DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

November 15, 2019

The Honorable James Richard Perry
Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-0701

Dear Secretary Perry:

For the past decade, the Defense Nuclear Facilities Safety Board (Board) has advised the Department of Energy on the need to strengthen the safety controls used to protect the public from potential radiological consequences of an earthquake impacting the Plutonium Facility at Los Alamos National Laboratory. While the Department has made physical improvements to the Plutonium Facility, we note that significant portions of the Department's strategy to upgrade safety controls have been delayed and the upgrades remain incomplete. At the same time, the Department is extending its reliance on this facility to execute key national security missions.

The attached report along with the Board's Technical Report 44, *Los Alamos National Laboratory Plutonium Facility Leak Path Factor Methodology*, dated November 12, 2019, identify weaknesses in the Plutonium Facility safety basis that should be addressed. These issues underscore the need for timely completion of safety control improvements that have stagnated over the last decade.

Pursuant to 42 U.S.C. §2286b(d), the Board requests a briefing within 60 days of receipt of this letter on 1) the NNSA strategy for ensuring the deficient safety systems at the Plutonium Facility will be upgraded in order to meet a schedule commensurate with future national security missions and 2) the approach for addressing the weaknesses in the analyses that support the Plutonium Facility safety basis as discussed in the attached report.

Yours truly,

Bruce Hamilton
Chairman

Enclosure

c: Mr. Joe Olencz

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Report

August 16, 2019

Safety Basis for the Plutonium Facility at Los Alamos National Laboratory

Summary. Members of the Defense Nuclear Facilities Safety Board's (Board) staff reviewed the safety basis for the Plutonium Facility (PF-4) at Los Alamos National Laboratory (LANL) [1–4]. The scope of the review included safety system deficiencies identified in the PF-4 documented safety analyses (DSA), the methodology used to calculate the facility leak path factor (LPF), and the hazard and accident analyses. The staff team conducted onsite discussions with the previous management and operating contractor, Los Alamos National Security, LLC (LANS), and National Nuclear Security Administration (NNSA) Los Alamos Field Office (NA-LA) personnel on August 29–31, 2017, December 19, 2017, and October 23–24, 2018. In addition to the onsite interactions, the Board's staff conducted several teleconference calls.

Based on its review, the staff review team identified safety concerns related to the accident progression for the post-seismic fire, methodology used to derive LPF, dose conversion factors for heat source plutonium oxides, assumptions related to the confinement doors, and compensatory measures for deficient safety systems. Collectively, these concerns call into question the overall adequacy of the current set of safety controls to protect the public and workers and reinforce the need to complete upgrades to the deficient safety systems.

After the staff team finished their review, NA-LA issued a safety evaluation report that unconditionally approved the annual update to the PF-4 safety basis [5, 6] in February 2019. This update addresses long-standing conditions of approval, many of which originated in 2008, and includes efforts to modernize the hazard analysis and consolidate multiple safety basis documents. In addition, this safety basis includes a lower first floor material-at-risk (MAR) limit to account for the seismically deficient safety systems. However, the staff team evaluated the changes made in the annual update of the safety basis and concluded that the concerns identified by the team from its review of the previous safety basis revision were not addressed.

Background. PF-4 is a hazard category 2 nuclear facility constructed in the 1970s to support actinide chemistry research and development. It is located in Technical Area (TA)-55 and approximately 1,000 meters from the site boundary. Current missions at PF-4 include nuclear weapon pit manufacturing, pit surveillance, pit disposition, and manufacturing radioisotope power sources for space and defense applications. Radioactive material at PF-4 includes weapons grade plutonium, heat source plutonium, tritium, highly enriched uranium, and smaller quantities of other transuranic isotopes. Weapons grade and heat source plutonium in PF-4 exist in solid forms (metal or powder), molten metal, or in solution.

The current approved DSA was written to Department of Energy (DOE) Standard 3009-94, Change Notice 3, *Preparation Guide for U.S Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses* [7]. In the DSA, significant accident scenarios at PF-4 include operational facility fires, flammable gas deflagrations, and seismically induced spills and fires. The DSA assumes a performance category (PC) 3 seismic event for the evaluation-basis earthquake for the post-seismic fire accident scenario.

The post-seismic fire accident scenario has the highest postulated mitigated dose consequences to the maximally exposed offsite individual (24.2 rem committed effective dose [CED][1]) in the DSA. This is just below the Evaluation Guideline of 25 rem total effective dose (TED) listed in both DOE Standard 3009-94, Change Notice 3, and DOE Standard 3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis* [8]. The DSA credits the safety class passive confinement system (i.e., the building structure) and MAR limits to mitigate the consequences for this accident scenario. The safety basis quantifies the ability of the building to passively confine material in an accident scenario through the use of an LPF of less than one in the mitigated analysis.

Discussion. NNSA and the Board have agreed for more than a decade on the need to improve the credited safety systems at PF-4. In particular, LANL identified the need for upgrades to many of these systems in 2006 and developed a safety system upgrade project plan in 2009 [9]. In 2011, LANL reconfigured that project [10] into an annually updated project execution strategy (PES) that describes the strategy, cost, scope, schedule, and identified funding sources for the upgrades. LANL is now incorporating this strategy into its planning effort to support an increased pit manufacturing mission. LANL has completed several of the projects listed in the PES including analyzing the seismic capability for components of safety systems and making seismic upgrades to PF-4's structure, ventilation system, glovebox support stands for gloveboxes that contain molten plutonium operations, and the electrical distribution system.

However, a number of factors have caused LANL to delay upgrades to several of the key safety systems. These factors include unexpected engineering challenges, funding and scope perturbations in line item projects, and reprioritizations for emergent scope as the facility seismic analyses progressed. As shown in Table 1, estimated dates for completing upgrades to the fire barriers, as well as the ventilation and fire suppression systems, have slipped well beyond LANL's initial estimates. These systems are essential to LANL's safety control strategy for post-seismic fires.

[1] For comparison to the Evaluation Guideline, DOE Standard 3009 requires radiological dose consequences to be presented as TED. TED includes both the 50 year CED and direct exposures. For the two material categories of interest in the dose consequences calculation for the post-seismic fire accident scenario at PF-4 (i.e., weapons grade plutonium-equivalent and heat source plutonium), the 50 year CED outweighs by several orders of magnitude the dose consequences due to direct exposures. Therefore, the dose consequences reported as rem CED are equivalent to rem TED and can be directly compared to the Evaluation Guideline.

Table 1: Changes in Estimated Completion Schedule† for Safety System Upgrades			
Safety System	***Safety System Upgrade Benefits***	***2011 Baseline* [10]**	***2019 Update* [11]**
Laboratory Fire Barriers	Limit fires from spreading between laboratory rooms.	2015	2021
Fire Suppression Seismic Upgrades	Limit fires from spreading between laboratory rooms, reduce the intensity of fire, and potentially reduce the LPF for the post-seismic fire event.	2013	2024
Active Confinement Ventilation	Reduce LPF and reliance on passive confinement during seismic event.	2020	2025
Remove Seismically Unqualified Buildings for Firewater Main	Ensure water supply to fire suppression system after a seismic event.	2022	2026
† Completion schedule is based on fiscal year			

Based on its review of the PF-4 safety basis, the staff review team identified new concerns with the safety basis that reinforce the need to complete these upgrades and modifications to the deficient safety systems. Specifically, the staff team identified safety concerns related to the accident progression for the post-seismic fire, methodology used to derive LPF, dose conversion factors for heat source plutonium oxides, assumptions related to the confinement doors, and compensatory measures for deficient safety systems. These concerns demonstrate that NNSA and LANL may be underestimating the risk from a post-seismic fire accident scenario and further emphasize the need to upgrade the deficient safety systems. The staff team believes completing the planned upgrades for the safety systems should be the highest priority for improving the safety posture of the facility.

Non-conservative Post-seismic Fire Accident Progression—The accident progression postulated in the safety basis for the post-seismic fire accident scenario does not consider spilled MAR being impacted by seismically unqualified equipment. Currently, about 75 percent of the gloveboxes in the facility either do not meet their seismic criteria or have not yet been analyzed to demonstrate they will not topple in a seismic event. There are also large pieces of equipment and shielding that could create such impacts. Based on the analysis in Appendix A, the staff team found that including an additional insult where MAR is impacted by falling equipment in the quantitative accident analysis would increase the source term and result in mitigated dose consequences to the public that exceed the DOE Evaluation Guideline. This is because the bounding airborne release fraction (ARF) and respirable fraction (RF) values for the fraction of plutonium powder that is aerosolized by an impact (2.0×10^{-3}) is greater than the fraction of plutonium powder aerosolized for a spill (6.0×10^{-4}) and fire (6.0×10^{-5}) by one to two orders of magnitude. As shown in Table 2, the mitigated dose consequences for the post-seismic fire accident scenario increase such that the Evaluation Guideline could be exceeded by a factor of about three when considering this additional insult. Further, the Evaluation Guideline is exceeded by a factor of about 1.35 when considering this additional insult and the new first floor MAR limit.

Table 2: Mitigated Dose Consequences for Post-seismic Fire Accident Scenario		
Accident Progression	**MAR (kg Pu-EQ)**	**Dose (rem CED)**
Seismic Event with Spill and Fire (as analyzed in the DSA)	2,600	24.2
Seismic Event with Spill, Impact, and Fire	2,600	77
Seismic Event with Spill, Impact, and Fire	1,800	32

Non-conservative Leak Path Factor—As discussed in Technical Report 44, *Los Alamos National Laboratory Plutonium Facility Leak Path Factor Methodology* [12], November 12, 2019, the Board's staff team performed an independent analysis and identified concerns with LANL's statistical methodology for LPF. Specifically, the staff team found that the LPF values used in the accident analysis do not meet DOE Standard 3009-94 requirements on using conservative inputs and assumptions for calculations in the safety analysis. In addition, the staff team found discrepancies between hourly average and five minute average wind data and examples of LPF values that appear to be non-physical, which could invalidate a key assumption on the conservatism inherent in the method. Lastly, the staff team is also concerned with the lack of software quality assurance for the computational fluid dynamics code that LANL used to calculate the LPF values and inadequate records for the LPF calculation. Correcting the deficiencies in the calculations would likely lead to higher LPF values, which would further increase the mitigated dose consequences to the public for all postulated accident scenarios. Because LANL is developing a new LPF model, it is important that they remedy these concerns to derive technically defensible LPF values. Any increase in the LPF value for the post-seismic fire accident scenario would result in the calculated mitigated dose consequence exceeding the Evaluation Guideline.

Inappropriate Dose Conversion Factors for Heat Source Plutonium Oxides—For the purposes of calculating dose consequences, radiological material is classified as Type S (slow), Type M (moderate), and Type F (fast), which correspond to how quickly inhaled, aerosolized material is absorbed into the bloodstream. A faster rate of absorption corresponds to a higher dose conversion factor, which results in higher dose consequences. This is important for heat source plutonium because the dose conversion factor for Type M is approximately three times greater than Type S. The PF-4 safety basis applies a Type S dose conversion factor to heat source plutonium oxides (i.e., fine powders and granules) that have been heated above 800°C for at least two hours. For heat source plutonium oxides that have not been heat treated at 800°C, the PF-4 safety basis applies a LANL-derived intermediate dose conversion factor (between Types S and M). Based on the analysis in Appendix B, the staff team concludes that the intermediate dose conversion factor is not technically defensible and is incorrectly applied to certain forms of heat source plutonium. This results in underestimated dose consequences to the public and workers.

Non-conservative Confinement Doors Assumption—The PF-4 DSA [5] assumes that the confinement doors (i.e., exits for evacuation) are open for only five minutes following a seismic event. The five minute assumption is based on timed evacuations of personnel during drills. This assumption has a major impact on the LPF calculation, given that the doors are unfiltered release points from the facility. This assumption is not protected in practice, as the doors are not prohibited from being open longer than five minutes, and there are a number of reasons why they could remain open longer (e.g., access by emergency responders).

Lastly, this assumption also impacts how LANL safety basis analysts evaluated other inputs and assumptions in the accident analysis, such as which rooms were selected to have a fire and important inputs for dose consequences calculations. Specifically, the staff team found the following:

1) LANL does not analyze post-seismic fires in laboratory rooms that have pyrophoric materials because it assumes these would be low energy events and the resulting fire would not grow sufficiently within the first five minutes of the accident to impact the dose consequences.

2) LANL did not select the more conservative bounding ARF and RF values for boiling aqueous solutions when under thermal stress for the post-seismic fire accident because it assumes that five minutes would not be enough time for the aqueous solutions to boil.

3) LANL did not select the more conservative bounding ARF and RF values for aqueous and organic solutions being burned to complete dryness when under thermal stress for the post-seismic fire accident because it assumes that five minutes would not be enough time for the solutions to be burned to complete dryness.

These release phenomena would further increase the mitigated dose consequences to the public for postulated seismic events.

Inappropriate Compensatory Measures for Deficient Systems—The PF-4 DSA [5] identifies deficiencies in several safety systems that are part of the post-seismic fire control strategy, including the fire suppression system, glovebox system, and components of the active confinement ventilation system. For each deficiency, the safety basis lists a compensatory measure. However, based on the analysis in Appendix C, the staff team found that the compensatory measures do not always ensure that the systems would be able to perform their intended safety function or that the hazards they are credited to protect would be prevented or mitigated. Therefore, the overall safety control strategy may not provide adequate protection to the public or workers. As discussed above, LANL has submitted plans to address these deficiencies. While LANL completed some of the upgrades identified in the PES, upgrade projects related to several of the key credited safety systems continue to be delayed.

Conclusion. Based on the findings detailed in this report, the Board's staff team concludes that the approved PF-4 safety basis [5, 6] does not appropriately analyze the hazards at PF-4 and that the current safety control strategy does not adequately protect the public from the post-seismic fire accident scenario. In addition, the staff team concludes that inadequate documentation and limited software pedigree regarding the derivation of LPF values used in the DSA challenge the efficacy of the primary control that is credited to protect the public from the consequences of a seismic event (i.e., confinement by the building structure). NNSA and the Board have agreed for more than a decade on the need to improve the credited safety systems at

PF-4; however, these improvements have been delayed. The concerns detailed in this report further emphasize the need for timely upgrades to PF-4's deficient safety systems.

Appendix A: Non-conservative Post-seismic Fire Accident Progression

In the quantitative accident analysis for the post-seismic fire scenario, the approved Plutonium Facility (PF-4) documented safety analysis (DSA) [5] assumes that (1) only material-at-risk (MAR) on the first floor will be affected, (2) fires will only occur in rooms that process molten plutonium and in one room that is assumed to contain all of the heat source plutonium, (3) the building structure is not damaged, and (4) MAR primarily exits the facility through the exterior doors. The accident progression for the post-seismic fire scenario assumes that during a seismic event, gloveboxes will shake and spill all of the radiological material assumed to be on the first floor. A fraction of the material becomes aerosolized as it falls through the air and impacts the ground. In rooms that are assumed to have a fire, the fire aerosolizes a fraction of the MAR that was not aerosolized by the spill.

In its dose consequence calculations for the post-seismic fire accident, Los Alamos National Laboratory (LANL) partitions the first floor MAR between the laboratory rooms on the first floor [14]. The distribution is based on operations that occur in each of the laboratory rooms. LANL does not list an individual MAR limit for each laboratory room (with the exception of one heat source plutonium room). To mitigate this accident, the DSA credits the safety class passive confinement system (i.e., the building structure) and MAR limits. The DSA calculates the mitigated dose consequences to the maximally exposed offsite individual to be 24.2 rem committed effective dose (CED).

The Board's staff team found that the accident progression omitted a credible insult to the MAR. It is credible for equipment that is not seismically qualified to fall and impact MAR during a seismic event. Department of Energy (DOE) Standard 3009-94, Change Notice 3, *Preparation Guide for U.S Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses* [7], states, "Evaluate secondary events directly caused by natural events, such as earthquake induced fires, based on their physical possibility for facility conditions (i.e., the induced accident must already potentially exist in the absence of the seismic event)." Therefore, to be compliant with DOE Standard 3009, the accident analysis must consider impacts to MAR—in addition to entrainment while falling—when determining the unmitigated dose consequences.[2] Equipment that could impact the MAR includes gloveboxes, shielding, and large, non-seismically qualified equipment within gloveboxes. Including an impact term in the accident progression would result in further aerosolization of MAR, thus increasing the source term for seismic events.

The staff team performed calculations of dose consequences to the public from a seismic event for the first floor of PF-4 that included the effects of an impact source term. In general, the staff team's calculations used inputs and assumptions consistent with the PF-4 DSA. In order to assess the significance of including an impact term in the source term calculation, the staff team did not account for the other non-conservative aspects identified during its review (e.g., leak path factor [LPF] values).

[2] DOE National Training Center course SAF-710, *Safety Basis Document Preparation*, considers a similar seismic event in an illustrative exercise and includes impact in its accident progression.

In its analysis for the post-seismic fire accident, the staff team assumed the following sequence of events: (1) gloveboxes shake or collapse during a seismic event, resulting in MAR spilling onto the floor; (2) other gloveboxes, drop boxes, and equipment that are not seismically qualified then impact MAR; and (3) a fire starts in specific PF-4 rooms. The staff team considered the same safety controls that the DSA identified to assess the mitigated dose consequences to the public (i.e., the safety class passive confinement system and MAR limits). The staff team also analyzed this same accident progression with a reduced first floor MAR limit, listed in the recently approved DSA [5], that LANL established as a compensatory measure due to deficiencies with the ventilation system and fire suppression system.

When including the additional insult due to MAR being impacted, the staff team selected airborne release fraction (ARF) and respirable fraction (RF) values that were consistent with a previous PF-4 safety basis addendum that analyzed a post-seismic collapse of PF-4[3] [15]. In the addendum, LANL re-analyzed the post-seismic spill accident and included an additional contribution to the source term due to the falling structure or debris impacting the MAR. The staff team adjusted some of the values due to the difference in height of the gloveboxes compared to the height of the ceiling. In addition, the staff team conservatively assumed that all MAR not aerosolized from the spill was subject to impact from falling debris (i.e., assumed a damage ratio of 1).

The staff team found, with the inclusion of the impact source term, the calculated mitigated dose consequences to the public for a seismic spill, impact, and fire event exceed the DOE Standard 3009 Evaluation Guideline of 25 rem total effective dose (TED) by a factor of three (i.e., ~75 rem TED). Applying the reduced first floor MAR limit that LANL has instituted results in calculated mitigated dose consequences that exceed the Evaluation Guideline by a factor of 1.35 (i.e., ~35 rem TED). Table A.1 below shows how the mitigated dose consequences for the post-seismic fire accident scenario changes when considering this additional insult and the new first floor MAR limit.

Table A.1: Mitigated Dose Consequences for Post-seismic Fire Accident Scenario

Accident Progression	MAR (kg Pu-EQ)	Source Term due to Spill and Fire (g Pu-EQ)	Source Term due to Impact (g Pu-EQ)	Dose (rem CED)
Seismic Event with Spill and Fire (as analyzed in the DSA)	2,600	994	N/A	24.2
Seismic Event with Spill, Impact, and Fire	2,600	994	2208	77
Seismic Event with Spill, Impact, and Fire	1,800	516	840	32

[3] While a similar approach was used from the TA-55 DSA addendum [16] facility collapse accident analysis, the staff team does not endorse the technical validity of each assumption (e.g., LPF, ARF, and RF values) and only followed this approach to illustrate the additional insult contribution from impact to MAR based on a previous LANL analysis.

The staff team discussed this concern with LANL, which resulted in LANL safety basis analysts initiating its new information process. LANL concluded that the ARF×RF values currently used in the PF-4 DSA are sufficiently conservative, and that there is no potential inadequacy of the safety analysis. LANL included the discussion and results from the new information report [16] in the newest revision of the DSA [5]. The LANL report concludes that using ARF×RF values for "free-fall spills" of powders is conservative and more representative than using the bounding ARF×RF values for "suspension of bulk powder by debris impact and air turbulence from falling objects" for powders as described in DOE Handbook 3010-94 *Airborne Release Fractions/Rate and Respirable Fractions for Nonreactor Nuclear Facilities* [17]. LANL provides several reasons to support this conclusion.

LANL states that there are no substantial portions of structural features and equipment that could fall onto all of the bare powder MAR resting on the laboratory floor after having been spilled and PF-4 does not have operations that involve bare powder resting on a flat surface uncontained. However, the staff team notes that there are several gloveboxes with known seismic deficiencies. Due to these deficiencies, LANL continues to assess the seismic performance of existing glovebox systems. As of April 2019, LANL identified the following:

- All gloveboxes in PF-4 required to meet performance category (PC)-3 seismic criteria have either been upgraded to do so or are currently inactive;
- Approximately 20 percent of the gloveboxes required to meet PC-2 seismic criteria[4] meet or exceed their requirement;
- Approximately 15 percent of gloveboxes that are required to meet PC-2 seismic criteria do not; and
- Approximately 60 percent of the gloveboxes required to meet PC-2 seismic criteria have no known analysis associated with them.

In addition, LANL identified that approximately 75 percent of the gloveboxes that process heat source plutonium either do not meet the PC-2 seismic criteria or have not yet been analyzed. Heat source plutonium is a major contributor to the source term in the accident analysis. Based on the number of deficient and unanalyzed gloveboxes, the staff team finds it credible for some MAR to be impacted by equipment.

[4] PC-2 structures, systems, and components (SSCs) have an annual failure probability of $5x10^{-4}$. Depending on the controlling failure mode, collapse mechanisms may be sudden or gradual; non-ductile failure modes (such as anchorage failure) may cause gloveboxes rated less than PC-2 to rip out their supports and topple in a PC-2 level event, while more ductile failure modes like brace yielding may lead to large deformations that provide some margin beyond the design basis load.

LANL also states the floor of PF-4 would not react to such an impact in the same way as the testing apparatus and setup used to derive the impact ARF×RF value and surrogate material that was used in the test was free flowing (i.e., having no cohesion), which is not representative of plutonium oxide. While the floor at PF-4 and the plutonium oxide may behave differently than the materials and apparatus used in the testing cited in DOE Handbook 3010-94, the staff team concludes that aerosolization of MAR after being impacted remains credible.

The staff team agrees that the ARF×RF value used for the spill part of the accident progression is conservative. However, the DSA does not separately analyze any MAR being impacted by large, non-seismically qualified equipment (e.g., other gloveboxes, drop boxes, trolley lines) after it has been spilled out of the glovebox from a seismic event and is lying uncontained on the PF-4 floor. Given that the DSA determined the mitigated dose consequences for the post-seismic fire scenario to be just below the Evaluation Guideline, any additional insult to the MAR in PF-4 likely would cause the mitigated dose consequences to exceed the Evaluation Guideline, requiring additional safety class controls or additional modifications to MAR limits.

The staff team also recognizes that, in addition to reducing the first floor MAR limit, LANL has upgraded the support stands for gloveboxes that house molten plutonium operations to survive the evaluation-basis seismic event. However, LANL has not evaluated how this upgrade and new MAR limit impact the mitigated dose consequences to the public. For the glovebox stand upgrades, it is unclear to the staff team if the fire hazard in molten plutonium operations rooms would be eliminated, given that there are pyrophoric materials in these rooms that could initiate a room fire. In addition, the DSA notes that even if a glovebox does not topple, the seismic vibration of the glovebox will suspend some powder. For the new first floor MAR limit, LANL has not updated the DSA to reflect which material (weapons grade plutonium-equivalent or heat source plutonium) or material form (e.g., bulk powder, metal) would be reduced; these factors strongly influence the resulting accident consequences. LANL also has not evaluated how the new reduced first floor MAR limit impacts the apportionment of MAR among the laboratory rooms; this will also impact the calculated accident consequences.

Appendix B: Inappropriate Dose Conversion Factors for Heat Source Plutonium Oxides

The staff team found that the Los Alamos National Laboratory (LANL) Plutonium Facility (PF-4) documented safety analysis (DSA) [5] is misapplying dose conversion factors to certain forms of heat source plutonium (HS-Pu) materials, resulting in underestimated dose consequences. Specifically, the staff team found that the application of a dose conversion factor associated with a Type S lung clearance value for certain forms of HS-Pu oxide was not technically supported. Additionally, the staff team found that the application of an intermediate (between Type S and Type M) dose conversion factor for certain other forms of HS-Pu was also not technically supported. The staff team believes that weaknesses in LANL's implementation of quality assurance processes contributed to this issue.

For the purposes of calculating dose consequences, radiological material is classified as Type S (slow), Type M (moderate), and Type F (fast). These categories are based on the biokinetics of how quickly inhaled aerosolized material is absorbed into the bloodstream. A faster rate of absorption corresponds to a higher dose conversion factor. For HS-Pu, the dose conversion factor for Type M is 2.875 times greater than Type S.

International Commission on Radiological Protection (ICRP) Publication 71 [18] documents numerous studies on the biological effects of plutonium-238 oxides ($^{238}PuO_2$), including worker exposure cases and experimental studies investigating $^{238}PuO_2$ lung retention in dogs. ICRP-71 found that some of the data was more consistent with Type S material behavior and some more consistent with Type M. Table B.1 presents the ICRP's interpretation of several studies documenting inhalation of $^{238}PuO_2$ in humans and dogs.

Table B.1: ICRP-71 Guidance on Heat Source Plutonium	
Type M	**Type S**
"…lung retention and absorption to blood of **^{238}Pu [plutonium-238] in dogs** inhaling the dioxide form (Mewhinney and Diel, 1983; Park *et al.,* 1986a,b) **were consistent with Type M**. Similarly, workers inhaling purported oxide or "ceramic" forms of ^{238}Pu showed urinary excretion patterns leading to inferred lung retention patterns also **indicative of Type M** (Guilmette *et al.* 1994; Hickman *et al.* 1995) [emphasis added]."	"…some cases of exposure to ^{238}Pu oxide have been more consistent with data from **workers exposed** to $^{239}PuO_2$, i.e. **more consistent with Type S** solubility (Fleming and Hall, 1978; Newton et al., 1983) [emphasis added]."

Notably, paragraph 70 of ICRP-71 states, "Studies of common chemical forms showing characteristics of absorption Types M and S have been found in the literature. A default Type M is recommended for use in the absence of specific information...."

In March 2018, LANL personnel issued a report [19], written by members of LANL's internal dosimetry team, that detailed worker exposures to inhaled heat source plutonium over the past 20 years. The report analyzed how well biokinetic models (including, but not limited to the ICRP Type S and Type M models) correspond to exposure data. The report determined that none of the biokinetics models should be ruled out as unimportant when describing future intakes. By weighting posterior probabilities by the committed effective dose, LANL concluded that 85 percent of the total dose from the exposure incidents examined corresponded to models Type M or larger. When excluding a March 2000[5] incident, the LANL report found that models with dose coefficients of Type M and larger are approximately 47 percent probable.

On July 18, 2018, the staff team conducted a teleconference with the site to discuss how LANL addressed the information from ICRP and its own biokinetics report with respect to the dose conversion factors used in the PF-4 DSA. Subsequent key developments include:

- On July 19, 2018, LANL safety basis personnel entered the new information process indicating that Type M is most appropriate for $^{238}PuO_2$ material not heated to 800°C.
- On August 15, 2018, LANL declared a potential inadequacy of the safety analysis for this issue. As a result, it implemented an operational restriction to apply the Type M conversion factor for calculating compliance with the material-at-risk limits for forms of $^{238}PuO_2$ that had not been heated to 800°C.
- On August 30, 2018, LANL safety basis personnel notified PF-4 management that the unresolved safety question determination was positive [20].
- On December 14, 2018, LANL submitted an evaluation of the safety of the situation (ESS) [21], which the National Nuclear Security Administration Los Alamos Field Office approved on March 1, 2019 [22].

Technical Concerns with the ESS—The ESS concluded that HS-Pu oxides at PF-4 that have been heated above 800°C for a least two hours will continue to be categorized as Type S. Additionally, the ESS concluded that an intermediate solubility class (between Type S and Type M) would be applied to certain other forms of HS-Pu that have not been heated to 800°C. The staff team identified flaws in the technical arguments supporting both of these conclusions.

The ESS references a study by Park [23] as the basis for establishing the 800°C threshold for applying the intermediate solubility class. The Park report presents measured lung retention as a function of time for dogs that were exposed to $^{238}PuO_2$ through inhalation. Based on their review of the Park data, LANL safety basis personnel concluded that the $^{238}PuO_2$ material used in the experiments (i.e., heated to 800°C for two hours) exhibited behavior consistent with Type S material. They based this conclusion on a determination—without documenting their rational—that the Park data demonstrated a 50 percent retention time of 400 days.

Annexe D of ICRP-71 provides guidance for assigning lung clearance types to radionuclides based on experimental data. Figure D.2 in ICRP-71 establishes regions for assigning lung clearance types to experimental data of lung retention behavior. Figure B-1 below overlays Park's fit of the experimental data (initial lung burden [ILB]) with Figure D.2 of

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[5] Data collected from the March 2000 event correlates to the most conservative model (ICD, a LANL-derived model); however, the LANL report excludes the event in its conclusion stating, "… the March 2000 incident resulted in more than two-thirds of the ^{238}Pu inhalation population doses between 1997 and 2017."

ICRP-71. The resulting figure with the corresponding trend line demonstrates that 50 percent lung retention occurs at 134 days, which the ICRP guidance indicates is consistent with Type M material.

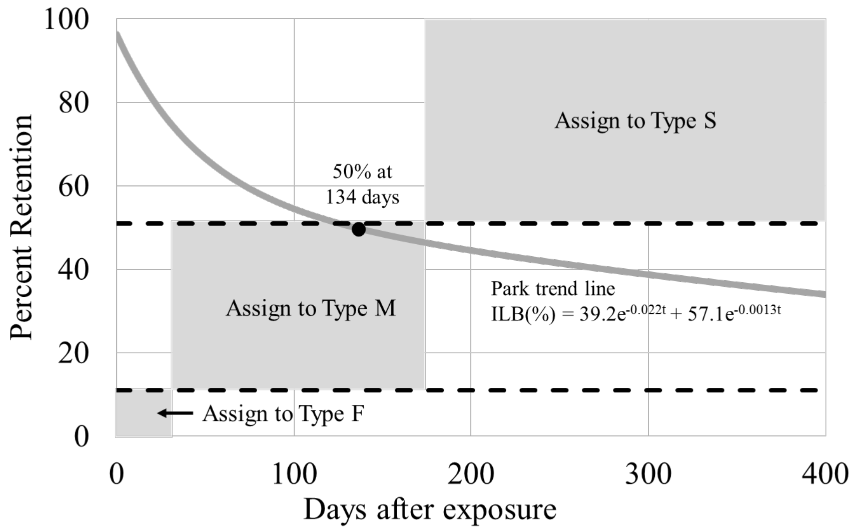

Figure B-1. *ICRP-71 Annexe D.2 Recommended Assignments against Park's Data*

The staff team is also concerned that LANL has not provided a technical basis for the application of the intermediate dose conversion factor to other forms of HS-Pu including oxalates, non-fired granules, and hydroxide cakes. ICRP does not provide guidance for ^{238}Pu in these forms nor does it relate their solubility characteristics to ^{238}Pu oxides. Without a firm technical basis, the staff team believes that LANL should be using ICRP's recommended default of Type M.

Weaknesses in the Quality Assurance Processes for the ESS—The staff team has the following concerns related to quality assurance processes used in the ESS:

- The ESS does not indicate a formal review signature by subject matter experts (e.g., health physicists, actinide chemists). In the staff team's opinion, the ESS was of a sufficiently specialized technical nature that would warrant such a review. Alternatively, the staff team notes that LANL should have applied its procedure for calculations supporting safety bases [24]. This procedure implements requirements from Subpart A of 10 Code of Federal Regulation 830, *Nuclear Safety Management*, to ensure appropriate review and documentation of analyses that support the safety basis.

- The ESS states that data collected from the Park report indicates a retention half-time of 400 days for $^{238}PuO_2$ to leave the lungs, thus demonstrating Type S behavior. However, the ESS does not provide or reference documentation demonstrating how LANL safety analysts arrived at this 400-day retention time. Adherence to LANL's calculation procedure may have identified this concern.

- The ESS references the written professional opinion of the LANL internal dosimetry team [25] multiple times to support the conclusion that an intermediate dose conversion factor (between Type S and Type M) should be used for HS-Pu oxide that has not been heated to 800°C for two hours. While representatives of the internal dosimetry team verbally agreed with this conclusion during the April 18, 2019, teleconference, their report does not mention firing temperatures or times. The staff team believes that the report referenced by the ESS does not substantiate the conclusion in the ESS and that the review process for the ESS should have identified this concern.

Appendix C: Inappropriate Compensatory Measures for Deficient Systems

The Los Alamos National Laboratory (LANL) Plutonium Facility (PF-4) documented safety analysis (DSA) [5] identifies deficiencies in several safety systems that are part of the post-seismic fire control strategy, including the fire suppression system, glovebox system, and components of the active confinement ventilation system. For each deficiency, the safety basis lists a compensatory measure. However, the Defense Nuclear Facilities Safety Board's (Board) staff team found that the compensatory measures do not always ensure that the systems would be able to perform their intended safety function or that the hazards they are credited to protect against would be prevented or mitigated. Therefore, the overall safety control strategy may not provide adequate protection to the public or workers.

Fire Suppression System—Table C.1 lists the deficiencies and compensatory measures for the fire suppression system. These deficiencies prevent the fire suppression system from meeting its functional requirement of providing sufficient water flow and volume to the PF-4 sprinklers during and after a performance category (PC)-2 seismic event. For example, collapse of a seismically unqualified building connected to the fire water loop may prevent the fire suppression system from delivering adequate water to a fire in PF-4.

Table C.1: Fire Suppression System Deficiencies and Compensatory Measures

Deficiency	Compensatory Measures	Staff Team Assessment
Seismically unqualified buildings and components connected to the underground fire water main.	Check valves to isolate non-seismically rated structures or components from the PF-4 fire suppression system, with operator actions to close bypass valves if needed. Off-normal operating procedures (i.e., alarm responses, abnormal operating procedures).	Both compensatory measures rely on human action following a seismic event. Depending on human action is not as reliable as engineered controls.
Seismic interaction concerns for various portions of the fire suppression system.	Reduced material-at-risk (MAR) limit for first floor and vault.	Reduction in MAR is appropriate to reduce the potential consequences. However, LANL has not specified which material would be reduced. The material dispersibility and chemical form have a major impact on potential dose consequences

While the compensatory measures for the seismically unqualified buildings and components are reasonable for the PC-2 seismic event, the deficiencies prevent LANL from upgrading the fire suppression system to safety class and meeting PC-3 seismic criteria. LANL identified the need for this upgrade in 2006 and has planned this upgrade since 2009 [9] as part of an expanded suite of controls for the post-seismic fire scenario. For the compensatory measure for the seismic interaction concerns, the staff team agrees that a reduction in MAR is an appropriate compensatory measure to reduce the potential accident consequences. However, LANL safety analysts have not specified which material would be reduced in the technical safety requirements. Material dispersibility and chemical form have a major impact on dose consequences and will strongly affect the effectiveness of this compensatory measure.

Glovebox System and Support Stands—Table C.2 lists the deficiency and compensatory measure for the glovebox system and support stands. This deficiency prevents the glovebox system from performing its safety function of providing confinement to material in the glovebox under accident conditions. For example, during a seismic event, gloveboxes that do not meet the appropriate performance category requirements could topple and spill their contents. LANL has also recognized the need to remedy this deficiency since at least 2006.

Table C.2: Ventilation System Deficiencies and Compensatory Measures

Deficiency	Compensatory Measures	Staff Team Assessment
Not all glovebox support stands meet PC-2 criteria.	Seismic power shutoff system, which cuts off power to laboratory gloveboxes in the event an earthquake of sufficient magnitude.	Seismic shutoff switch eliminates a potential ignition source during and after a seismic event, but does not assist the gloveboxes in meeting their safety function of not toppling during a seismic event.

As a compensatory measure for this deficiency, the DSA lists the seismic power shutoff system, which cuts off power to laboratory gloveboxes in the event of an earthquake of sufficient magnitude. The staff team recognizes that the seismic shutoff switch eliminates a potential ignition source during and after a seismic event. However, this compensatory measure does not assist the gloveboxes in meeting their intended safety function.

Ventilation System—Table C.3 lists the deficiencies and compensatory measures for the ventilation system. These two deficiencies prevent the ventilation system from performing its safety function of providing confinement to material under accident conditions. The ventilation system would not be able to ensure that airborne radioactive material was drawn through the high-efficiency particulate air (HEPA) filters in the event of a design basis seismic accident.

Table C.3: Ventilation System Deficiencies and Compensatory Measures		
Deficiency	**Compensatory Measures**	**Staff Team Assessment**
Ductwork and components of the system that are not qualified to survive a PC-2 seismic event.	Reduced MAR limit for first floor.	Reduction in MAR is an appropriate way to reduce the potential consequences. However, LANL has not performed an analysis on how the MAR reduction compensates for the seismic deficiencies.
Current fire analysis reflects a peak room temperature that exceeds the downstream HEPA filter rating.	For single room fire, the fire suppression system will reduce the temperature below the HEPA filter rating. For a post-seismic fire, seismic power cutoff switch will reduce ignition sources and reduce the likelihood of fires.	The compensatory measures for a post-seismic fire will not necessarily protect the HEPA filters from heat damage. This deficiency will need to be resolved for the system to be credited to function for a post-seismic fire.

The staff team agrees that a reduction in MAR is an appropriate compensatory measure to reduce the accident consequences resulting from the seismically unqualified ductwork and components deficiency. However, LANL has not performed an analysis of the degree to which the MAR reduction compensates for the ventilation system deficiencies for a PC-2 seismic event. The compensatory measures for a post-seismic fire will not necessarily protect the HEPA filters from heat damage, but this point is likely moot since the ventilation system is not expected to function following a seismic event. Notwithstanding these deficiencies, LANL has recognized the need to upgrade some of the active ventilation system to meet PC-3 seismic standards and safety class requirements since 2006.

Project Execution Strategy—LANL developed the initial Technical Area (TA)-55 Project Execution Strategy (PES) [10] as part of the Department of Energy's response to Board Recommendation 2009-2, *Los Alamos National Laboratory Plutonium Facility Seismic Safety* [26]. The PES is an annually updated document that describes the scope, budget, and path forward for a set of upgrades, modifications, and maintenance activities at PF-4 that are necessary to achieve a further reduction of the mitigated dose consequences to the public for seismically induced events. The projects listed in the PES are intended to resolve the deficiencies discussed above.

Over the past several years, LANL has been completing projects listed in the PES, which is discussed in the current revision [11]. These projects include analyzing the seismic capability for components of safety systems and making seismic upgrades to PF-4's structure, ventilation system, glovebox support stands for gloveboxes that contain molten plutonium operations, and electrical distribution system. However, upgrades to several of the key safety systems have experienced delays due to unexpected engineering challenges, funding and scope perturbations in line item projects, and reprioritizations for emergent scope as the facility seismic analyses progressed (see Table C.4). These systems are essential to LANL's safety control strategy for post-seismic fires.

Table C.4: Changes in Estimated Completion Schedule† for Safety System Upgrades

Safety System	***Safety System Upgrade Benefits***	***2011 Baseline* [10]**	***2019 Update* [11]**
Laboratory Fire Barriers	Limit fires from spreading between laboratory rooms.	2015	2021
Fire Suppression Seismic Upgrades	Limit fires from spreading between laboratory rooms, reduce the intensity of fire, and potentially reduce the LPF for the post-seismic fire event.	2013	2024
Active Confinement Ventilation	Reduce LPF and reliance on passive confinement during seismic event.	2020	2025
Remove Seismically Unqualified Buildings for Firewater Main	Ensure water supply to fire suppression system after a seismic event.	2022	2026
† Completion schedule is based on fiscal year			

In addition to these delays, the National Nuclear Security Administration (NNSA) has changed the scope of the TA-55 Reinvestment Project, which supports two of the key projects listed on the PES. In particular, NNSA de-scoped the projects that would upgrade the fire suppression system to safety class and the ventilation system to an active confinement safety class ventilation system. As previously mentioned, both NNSA and the LANL contractor have acknowledged that both of these upgrades are necessary to reduce the off-site dose to the public since 2006 [27]. LANL now envisions supporting these projects through operating funds that are subject to potential yearly competing demands. This change has also resulted in additional years of delay.

As part of a TA-55 reinvestment project, NNSA planned to remove non-seismically qualified buildings from the safety class underground fire water main. However, on June 22, 2016, NNSA approved removing the fire water main scope from this project [28]. Through subsequent analysis, LANL determined that the best method for addressing this vulnerability would be to extend a high pressure domestic main from TA-48 to provide suppression water to the non-seismically qualified buildings. These buildings would then be completely separated from the TA-55 safety class underground fire water main. LANL preferred this alternative because it requires little work on the existing safety class system and should provide sufficient pressure and flow to preclude the need for new fire pumps for the non-seismically qualified facilities. LANL informed the staff team that it is developing a project plan to execute this strategy, but does not expect to complete the project until fiscal year 2026. In the first iteration of the PES [10], LANL expected to have a safety class fire suppression system for PF-4 by 2022.

The TA-55 reinvestment project also planned for line-item funding to upgrade the ventilation system to meet safety class requirements. However, in the same June 22, 2016, document [27], NNSA approved removing the active confinement ventilation system scope from the reinvestment project. LANL is addressing this deficiency by implementing a series of small modifications to improve the robustness of the ventilation system that do not require line-item funding. For example, LANL has completed upgrades to passive components of the bleed-off system to reduce the potential for releases from PF-4. Specifically, LANL modified anchorage of the safety significant bleed-off ductwork to meet PC-3 seismic requirements. LANL also has developed a seismic equipment list outlining everything that LANL needs to address to support a safety class ventilation system. LANL plans to use the list to determine which components of the ventilation system meet safety class requirements and prioritize the components that need to be upgraded. LANL expects to complete the ventilation system modifications in fiscal year 2025. In the first iteration of the PES, LANL expected to have a safety class ventilation system by 2020.

After annually revising the PES, the LANL contractor submits it to NNSA's Los Alamos Field Office (NA-LA) for information. From discussions with NA-LA, the staff team determined that NA-LA does not perform oversight of the PES with respect to the identified projects, priorities, or funding sources. In addition, as discussed above, the projected completion date for each project continues to slip almost every year. Therefore, the staff team is concerned that LANL and NNSA may again delay or de-scope the projects, and PF-4's safety systems will continue to be deficient.

References

[1] Los Alamos National Laboratory, *TA-55 Documented Safety Analysis*, TA55-DSA-2014-R2, Revision 2.0, Los Alamos National Laboratory, Los Alamos, NM, July 2017.

[2] Los Alamos National Laboratory, *TA-55 Technical Safety Requirements (TSRs)*, TA-55-TSR-2014-R2, Revision 2.0, Los Alamos National Laboratory, Los Alamos, NM, August 2017.

[3] Los Alamos National Laboratory, *TA-55 Documented Safety Analysis*, TA55-DSA-2016-R0, Revision 0, Los Alamos National Laboratory, Los Alamos, NM, October 2016.

[4] Los Alamos National Laboratory, *TA-55 Technical Safety Requirements (TSRs)*, TA-55-TSR-2016-R0, Revision 0, Los Alamos National Laboratory, Los Alamos, NM, October 2016.

[5] Los Alamos National Laboratory, *TA-55 Documented Safety Analysis*, TA55-DSA-2018-R0, Revision 0, Los Alamos National Laboratory, Los Alamos, NM, August 2018.

[6] Los Alamos National Laboratory, *TA-55 Technical Safety Requirements (TSRs)*, TA-55-TSR-2018-R0, Revision 0, Los Alamos National Laboratory, Los Alamos, NM, August 2018.

[7] Department of Energy, *Preparation Guide for U.S Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, DOE Standard 3009-94, Change Notice 3, Washington, DC, March 2006.

[8] Department of Energy, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, DOE Standard 3009-2014, Washington, DC, November 2014.

[9] Los Alamos National Laboratory, *SSUP* [Safety System Upgrade Project] *Project Implementation Plan*, Revision 0, Los Alamos National Laboratory, Los Alamos, NM, March 2009.

[10] Los Alamos National Laboratory, *TA-55 Project Execution Strategy*, TA55-PES-11-001, Revision 0, Los Alamos National Laboratory, Los Alamos, NM, August 2011.

[11] Los Alamos National Laboratory, *TA-55 Project Execution Strategy*, TA55-PES-11-001, Revision 7, Los Alamos National Laboratory, Los Alamos, NM, December 2018.

[12] Defense Nuclear Facilities Safety Board, *Los Alamos National Laboratory Plutonium Facility Leak Path Factor Methodology*, Technical Report 44, Washington, DC, November 12, 2019.

[13] Los Alamos National Laboratory, *Update of Accident Analysis Calculations and the TA-55 DSA and TSR to Meet DOE-STD-3009-2014*, PLAN-TA55-525-R3, Revision 3, Los Alamos National Laboratory, Los Alamos, NM, July 2019.

[14] Los Alamos National Laboratory, *TA-55 Seismic Spill and Fire Aerosolized Material Model*, SBD-CALC-TA55-12-017-R1, Revision 1, Los Alamos National Laboratory, Los Alamos, NM, September 2013.

[15] Los Alamos National Laboratory, *TA-55 Documented Safety Analysis Addendum in Response to Nonlinear Analysis Results*, TA-55-DSA-2011 Addendum 1-R1, Revision 1, Los Alamos National Laboratory, Los Alamos, NM, January 2013.

[16] Los Alamos National Laboratory, *ARF×RF for Powders in TA55 DSA Seismic Event Impact/Spill*, TA55-NI-2293, Los Alamos National Laboratory, Los Alamos, NM, May 2018.

[17] Department of Energy, *Airborne Release Fractions/Rate and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE Handbook 3010, Washington, DC, December 1994.

[18] International Commission on Radiological Protection, *Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part 4 Inhalation Dose Coefficients*, ICRP Publication 71, Ottawa, Ontario, Canada, September 1995.

[19] Poudel, D., Waters, T., Klumpp, J., and Bertelli, L., *Biokinetics of Inhaled 238Pu at Los Alamos National Laboratory: Analysis of Intakes in the Last Two Decades*, LA-UR-18-22690, Los Alamos National Laboratory, Los Alamos, NM, 2018.

[20] Los Alamos National Laboratory, *Pu-238 Solubility Class for PuO2*, Revision 0, Los Alamos National Laboratory, Los Alamos, NM, August 2018.

[21] Los Alamos National Laboratory, *Plutonium-238 Dioxide Solubility*, ESS-TA55-122-R0, Revision 0, Los Alamos National Laboratory, Los Alamos, NM, December 13, 2018.

[22] National Nuclear Security Administration Los Alamos Field Office, *Technical Area 55 – Approval of ESS-TA55-122-R0, Plutonium-238 Dioxide Solubility*, Los Alamos, NM, March 2019.

[23] Park, J. F., *Inhaled Plutonium Oxide in Dogs*, PNL-7200 Pt. 1, Pacific Northwest Laboratory Annual Report for 1989 to the DOE Office of Energy Research, Richland, WA, May 1990.

[24] Los Alamos National Laboratory, *Calculations*, AP-341-605, Revision 3, Los Alamos National Laboratory, Los Alamos, NM, June 2013.

[25] Memorandum from J. Hoffman to J. Johnson, *Professional Opinion on Solubility of 238Pu-oxides*, RP-SVS-18:011, Los Alamos National Laboratory, Los Alamos, NM, November 5, 2018.

[26] Defense Nuclear Facilities Safety Board, *Recommendation 2009-2, Los Alamos National Laboratory Plutonium Facility Seismic Safety*, Washington, DC, October 26, 2009.

[27] Los Alamos National Laboratory, *PF-4 Ventilation System Evaluation: Deliverable 8.5.4 and 8.7 of the DNFSB Recommendation 2004-2*, FOD-TA-55: (U) 06-039, November 2006.

[28] National Nuclear Security Administration, *Scope of Analysis of Alternatives (AoA) for Technical Area 55 Reinvestment Project, Phase III (TRP III) at the Los Alamos National Laboratory*, June 2016.