (stardust) added to the $^{239}$Pu in a POC. A CCO has 1.9 times the fissile plutonium permitted in a POC so this argument may not be applicable.
- At the time of this report, rigorous analysis to support termination safeguards of $^{239}$Pu in a CCO for either transportation or emplacement in WIPP has not been published.
High Bridge concludes that the DOE/NNSA plan to dispose of surplus weapons plutonium by diluting it and storing it in WIPP would violate the terms of the Plutonium Management and Disposition Agreement (PMDA) signed by the U.S. and Russia in 2000 and amended in 2010. The PMDA provides for the disposition of 34 metric tons of surplus weapons-grade plutonium by each side. This is enough material for approximately 17,000 nuclear weapons. Russia has long argued that disposing of weapons-grade plutonium in a geologic repository, such as Yucca Mountain or WIPP, is another form of long-term storage because it fails to degrade the isotopic composition of the plutonium thus continuing to allow it to be used for nuclear weapons purposes. As a result, the PMDA codifies the technical approaches for both countries to dispose of their surplus weapons-grade plutonium by irradiating it as mixed oxide (MOX) fuel in nuclear reactors to produce electricity. Once irradiated and converted to spent fuel, the plutonium can no longer be readily used in a nuclear weapon, thereby preventing it from falling into the hands of terrorists or rogue nations, i.e., “Spent Fuel Standard” as recommended by the U.S. National Academy of Sciences.

As set forth in the PMDA, Russia will dispose of its 34 MT of weapon-grade plutonium by fabricating it into MOX fuel to be burned in fast reactors operating under stringent nonproliferation conditions. The United States agreed with Russia’s use of fast reactors provided that Russia configured its reactors to burn more plutonium than they produce, operate under an extensive monitoring and inspection regime and agree to never reprocess spent fuel containing disposition (34 MT) plutonium. These very specific nonproliferation requirements (and others) are essential to provide the U.S. with confidence that Russia is disposing of its weapons-grade plutonium in accordance with the terms and conditions of the PMDA.

Thus far, the United States has not engaged Russia in detailed negotiations on changing the PMDA to permit weapons-grade plutonium disposition in WIPP. Historically, negotiations with Russia regarding the sensitive topic of weapons-grade plutonium disposition have been difficult and time-consuming.
(frequently taking years). There is nothing to suggest that negotiating a change to the U.S. disposition approach would be any different given the current animus between the two sides as recently evidenced by Russian President Putin’s decision not to attend the 2016 Nuclear Security Summit in Washington.

Failure to reach agreement with Russia and amend the PMDA could result in Russia abandoning efforts to dispose of its surplus weapons plutonium. At a minimum, nonproliferation experts believe that if Russia were to abandon its long-standing position on the need to convert the plutonium to forms that can never again be used for weapons and accept the U.S. plan of diluting its weapons-grade plutonium and storing it in WIPP, Russia would demand relief from the stringent nonproliferation conditions contained in the amended PMDA that force Russia to operate its reactors in an inefficient and intrusive manner. Yet, these are the very requirements that are needed to provide the U.S. with confidence that Russia is disposing of its weapon-grade plutonium in accordance with the terms and conditions of the PMDA.

DOE/NNSA, the Plutonium Working Group (PWG), Aerospace, and the DOE Red Team all seem to discount the importance and the difficulty of amending the PMDA. Further, they all assert that the DOE could begin working on the Dilute and Dispose option almost immediately with little or no delay caused by amending the Plutonium Management and Disposition Agreement with Russia. DOE/NNSA and their consultants seem to view the PMDA as a minor issue that can be easily resolved once DOE officially abandons the MOX program in favor of the Dilute and Dispose option. This conclusion may be another costly and time consuming distraction from the critical mission of disposing of post-Cold War stocks of surplus weapons-grade plutonium.

**Comparative Costs of Diluted Plutonium Storage at WIPP vs. MOX Fuel Irradiation**

The DOE/NNSA has stated that cost is the major driving force for the plutonium disposition program. It has frequently cited the Aerospace 2015 Assessment of MOX estimated costs of about $1 billion per year (nearly $45.7 billion for about 50 years) as the reason it has decided to follow the plutonium dilution storage path at WIPP with estimated costs of about $400 million per year ($13.1 billion for about 30 years). High Bridge evaluated these Aerospace cost assessments and has concluded that the estimates are based on significantly flawed and incorrect analyses. The Aerospace approach was driven by very narrow parameters that maximized the MOX Fuel Irradiation costs while minimizing the WIPP Dilution Storage costs. Additionally, many significant WIPP cost and schedule elements required to deal with greatly increased plutonium quantities and concentrations (a 243 fold increase over the WIPP design basis) were not analyzed by Aerospace. Most importantly, Aerospace never analyzed the costs associated with these increased plutonium quantity and concentration levels from a nuclear criticality safety or FEIS regulatory compliance perspective.

As mentioned earlier, High Bridge performed a technical analysis that determined that the DOE/NNSA proposed plutonium disposal option will likely achieve a criticality during the period of regulatory concern. Therefore, five WIPP diluted plutonium storage scenarios were developed by High Bridge were evaluated based on reducing plutonium concentration levels to avoid criticality and ensure safety. The costs resulting from these scenarios were evaluated. High Bridge concludes that its scenario 5 is the most likely approach that will ensure safe and legal WIPP operations by avoiding nuclear criticality.

Based on these analyses, High Bridge concludes that the life cycle cost for the WIPP diluted storage option is $46.8 billion (not $13.1 billion as estimated by Aerospace) and that the life cycle cost for MOX Fuel Irradiation is $19.4 billion (not $47.5 billion as estimated by Aerospace). This High Bridge MOX estimate
represents a cost of about $500 million a year to complete construction and less than $400 million a year for operations. The life cycle costs for completing the MOX program never approaches $1 billion/year.

The WIPP dilution storage option estimated cost of $46.8 billion is more than double the MOX fuel irradiation estimated cost of $19.4 billion. The WIPP dilution storage option estimated duration to dispose of the 51.3 MT of surplus plutonium is 55.3 years and more than double the MOX fuel irradiation estimated duration of about 25 years. None of the High Bridge analysis leading to its estimates have been recognized or evaluated by Aerospace.

Moreover, the Aerospace cost estimate ignores the fact that if the MOX program is cancelled, all WIPP dilution storage NEPA regulatory and design bases need to be increased to cover the entire amount of surplus plutonium to be stored at WIPP. The High Bridge analysis in this report is based on 51.3 MTs of plutonium, while other sources place the surplus plutonium quantity at closer to 61.5 MTs. The NEPA and legal regulatory processes and approvals, along with the revised Land Withdrawal Act law, need to be completed before any surplus plutonium can be placed in WIPP.

Exhibit 1-5 summarizes the High Bridge estimated impacts on the WIPP repository for these five scenarios to store 51.3 MT of weapons plutonium. Scenario 1 considers the approach proposed by the Plutonium Working Group for disposing of this material in CCOs and endorsed by DOE/NNSA. Scenario 2 considers disposing of this material in POCs, given POCs are qualified for use at WIPP. Scenario 3 considers reducing the concentration of fissile material to the ANSI standard minimum for criticality of 7.3 kg/m³ in CCOs. Scenario 4 considers the reduction of the concentration to meet the concentration used by Sandia when qualifying WIPP. Scenario 5 considers the plutonium being diluted to the average fissile content density of 0.12 kg/m³ of WIPP as defined in the FEIS design basis using 55-gallon drums and an incompressible inert material.

### Exhibit 1-5 - Key Metrics for WIPP Plutonium Storage Cost Estimate Scenarios

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>Plutonium Concentration kg/m³</th>
<th>Drums</th>
<th>Duration Required Years to Emplace</th>
<th>Volume m³</th>
<th>Storage Rooms</th>
<th>Will Go Critical</th>
<th>FEIS Compliant</th>
<th>Scenario Estimated Cost $Billions</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIPP Design &amp; FEIS Basis</td>
<td>0.12</td>
<td>N/A</td>
<td>25</td>
<td>175,564</td>
<td>56</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Storage Scenarios:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 1 Using CCOs</td>
<td>29.2</td>
<td>171,000</td>
<td>4.6</td>
<td>35,568</td>
<td>21</td>
<td>Yes</td>
<td>No</td>
<td>$19.9</td>
</tr>
<tr>
<td>Scenario 2 Using POCs</td>
<td>16.7</td>
<td>301,765</td>
<td>8.2</td>
<td>62,767</td>
<td>35</td>
<td>Likely</td>
<td>No</td>
<td>$22.6</td>
</tr>
<tr>
<td>Scenario 3 Concentration Reduced to ANSI Standard</td>
<td>7.3</td>
<td>539,780</td>
<td>14.6</td>
<td>112,274</td>
<td>53</td>
<td>No</td>
<td>No</td>
<td>$26.6</td>
</tr>
<tr>
<td>Scenario 4 Concentration Reduced to Sandia Single Point Value</td>
<td>3.0</td>
<td>1,313,465</td>
<td>35.4</td>
<td>173,200</td>
<td>128</td>
<td>No</td>
<td>No</td>
<td>$37.0</td>
</tr>
<tr>
<td>Scenario 5 Concentration Reduced to WIPP Design Value</td>
<td>0.12</td>
<td>2,053,337</td>
<td>55.3</td>
<td>427,094</td>
<td>203</td>
<td>No</td>
<td>No</td>
<td>$46.8</td>
</tr>
</tbody>
</table>
It should be noted that only 23,600 cubic meters or 13 percent of the total WIPP repository volume of 175,564 cubic meters remains available for yet unidentified EM TRU waste.

All of the scenarios shown on Exhibit 1-5 address significant issues with DOE/NNSA plans to dispose of 51.3 MT of plutonium at WIPP. None of them will eliminate the need for a full and open NEPA process to provide the decision-maker information on the potential environmental consequences of adopting this proposal. In addition to this NEPA process addressing all reasonable alternatives, an amendment of the PMDA would be required along with a full legislative process to amend the LWA to permit this option to take place. Beyond the identified cost impacts associated with implementing the diluted plutonium storage option at WIPP, each dilution scenario significantly extends the operating period of WIPP well beyond the current planned lifetime, which represents a large part of the estimated cost for each scenario.

The current regulatory and statutory authorized size of WIPP involves a volume of 175,564 m$^3$, 10 panels, and 70 rooms. Exhibit 1-5 shows the number of drums increasing 10 times, repository volume increasing 3 times, and repository panels/rooms increasing 3 times to achieve the FEIS design basis fissile concentration of 0.12 kg/m$^3$ (Scenario 5). The estimated cost for each of these scenarios increases in proportion to the reducing plutonium concentrations and increasing plutonium quantities, repository volumes, and storage emplacement durations.

**Team Member Qualifications**

High Bridge is a nuclear industry consulting firm with recognized expertise in providing independent technical and economic assessments of complex facilities and programs. High Bridge assembled a team of subject matter experts to perform an assessment of the adequacy of the WIPP EM Repository to accept significant quantities of NNSA weapons plutonium in addition to the EM legacy TRU wastes destined for WIPP. Team members included:

- A Team Leader with over 40 years of experience in nuclear construction and independent assessments of complex industrial and DOE mega-projects
- A retired Professor of Nuclear Science and Engineering from MIT,
- A retired Professor of Engineering and Computer Science from the University of Tennessee and a former Division Director of Research and Development for the Tennessee Valley Authority,
- A former Chief Nuclear Engineer for Burns and Roe,
- An attorney recognized as an expert on the National Environmental Policy Act (NEPA) and formerly a top legal advisor for the Department of Energy (DOE) and the National Nuclear Security Administration (NNSA),
- Studsvik Scandpower, Inc., an international firm with recognized expertise in nuclear physics and criticality scientific analysis

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4 Original design called for 8 panels but was recently revised to permit a total of 10 panels.