DEFENSE NUCLEAR FACILITIES SAFETY BOARD
Washington, DC 20004-2901

November 2, 2021

The Honorable Jennifer Granholm
Secretary of Energy
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Secretary Granholm:

The Defense Nuclear Facilities Safety Board (Board) considered your office's February 25, 2021, response and the briefing your staff provided on April 28, 2021, regarding Recommendation 2012-1, *Savannah River Site Building 235-F Safety*. The Board is encouraged by the progress made toward improving the safety posture at Building 235-F, including removal of combustibles, ignition sources, and some material-at-risk. However, the Building 235-F safety basis still contains deficiencies that make it inconsistent with Department of Energy (DOE) standards.

The Board believes that bringing the safety basis into compliance with DOE standards would require upgrading key elements of the fire protection program to a specific administrative control and may include upgrading defense-in-depth controls such as the E-5 ventilation system and sand filter to safety significant. Classifying this ventilation system as safety significant would provide continued assurance of worker safety across the range of accident scenarios.

To further improve the safety posture of Building 235-F, DOE should consider expanding the structural integrity program and continuing inspections during long-term safe storage. Finally, the Board encourages DOE to ensure that Building 235-F deactivation and decommissioning activities are completed expeditiously to reduce the risk posed by legacy hold-up material.

Given the concerns described in the attached report and pursuant to 42 United States Code § 2286b(d), the Board requests an annual briefing and report on (1) progress made to deactivate and decommission Building 235-F; (2) results of radiological surveys and inspections to verify that contamination is not spreading; (3) status and schedule for establishing a final end state determination with regulatory authorities; (4) results of structural integrity inspections, and

any corrective actions identified and implemented from these inspections; and (5) any changes to the status of the E-5 ventilation system and sand filter, including any maintenance activities performed. This reporting requirement amends and supersedes previous reporting requirements on Building 235-F.

Sincerely,

Joyce L. Connery

Joyce L. Connery
Chair

Enclosure

c: Mr. Michael Budney
Mr. Joe Olencz

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Report

Date: July 27, 2021

Review of Savannah River Site's Building 235-F Safety Basis

Summary. The Defense Nuclear Facilities Safety Board (Board) identified safety concerns related to the hazards associated with plutonium-238 (Pu-238) hold-up material in Building 235-F at the Savannah River Site (SRS), which is scheduled for deactivation within the next two years.

The Board issued Recommendation 2012-1, *Savannah River Site Building 235-F Safety,* on May 9, 2012, which documented these concerns and recommended several actions the Department of Energy (DOE) should take to improve the Building 235-F safety posture. In response, DOE developed a recommendation implementation plan and completed actions to improve the safety of Building 235-F, including removing some material-at-risk (MAR). DOE recently stated that it had completed all recommendation implementation plan actions and ceased MAR removal activities. DOE did not remove all MAR from Building 235-F. Further, DOE recently downgraded existing safety controls in response to a revised accident analysis.

The Board's staff team reviewed DOE's revised implementation plan and its current approach to controlling hazards in Building 235-F. During its review, the Board's staff team identified that the safety basis inappropriately screens out credible accident scenarios and uses non-conservative assumptions in the hazards and accident analyses. The use of these non-conservative assumptions is somewhat mitigated by several conservative assumptions used in the analyses. However, the safety basis does not provide any quantitative calculations or evidence suggesting that the overall conservatism of the accident analysis outweighs the non-conservatisms. To provide perspective, the Board's staff team calculated what the dose consequences would be if the non-conservatisms were addressed in the safety basis. The resulting analysis demonstrated that several accidents could exceed DOE's 100 rem dose consequence threshold to the co-located worker.

Building 235-F has several defense-in-depth controls (e.g., sand filter and fire protection program) that would help mitigate or prevent some accidents. The Board's staff team believes that these controls should be elevated to safety-significant due to their importance to the safety basis. This approach would account for uncertainties in the accident analysis and would be consistent with DOE directives. However, it is important to note that Building 235-F is undergoing deactivation, so the time at risk for the remaining MAR is short compared to typical operating facilities. Accordingly, if DOE does not choose to upgrade controls to safety-significant, it should ensure deactivation and decommissioning activities are expedited and not delayed.

Further, DOE should expand the structural integrity program to require inspection of non-safety structures, systems, and components (SSCs), and ensure that the program is implemented

with the same level of rigor during long-term safe storage as it will be during deactivation. Maintaining the structural integrity program is important as inspections could identify potential corrosion issues, which could lead to overhead components falling and impacting process enclosures, potentially leading to the spread of radioactive contamination. Additionally, an expanded structural integrity program will help ensure that the seismic impact ratio used in the accident analysis remains reasonably conservative.

Background. Building 235-F at SRS was constructed in the 1950s and was used primarily for plutonium and neptunium component production until the 1980s. In 2006, DOE terminated the last remaining mission of storage, surveillance, and repackaging of special nuclear material and removed most of the material. However, the building still contains residual holdup—the majority of which is in the form of Pu-238 located in the Plutonium Fuel Form (PuFF) Facility. The Board was concerned with the hazards remaining in Building 235-F and issued Recommendation 2012-1, *Savannah River Site Building 235-F Safety,* on May 9, 2012, which included the following three sub-recommendations [1]:

- ***Sub-Recommendation 1.*** Take action to immobilize and/or remove the Pu-238 that remains as residual contamination within Building 235-F.

- ***Sub-Recommendation 2.*** Take near-term actions and implement compensatory measures to improve the safety posture of Building 235-F and reduce the potential for and severity of a radiological release.

- ***Sub-Recommendation 3.*** Take actions to ensure that the SRS emergency response to a radiological release from Building 235-F is adequate and effective.

DOE issued its original Implementation Plan for Recommendation 2012-1 on December 5, 2012 [2]. Subsequently, DOE completed a number of risk-reduction actions, including removing facility MAR, combustibles, and ignitions sources. In May 2020, DOE developed a revised implementation plan outlining significant changes to the overall strategy used to address the hazards in Building 235-F [3]. Specifically, the revised implementation plan focused on eliminating fire risks instead of removing additional MAR. Further, DOE ceased MAR removal activities and downgraded existing safety controls in response to a revised accident analysis.

On June 22, 2020, DOE sent a letter to the Board, stating that DOE "has completed all actions identified in the Department's May 2020, revised Implementation Plan in response to the DNFSB Recommendation 2012-1" [4]. On December 23, 2020, the Board responded to DOE, noting positive improvements to reduce the risks at Building 235-F [5]. However, the Board stated, "Upon review, the Board believes that halting MAR removal is acceptable as long as the revised implementation plan is updated to ensure that Building 235-F's E5 ventilation system and sand filter are maintained as safety significant equipment, including retention of the technical safety requirements for sand filter efficiency, during the facility's deactivation period."

On February 25, 2021, DOE responded to the Board that, "DOE intends to ensure that the next revision of the Documented Safety Analysis (DSA) and supporting documentation

appropriately document the technical basis for the performance characteristics and safety classification of the Building 235-F ventilation system" [6].

Staff Review—Throughout 2020 and 2021, the Board's staff team reviewed DOE's and Savannah River Nuclear Solutions' (SRNS) approaches to addressing Board Recommendation 2012-1 and revisions 4 and 5 of the Building 235-F safety basis. The staff team also held multiple meetings with personnel from the SRS Operations Office and SRNS to discuss the Building 235-F safety basis and control strategy.

This report documents the results of the Board's staff team's review and identifies deficiencies with the Building 235-F safety basis that may impact the credited control set used to protect the worker.

Discussion. The Board's staff team identified several safety items during its review of the Building 235-F safety basis. These include: (1) Inappropriate analysis of fire scenarios, (2) Non-conservative analysis of seismic events, (3) Non-conservative selection of lung absorption class, and (4) Concerns with the overall conservatism of the accident analysis. These safety items are described in more detail throughout this report.

Inappropriate Analysis of Fire Scenarios. Revision 5 of the Building 235-F basis for interim operation (BIO) inappropriately relies on non-credited initial conditions to screen out fire scenarios impacting hold-up MAR from further analysis. As a result, the BIO circumvents the control selection process, which is inconsistent with DOE directives.

Background—The Building 235-F BIO states that a fire impacting locations where residual hold-up MAR is present is not credible. Specifically, the BIO states, "It was determined that full facility fires, regardless of origin including the DBE [design basis evaluation], are considered not credible due to low combustible loading and lack of continuity of combustibles in the enclosure rooms and within the process enclosures where the MAR is being confined. While operational fires in the facility are still credible, the spread of such fires throughout the facility or the capacity to release holdup MAR confined in enclosures is not credible due to facility conditions that are maintained through facility procedures and processes" [7].

During discussions with the Board's staff team, DOE clarified that it believes "there is no potential to physically support the development of a fire intense enough to involve the MAR" and that this conclusion is supported by two independent evaluations: SRNS-RP-2019-00698, *Building 235-F Evaluation of the Current Status of the Facility*, [8] and SRNS-TR-2019-00378, *Report on the Peer Review of the SRS 235-F Fire Hazard and Risk Technical Evaluation*, [9].

SRNS-RP-2019-00698 states, "The purpose of this evaluation is to determine if a single seismic event can result in five (5) separate fires within the facility that collectively could result in the release of an unacceptable level of Material at Risk (MAR); 100 REM to site employees. Five (5) simultaneous fires after a seismic event are not likely, but there is no technical basis to rule-out a single event with multiple fires." Further, this report concludes, "Based on the walk down and a review of the documents referenced below, in my opinion if the suggestions found in Section 8.3 are implemented, the chances of a fire impacting MAR after a seismic event are not

plausible. Due to the low level of combustibles, lack of continuity, and established combustible control programs [*sic*]."

SRNS-TR-00378 peer reviewed SRNS-RP-2019-00698, and concluded:

[T]he overall risk of a fire propagating throughout the SRS 235-F facility is low based on the following factors:

- *The facility has a low combustible loading, with potential exceptions noted in this report (5.1.9 and 5.1.10);*
    - *The combustible loading will be further reduced by the planned removal of ceiling tiles and plastic light diffusers from the facility;*
- *The facility has a high degree of compartmentation that reduces the potential for multi-compartment fire spread;*
- *The facility is windowless concrete structure that will not have sufficient ventilation to support a post-flashover fire;*
- *The facility has early warning smoke and heat detection that is monitored at a constantly attended location;*
- *It is assumed that emergency responders are properly and adequately trained and equipped to respond quickly and efficiently to fire alarms received from the facility.*

Board's Staff Team Analysis: Inappropriate Initial Conditions—Both fire protection reports [8], [9] provide a realistic snapshot of the current fire risk at Building 235-F. However, these reports would more appropriately serve as inputs into the fire hazards analysis and should not be used alone to rule out hazard scenarios in the safety basis. DOE directives explicitly prohibit consideration of many of the assumptions relied upon for the reports' conclusions during development of the unmitigated analysis in the safety basis. Specifically, the reports implicitly rely on combustible controls and the fire protection program as initial conditions and they assume non-credited controls will perform credited safety functions.

In the unmitigated analysis, it is inappropriate to credit combustible controls or other key elements of the fire protection program, even if they are elevated to a specific administrative control (SAC)[1]. DOE Standard 3009-94, which is the version cited in the SRNS contract, states, "the concept of 'unmitigated release' was developed to conservatively estimate the consequence potential from the candidate DBAs [design basis accidents] that are selected from the hazard analysis **without taking credit for any safety features**" [emphasis added].

[1] The staff notes that Revision 5 of the BIO does not credit combustible controls as a SAC.

DOE Standard 3009-14, which clarifies the requirements of DOE Standard 3009-94, is even clearer on this topic, and states, "The following conditions shall not be assumed to be available for unmitigated analysis…ACs [administrative controls] or safety management programs in the unmitigated analysis. For example, **combustible controls may not be used as an initial condition** to show that a full facility fire is not plausible" [emphasis added]. "ACs, such as combustible controls, that are elevated to a SAC as an initial condition for the unmitigated analysis would circumvent the control selection process considering the hierarchy of preferences, and place greater reliance on ACs over available engineered controls."

In addition to the assumptions regarding initial conditions, the reports assume non-credited controls will perform a credited safety function. Specifically, SRNS-TR-00378 states that the overall risk of a fire propagating is low based on "a high degree of compartmentation that reduces the potential for multi-compartment fire spread." However, these compartments are not credited as safety-significant design features rated to survive the accident. This approach is inappropriate for safety bases and is inconsistent with DOE Standard 3009-14, which states, "An assumption that an SSC exists does not automatically require SC [safety class] or SS [safety significant] designation. However, assumptions shall be protected at a level commensurate with their importance. For example, **if a passive barrier is assumed to survive a fire that would otherwise lead to a significant consequence, then the barrier's configuration would need to be protected as a TSR [technical safety requirement] design feature**" [emphasis added]. The SRNS report also mentions low combustible loading, early warning smoke/heat detection, and emergency response, but these controls are not credited in the BIO to perform a safety function and should not be used as an initial condition.

Board's Staff Team Analysis: Inappropriate Exclusion of Fire Scenarios—The Building 235-F BIO screens fire scenarios from impacting hold-up MAR in a manner that is inconsistent with DOE directives. Specifically, DOE directives provide guidance and requirements for excluding operational accidents. DOE Standard 3009-94 states, "There is no predetermined frequency cutoff value, such as 1E-6 per year, for excluding low frequency operational accidents (i.e., internally initiated)," where the definition of internally initiated includes "fires, explosions, spills, criticality."

This point is further clarified in DOE Standard 3009-14, which states, "For hazard evaluation of operational accidents, use of a lower binning likelihood threshold such as 10^{-6}/yr (i.e., beyond extremely unlikely) is not appropriate and should not be used as an absolute cutoff for dismissing physically possible low probability operational accidents such as 'red oil' explosions. This distinction is made to ensure objective evaluation of hazards and identification of available preventive and mitigative controls, whether any controls warrant safety classification, and whether the accident scenario should be considered a candidate for further accident analysis as a design/evaluation basis accident. However, hazard scenarios of operational accidents that are deemed not plausible per the criteria in Section 3.2.1, 'Design/Evaluation Basis Accident Selection,' may be excluded from the hazard evaluation also."

Section 3.2.1 of DOE Standard 3009-14 states that, "An operational event is not considered plausible if it is either:

- A process deviation that consists of a sequence of many unlikely human actions or errors for which there is no reason or motive. In evaluating this criterion, a wide range of possible motives, short of intent to cause harm, should be considered. Necessarily, no such sequence of events may ever have actually happened in any nonreactor nuclear facility; or

- A process deviation for which there is a convincing argument, given physical laws, that they are not possible. The criterion cannot be used if the argument depends on any feature of the design or materials controlled by the facility's safety features or administrative controls (ACs)."

Overall, the staff team agrees that the probability of a fire impacting hold-up MAR is low. However, the Board's staff team believes that a fire impacting hold-up MAR in Building 235-F is a physically possible event that should not be screened out from further accident analysis. Further, DOE has not demonstrated that this scenario meets the operational exclusion criteria listed in DOE Standard 3009-14.

Impact to Radiological Dose Consequences—The Building 235-F BIO excludes both fires that impact all hold-up MAR and small fires that impact only a subset of MAR. This is an extremely important assumption, as a fire that impacts all hold-up MAR in the process rooms would result in postulated radiological dose consequences to the co-located worker that exceed 2600 rem. Even a small fire that impacts a subset of MAR, on the order of 5 percent of the available inventory, would result in postulated radiological dose consequences to the co-located worker that exceed 100 rem. In both scenarios, safety significant controls to protect the co-located worker should be identified, consistent with DOE directives. As noted in SRNS-RP-2019-00698, "Five (5) simultaneous fires after a seismic event are not likely, but there is no technical basis to rule-out a single event with multiple fires." Accordingly, the SRNS evaluation suggests that fires smaller than a full-facility fire should not be ruled out.

DOE Perspective and the Board's Staff Team's Response—During staff-to-staff interactions, DOE stated that it believes fires should be considered as evaluation basis accidents when significant accumulations of flammable material are exposed to fire initiators. However, in this case DOE determined that a fire large enough to breach containment and involve the hold-up MAR in Building 235-F is not physically possible based on the quantity of combustible material present. Accordingly, DOE Standard 3009 would not require it to be considered an evaluation basis accident because it is not a physically credible event. DOE's independent evaluation supports the conclusion that the probability of a fire impacting hold-up MAR is not credible.

The Board's staff team disagrees with DOE's interpretation because DOE has not credited the containment structure as a safety control to prevent fires from involving MAR. Therefore, it cannot be used as an initial condition or passive design feature to show that a fire impacting MAR is prevented. Further, DOE does not have a credited safety control to prevent accumulation of combustibles. It is inconsistent with DOE directives to assume a lack of combustibles as an initial condition.

DOE also noted that while it does not have a combustible loading SAC, it does have a robust fire protection program, and the site's unreviewed safety question process would identify tasks that would bring in significant quantities of combustibles. The staff team believes that while the unreviewed safety question process may be appropriate for identifying tasks that would intentionally bring in significant quantities of combustibles, it may not capture the slow accumulation of transient combustibles (e.g., poor housekeeping, accumulation of job control waste), and should not be relied upon in the unmitigated analysis.

Conclusion—Revision 5 of the Building 235-F BIO inappropriately screens fire scenarios impacting hold-up MAR from further analysis in the safety basis. As a result, SRNS has not identified any credited controls to prevent or mitigate this high-consequence accident. Instead, SRNS relies on several non-credited initial conditions to assume the event is not plausible (e.g., low current combustible loading, the fire protection program, and non-credited fire barriers). SRNS' approach is inconsistent with DOE directives and circumvents the control selection process described in DOE Standard 3009.

To be consistent and compliant with DOE directives, the Board's staff team believes that SRNS should perform an unmitigated analysis that assumes a fire can impact hold-up MAR. Depending on the consequences, appropriate credited controls should be derived, which may include a combustible controls SAC that is supported by a robust fire protection safety management program. If the analysis determines that the consequences to the public and/or the worker are significant, additional controls may be warranted, such as crediting the E5 ventilation system (including its sand filter). This is consistent with the defense-in-depth concept outlined in DOE directives.

If the consequences exceed DOE guidelines and the only controls derived are SACs, then a hierarchy of controls evaluation should be performed, consistent with DOE directives. Specifically, DOE Standard 3009-14, which clarifies requirements in DOE Standard 3009-94, requires that "When the hierarchy of controls is not used for situations requiring SC/SS controls (e.g., a SAC is selected over an available SSC), the DSA shall provide a technical basis that supports the controls selected."

Non-Conservative Analysis of Seismic Events. For seismic hazards without a fire, the Building 235-F accident analysis includes two separate release mechanisms: entrainment and falling objects that impact MAR. The Board's staff team believes that the accident analysis for this event should analyze three separate and unique release mechanisms: (1) seismic shaking that affects most Pu-238 material in Building 235-F, (2) falling objects that affect a subset of Pu-238 in Building 235-F, and (3) entrainment. Analyzing these three release mechanisms is consistent with previous iterations of the calculation for Building 235-F and several examples described in DOE directives. The current approach (e.g., two release mechanisms) used by SRNS reduces the amount of material impacted by a seismic event, and as a result, may underestimate the postulated radiological dose consequences to the co-located worker by more than a factor of two.

Background—Event DEACT-7-001, *Seismic event in Building 235-F results in a release of radioactive material,* in Revision 5 of the BIO has an entrainment term and a falling object

source term but does not consider a release from seismic vibration. The BIO references S-CLC-F-00646, which concludes a damage ratio of 0.194 is appropriate to account for falling object stresses (such as if the manipulators in the PuFF cells are damaged and components from them fall onto radioactive material in the cells) [10].

During discussions, DOE stated that they believe accounting for a seismic vibration source term was not technically justified. Specifically they stated, (1) based upon MAR removal experience, residual contamination should more appropriately be considered surface contamination vice loose powders and much of the material is not readily removable or dispersible, has adhered to enclosure surfaces, and has not been dislodged by thermal expansion/contraction or prior MAR removal activities; (2) DOE Handbook 3010 does not postulate release due to seismic shaking for surface contamination; and (3) plutonium oxide particles are expected to agglomerate due to moisture adsorption, which provides a mechanism for them to stick together. The tendency to agglomerate was consistent with observations made during MAR removal.

Board's Staff Team Analysis: Material Form—The Board's staff team agrees that the damage ratio of 0.194 used in the BIO for falling objects is conservative. However, there is no separate source term for material only affected by the seismic vibration portion of this accident. Accordingly, the overall calculation may underestimate the radiological dose consequences.

Further, the Board's staff team believes that while some of the material may not be easily dispersed and would not be subject to a vibration release (e.g., fixed contamination), this assumption should not apply to all hold-up material, especially areas in the facility that have not been decontaminated (e.g., areas that could not be reached through the available gloveports, such as ceilings and walls). The BIO's assumption that all material in Building 235-F is not subject to a vibration release is not a conservative assumption and underestimates the source term. Assuming a vibration release is also consistent with DOE directives, as noted below.

DOE Standard 3010, *Airborne Release Fractions/Rate and Respirable Fractions for Nonreactor Nuclear Facilities,* indicates that there is a release from the vibration shock of surface contamination or loose powder that agglomerates during an earthquake. For surface contamination, DOE Handbook 3010 states, "The bounding ARF and RF values assessed for vibration-shock impact of loose surface contamination on an unyielding surface are 1E-3 and 1.0." DOE Handbook 3010 also states, "The powder undergoing vibration shock (e.g., seismic vibration) is bounced into the air while subject to the same airspeeds as would impact the material for aerodynamic entrainment….Based on experience and judgement, Mishima, Schwendiman and Ayer (October 1978) selected a bounding ARF and RF of lE-3 and 1.0 for the suspension of powder-like surface contamination by shock-vibration."

For powder agglomeration, DOE Handbook 3010 Section 4.4.3.3.1 *Vibration Shock* states, "Particles comprising surface contamination are assumed to be more widely dispersed and not as agglomerated as 'thick' layers of particles that represent powders. Figure A.41 indicates the forces necessary to deagglomerate/disperse powders. Therefore, for clumps/piles of powder, the same value for the ARF, 1E-3, is recommended but the RF is reduced to 0.1 due to the difficulty of deagglomerating powders."

Further, DOE Handbook 1224, *Hazard and Accident Analysis Handbook*, provides an applicable example under "Earthquake Event." This example describes the source term from a fuel fabrication line that contains four gloveboxes affected by an earthquake. Specifically, the handbook states, "Another possible source of airborne material would be the **seismic vibration experienced by surface contamination in all four gloveboxes**. This material might contribute in a minor way for the first three gloveboxes as it could have a larger ARF (for smaller quantities) than bulk powder contained in cans or equipment. **It could even prove the dominant source term** from glovebox #4 [a glovebox containing ceramic material impervious to the stresses of falling objects] if the ceramic fuel forms in question truly are undamaged in the post-seismic state.... This drives home again the point that the source term analysis assesses multiple factors. While individual factors should not be unrealistically exaggerated, **no potential contributor should be dismissed without consideration**" [emphasis added].

DOE Handbook 1224 goes on to clarify:

> *Consider the example facility of Figures 5–2 and 5–3, specifically the fuel fabrication line. Presume for the moment that the structural collapse depicted in Figure 5–3 does not occur and all four gloveboxes remain intact (i.e., upright in a largely undamaged state) during a seismic event. What stress is then being imposed on any powder contained in the glovebox?*
>
> *The four main categories of potential stress are explosive, thermal, mechanical, and aerodynamic entrainment. No explosion or fire is postulated for this event. No debris impacts either the powder or its outer glovebox confinement. This could lead an analyst to dismiss mechanical impact as well, but that would be a mistake, because **even intact gloveboxes will experience transitory movement of structural members and an associated seismic vibration**. If the gloveboxes held only solid metal, such a stress would present no significant force. **For the much more fragmented powders, however, that force is sufficient to produce a small amount of aerosolization.***
>
> *Examining Table 5-1 for mechanical stresses indicates that an ARF and RF of 1E-3 and 0.1, respectively, are assigned for shock/vibration of bulk powders. Previous examinations of this case have indicated the maximum MAR is 6,000 g of plutonium oxide powder for all four gloveboxes. The initial source term would therefore be 6 g, and the initial respirable source term 0.6 g.*
>
> *Given this 0.6 gram respirable release, **could surface contamination produce a significant contribution**? Table 5-1 indicates that the ARF and RF for shock/vibration of loose surface contamination is assigned an ARF and RF of 1E-3 and 1.0, respectively, thus yielding a combined ARF/RF one order of magnitude greater than that for bulk powder. For the purpose of discussion in this example, if significant contribution is defined as 10 percent of the 0.6 gram source term, then surface contamination would have to contribute 0.06 g of airborne material to be significant. Working backward with the ARF/RF of 1E-3 yields a required surface contamination MAR of 60 g. That is certainly possible given that historical surface contamination levels for representative gloveboxes can range up to 50 g. Using a value of 0.1 g/ft$_2$ for powder handling gloveboxes (from historical experience), and assuming each glovebox is 12 feet by 4 feet by 4 feet (with a factor of 1.3 applied for equipment inside the gloveboxes) yields a total MAR of 116 g for all four gloveboxes. **It can be concluded, therefore, that surface contamination is a nontrivial***

contributor. *Both of these approaches to determine the level of surface contamination (MAR) and potential airborne release, are appropriate application of DOE-HDBK-3010-94"* [emphasis added].

Board's Staff Team Analysis: Structural Integrity Program—Revision 5 of the Building 235-F Technical Safety Requirements document [11] states, "A Structural Integrity Program shall provide for conducting of in-service inspections of safety structures, systems and components (SSCs) and their supports. This program shall provide reasonable assurance that the evidence of structural or functional degradation during services is detected to permit corrective action before the function of this SSC is compromised. This program shall be applicable to the Safety Class and Safety Significant SSCs identified in the BIO."

Accordingly, inspections for the structural integrity program may not apply to non-safety-related equipment. However, expanding the program to ensure that inspections of non-safety-related overhead equipment are included may be appropriate to identify potential corrosion issues. Corrosion could lead to components falling and impacting process enclosures causing radioactive contamination spread and invalidating the seismic impact fraction used in the accident analysis. It may be appropriate to also ensure that the routine inspections continue beyond deactivation through long-term safe storage.

Seismic Event Consequences—Table 3-21 of the BIO Revision 5 lists the unmitigated consequences for DEACT-7-001 as 92 rem. The hazards evaluation table lists the Building 235-F Building and Structures and Waste Inventory Control as safety significant controls. These controls are important and are used as initial conditions to determine the unmitigated consequences. No other safety significant controls were identified because the calculated dose consequences were below DOE's 100 rem threshold. However, as noted above, the calculation may underestimate the radiological dose consequences and could require consideration of additional safety-related controls if corrected. The overall conservatism of this calculation is further described in the *Overall Conservatism of the Accident Analysis* section of this report

DOE Perspective and the Board's Staff Team's Response —DOE stated that when Building 235-F was operational, loose contamination was periodically wiped from cell surfaces to prevent accumulation and that any remaining material could be generally characterized as fixed contamination. Accordingly, this material would not be subject to release from seismic shock-vibration. The Board's staff team agrees that some material is likely fixed contamination. However, this assumption should not be applied to all hold-up material, especially areas in the facility that have not been decontaminated (e.g., areas that could not be reached through the available gloveports such as ceilings and walls).

Conclusion—The Board's staff team believes that it is unreasonable to assume that all remaining material in Building 235-F can be considered fixed contamination, and at least some MAR not impacted by falling objects would undergo vibration/flexing that would cause a release during a seismic event. This approach is consistent with examples outlined above from DOE Handbook 3010 and DOE Handbook 1224. Accordingly, Revision 5 of the BIO may underestimate the radiological dose consequences for DEACT-7-001, which could result in controls that are inconsistent with what is required by DOE standards.

Non-Conservative Selection of Lung Absorption Class. Revision 5 of the Building 235-F BIO uses lung absorption Type S instead of lung absorption Type M for Pu-238. Type S may be appropriate for pure Pu-239 oxide; however, there are several scientific studies that suggest Type M may be more appropriate for Pu-238 oxide, which is the predominant material in Building 235-F. Use of Type S lung absorption class may cause the postulated radiological dose consequences to the co-located worker to be underestimated by about a factor of three for most accident scenarios.

Background—Different chemical forms of a radionuclide behave differently from each other when they are inhaled into the human body. To account for these differences, the health physics community uses the concept of lung absorption type. The International Commission on Radiological Protection (ICRP) defines three lung absorption categories: fast (F), moderate (M), and slow (S) depending on how quickly a material is absorbed from the lungs into the blood stream. These lung absorption types are needed to select inhalation dose coefficients, and in the case of plutonium, Type M results in a higher radiological dose consequence than Type S [12], [13].

Board's Staff Team Analysis: Lung Absorption for Pu-238 Oxide—The Building 235 BIO cites S-ESR-G-0045 [14] to justify Type S lung absorption type selection for Pu-238 oxide, and uses ICRP 68 [13] and ICRP 72 [12] for inhalation dose coefficients. ICRP 68 is used to determine worker dose consequences, while ICRP 72 is used to determine public dose consequences. ICRP 72 contains inhalation dose coefficients that were calculated in ICRP 71 [15].

ICRP 71 indicates that while Type S may be appropriate for pure Pu-239 oxide; it may not be appropriate for Pu-238 oxide. Specifically, Paragraph 264 of ICRP-71 states, "Bioassay data from accidentally exposed workers as well as data from experimental studies have shown a much greater rate of absorption of plutonium to blood following inhalation of $^{238}PuO_2$ compared with that of $^{239}PuO_2$. This has been attributed to radiolytic fragmentation of the particles due to the high specific activity of ^{238}Pu (Fleisher and Raabe 1977; Diel and Mewhinney, 1983). Thus, the lung retention and absorption to blood of ^{238}Pu 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)."

Further, Bair, et al. [16], performed a literature review of how plutonium behaved in a variety of animals. The study concluded, "Experimental animal data indicate that $^{238}PuO_2$ is relatively readily transported from the respiratory tract to other tissues in the body – that it is more transportable than $^{239}PuO_2$ even when both compounds were prepared under similar conditions, exhibit similar aerosol characteristics, and are indistinguishable by all tests including X-ray diffraction, but do differ in specific activity…. It has been proposed that the relatively high specific activity of ^{238}Pu causes spallation from the surface of the particles, - that $^{238}PuO_2$ particles are relatively unstable, disintegrating to smaller particles of increased solubility in tissue fluids. Also because of the energy in each plutonium particle, the microenvironment around the particle is at relatively high temperature. This could increase the rate of solubility of

the $^{238}PuO_2$ particles. This is consistent with the observed accumulation of ^{238}Pu in bone after inhalation of $^{238}PuO_2$."

The Board issued a letter and staff report to the Secretary of Energy on November 15, 2019, regarding the safety basis for the Plutonium Facility (PF-4) at Los Alamos National Laboratory (LANL) [17]. Appendix B of the staff report, *Inappropriate Dose Conversion Factors for Heat Source Plutonium*, notes concerns with use of lung absorption Type S for LANL's inventory of Pu-238 material. Specifically, the report states, "In March 2018, LANL personnel issued a report (Poudel, et al.), 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…. When excluding a March 2000[2] incident, the LANL report found that models with dose coefficients of Type M and larger are approximately 47 percent probable."

However, the Board's staff team acknowledges that some data suggest Type S may be appropriate for Pu-238 oxide. Specifically, ICRP-71 states, "On the other hand, 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)." This ambiguity is further described in the section below, which includes the DOE perspective.

Accordingly, the underlying data for lung absorption selection is ambiguous; many studies suggest Type M is appropriate for Pu-238 material (including pure oxide/ceramics), while some studies suggest Type S is appropriate. At a minimum, several references state that Pu-238 material may be more soluble than Pu-239 material due to spallation and radiolytic fragmentation.

DOE Perspective and the Board's Staff Team's Response—During discussions, DOE stated that it believes selection of lung absorption Type S for Building 235-F material is technically defensible and conservative. Further, DOE cited Environmental Protection Agency Federal Guidance Report (FGR) 11, which lists the lung absorption class for plutonium oxide as class Y (yearly, which corresponds to Type S in modern health physics nomenclature) [18]. The Board's staff team agrees that FGR-11 supports the idea that Type S lung absorption class is appropriate for plutonium oxide. However, FGR-11 is outdated and does not specifically comment on the data suggesting that Pu-238 may act differently inside the body than Pu-239. The omission of this topic in FGR-11 should not be interpreted as affirmation that it is appropriate to model different isotopes in the same manner.

Conclusion—The Board's staff team believes that Revision 5 of the Building 235-F BIO does not have sufficient analysis or evidence to (1) support a lung absorption Type S designation for all Building 235-F Pu-238 oxide, and (2) show why lung absorption Type M is not applicable for Pu-238 contained in Building 235-F. Further, DOE has not performed any characterization

[2] 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."

experiments on the Pu-238 hold-up material to ensure that the material remained an oxide and did not change states due to aging or exposure to uncontrolled environments.

Considering the uncertainty of the lung absorption data and the lack of material characterization data, selecting the more conservative value for technically justified input parameters is consistent with DOE Standard 3009-94, which states, "The intent is that calculations be based on reasonably conservative estimates of the various input parameters." Selecting Type M lung absorption for Pu-238 would cause the radiological dose consequences to increase by approximately a factor of three for most accident scenarios.

Overall Conservatism of the Accident Analysis. Revision 5 of the BIO lists three accidents that are not prevented and result in co-located worker consequences that exceed 50 rem. DEACT 3-008 (breach of enclosure causes degraded enclosure vacuum results in a release of radioactive material), DEACT 6-004 (impact to transuranic waste transport vehicle during shipping with a subsequent fire resulting in a release of radioactive material), and DEACT 7-001 (seismic event in Building 235-F results in a release of radioactive material). Building 235-F does not currently have significant quantities of transuranic waste; therefore, the Board's staff team focused on DEACT 3-008 and DEACT 7-001. The analyses for these accidents contain multiple conservatisms and non-conservatisms, which are described below.

Conservatisms—Revision 5 of the Building 235-F BIO uses several conservative parameters in the accident analysis. These parameters are listed in the safety evaluation report [19] and include:

1. *Loose powder assumption - This calculation treats Fixed, non-removable MAR as loose powder (Assumption 5.2.1 [in S-CLC-F-00646]); this includes MAR adhered to or engrained in enclosure surfaces as well as MAR captured in furnaces, coolers, and other pieces of equipment.*

2. *2-Sigma (σ) uncertainty added to MAR inventory values - MAR estimates include significant added material with inclusion of 2σ uncertainty to address potential uncertainties on multiple levels. Actual assay data without excessive uncertainty is more representative of MAR physically present in the facility.*

3. *Respirable Fraction (RF) of 1.0 - This analysis uses the conservative Respirable Fraction (RF) of 1.0 for all areas and all MAR regardless of its current form. The Respirable Fraction has historically been 1.0 for ball milled Pu-238 in Building 235-F. However, it is more likely the Pu-238 has been mixed with Aluminum oxide, other contaminants, and decay products for many years allowing bonding. Therefore, an RF of 1.0 does not account for the current form of the hazard. Using a more realistic RF would significantly reduce the doses.*

4. *Application of Active entrainment stresses - MAR involved in indoor accidents are based on active ventilation system airflow over a homogeneous powder bed of loose powders. All indoor MAR is inside a robust enclosure where airflow, when present is directed to exhaust ducts in the ceilings of the enclosure, away from the most likely location for deposition of agglomerated MAR. MAR subjected to*

impact type primary stresses (i.e., seismic impact) should be treated as under rubble, not subject to airflow-induced entrainment.

5. *Existence of the Sand filter – The analysis [does not credit] the sand filter. If the source term is discharged from Building 235-F by E5 fans, the exhaust must pass through the sand filter to exit the facility. This will reduce further the calculated dose consequences.*

6. *No application of the stack height release - The stack has not been credited for the MOI [maximally exposed offsite individual] dose consequences. The 291-2F stack height is 32.9 m (108 ft) therefore, if applied, the MOI TED [total effective dose] would use a stack reduction factor of 77.6.*

The Board's staff acknowledges that there are several conservatisms with the calculation as stated above, but also notes there are non-conservatisms.

Non-conservatisms—The Board's staff team identified that there is sufficient uncertainty in the technical basis for several input parameters (e.g., lung absorption class, seismic vibration term) such that more conservative values may be appropriate. Adopting these values would cause significant increases in the calculated radiological dose consequences.

The BIO also relies on inappropriate and non-credited initial conditions to support its assertion that a fire impacting hold-up MAR is not a credible event. As a result, Revision 5 of the BIO does not analyze a fire (both seismically induced and internally initiated) impacting hold-up MAR as an evaluation basis event. This approach is inconsistent with DOE directives and circumvents the control selection process.

Results—Overall, the Board's staff team has not seen any quantitative calculations or evidence that suggests the overall conservatism of the BIO's accident analysis calculations outweigh the non-conservatisms. To provide perspective, the Board's staff team calculated what the consequences would be if the non-conservatisms were addressed in the existing BIO calculations. Specifically, Table 1 shows the results of staff calculations that determined the impact of changing input assumptions in the Building 235-F Revision 5 BIO accident analysis. The column "BIO Rev. 5 values CW [co-located worker] dose (Type S)" reports the co-located worker dose as documented in Revision 5 of the BIO, which uses Type S lung absorption. The column "Staff Calculation CW Dose (Type S)" lists the results from a staff calculation that assumes all holdup MAR in the facility is subject to seismic vibration and that a fire impacting MAR is credible. This calculation uses airborne release fractions and respirable fractions outlined in a previous SRNS calculation [10]. The column, "Staff Calculation CW Dose (Type M)" shows what the consequences would be if lung absorption Type M is used instead of Type S for Pu-238 for each postulated accident.

Table 1. *Impact of Changing Assumptions for Various Postulated Accident Scenarios.*

Postulated Unmitigated Accident Scenarios	BIO Rev. 5 Values CW Dose (Type S) (Rem)	Staff Calculation CW Dose (Type S) (Rem)	Staff Calculation CW Dose (Type M) (Rem)
Loss of Confinement	**54.8**	**N/A**	**150**
Seismic Event	**92**	**N/A**	**250**
Seismic Event + Vibration	**N/C***	**130-450**	**350-1200**
Seismic Event + Full Facility Fire	**N/C***	**>2700**	**>7400**
Small Fire (Impacts 5% of the Total Inventory)	**N/C***	**130**	**350**
Fire Impacting all Hold-up MAR:	**N/C***	**>2600**	**>7000**

*The Building 235-F BIO states that these events are not credible.

As noted in Table 1, more conservative assumptions that have a valid technical basis could result in large impacts to the postulated dose consequences to the co-located worker. For example, if Revision 5 of the BIO used lung absorption Type M instead of Type S for Pu-238, the unmitigated dose consequences would exceed the 100 rem co-located worker threshold for several accident scenarios and would require identification of safety significant controls. Similarly, even a small fire impacting a subset of the available hold-up MAR would result in consequences that exceed 100 rem to the co-located worker. A fire impacting the entire inventory would cause catastrophic consequences that would far exceed the 100 rem threshold. However, it is important to note that the calculations in Table 1 are conservative and do not consider some of the non-credited controls in the facility. These defense-in-depth controls are described below.

Defense-in-Depth Control Set—Regardless of the overall conservatism of the accident analysis, Building 235-F has several non-credited defense-in-depth controls that could help mitigate or prevent the accidents noted above. Specifically, the Building 235-F E-5 ventilation system and sand filter, the fire protection safety management program, and the non-combustible hot cells.

- **The E-5 ventilation system and sand filter** is listed in the Building 235-F safety basis as equipment important to safety, with the further statement that it will be operated and maintained throughout deactivation. Specifically, the safety basis states, "During deactivation and transition S&M [to surveillance and maintenance mode], the 294-2F sand filter provides support to the 235-F building performing a DID/ITS [defense-in-depth/important to safety] function. Building 235-F personnel are responsible for the maintenance of the 294-2F sand filter. The efficiency of the sand filter is at least 99.5% and will be tested by a Filter Testing Group periodically based on a nominal 18 month interval."

The SRNS unreviewed safety question procedure [20] further protects the functionality of the ventilation system and sand filter. Specifically, planned or unplanned changes that affect the performance of the DID/ITS ventilation system would trigger the unreviewed safety question process and would require DOE approval.

Overall, the Board's staff team believes that the ventilation system and sand filter should significantly reduce the radiological consequences to the public and the co-located worker if a radioactive release occurs.

- **The fire protection safety management program** reduces the likelihood of fires by controlling transient combustibles, flammable liquids, and reducing ignition sources.

- **The non-combustible hot cells** contain most of the MAR remaining in Building 235-F. These hot cells are essentially large stainless-steel boxes within thick concrete shielding walls. These hot cells would reduce the likelihood of a fire propagating outside of the cell from impacting the hold-up MAR. However, it is important to note that the cells have numerous penetrations.

While the defense-in-depth controls noted above provide protection as installed, the Board's staff team believes that some of these controls should be elevated to safety-significant in order to fully comply with DOE requirements. This approach would increase the assurance that the controls will remain in place and continue to function throughout the lifetime of the facility. Further, as noted throughout this report, the Board's staff team believes that several of these controls are implicitly relied upon in the unmitigated analysis, which is inappropriate and inconsistent with DOE directives as it circumvents the control selection process.

Conclusion—The BIO's accident analysis relies on several conservative and non-conservative parameters. The Board's staff team has not seen any quantitative calculations or evidence that suggests the overall conservatism of the BIO's accident analysis calculations outweigh the non-conservatisms. To provide perspective, the Board's staff team calculated what the consequences would be if the non-conservatisms were addressed. This resulted in significant increases to the calculated radiological dose consequences. Given the uncertainties in the hazard/accident analysis input parameters, the weaknesses in the current credited control set, and the potential severity of the radiological dose consequences to the co-located worker for several accidents (e.g., seismic event without a fire, loss of confinement, and fire events impacting hold-up MAR), the Board's staff team believes that designating additional safety significant controls may be warranted. As noted in the Board's December 23, 2020, letter, maintaining the Building-235 E5 ventilation system and sand filter as safety significant may be appropriate. Crediting the ventilation system and sand filter would be consistent with DOE's hierarchy of controls, which states that SSCs are preferred over administrative controls.

Further, DOE Standard 3009-14, which clarifies requirements in 3009-94, requires that, "When the hierarchy of controls is not used for situations requiring SC/SS controls (e.g., a SAC is selected over an available SSC), the DSA shall provide a technical basis that supports the

controls selected." The Board's staff team has not seen a hierarchy of controls analysis to support the selection of the current control set.

Overall Conclusion. The Board identified concerns with hazards associated with Pu-238 hold-up material in Building 235-F. It issued Recommendation 2012-1 on May 9, 2012, which recommended several actions DOE should take to improve the safety posture of Building 235-F. In response, DOE completed several actions, including removing some MAR from Building 235-F. Over the past two years, DOE downgraded existing safety controls, ceased MAR removal activities, and stated that they had completed all recommendation implementation plan actions. Significant quantities of Pu-238 material remain in Building 235-F.

The Board's staff team reviewed Revision 5 of the Building 235-F safety basis and identified that the safety basis inappropriately screens out credible accident scenarios and uses non-conservative assumptions in the hazards and accident analysis. The use of these non-conservative assumptions is somewhat mitigated by the use of several conservative assumptions in the analysis. However, the BIO does not have any quantitative calculations or evidence that suggest the overall conservatism of the BIO's accident analysis outweigh the non-conservatisms. To provide perspective, the Board's staff team calculated what the consequences would be if the non-conservatisms were addressed in the existing BIO. The resulting analysis demonstrated that several accidents would exceed DOE's 100 rem threshold to the co-located worker.

Building 235-F has several defense-in-depth controls (e.g., sand filter and fire protection program) that would help mitigate or prevent several of the accidents. The Board's staff team believes that designating these controls as safety significant may be warranted due to their importance to the safety basis. This approach would account for uncertainties in the accident analysis and would be consistent with DOE directives. However, it is important to note that Building 235-F is undergoing deactivation, so the time at risk for the remaining MAR is small compared to operating facilities. Accordingly, if DOE does not choose to upgrade controls to safety-significant, it should ensure deactivation and decommissioning activities are expedited and not delayed. In order to further improve the safety posture, DOE should consider expanding the structural integrity program to require inspections of overhead equipment and ensure that the program is implemented with the same level of rigor during long-term safe storage as it will be during deactivation.

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