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DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

September 24, 2020

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

Dear Secretary Brouillette:

The Defense Nuclear Facilities Safety Board has reviewed transuranic waste storage, handling, and processing across Los Alamos National Laboratory facilities. The Board has found that safety bases for both National Nuclear Security Administration and Environmental Management facilities at Los Alamos National Laboratory do not consistently or appropriately consider a potential energetic chemical reaction involving transuranic waste. Examples include:

- **Hazard analyses** lack systematic evaluations of the chemical compatibility of transuranic waste streams. These analyses are needed to fully identify potential chemical reaction hazards associated with waste constituents.

- **Accident analyses** are not bounding, assume inappropriate initial conditions, and do not defensibly estimate the quantity of radioactive material that may be released due to an energetic chemical reaction. As such, additional credited safety controls may be necessary to protect workers and the public.

- Some facilities store transuranic waste without any engineered controls beyond the waste container. The radiological release events that occurred at the Waste Isolation Pilot Plant and Idaho National Laboratory have demonstrated the importance of incorporating **multiple layers of protection** to reduce the consequences of an accident.

The attached technical report further details these topics. The concerns mirror those outlined in the Board's letter dated January 29, 2020, regarding needed revisions to DOE Standard 5506*, Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities*, and highlighted in the Board's June 20, 2019, public hearing.

Pursuant to 42 USC §2286b(d), the Board requests that DOE provide a report within 120 days of receipt of this letter that describes (1) whether the hazards associated with the current transuranic waste container population at Los Alamos National Laboratory are consistently and adequately controlled and DOE's basis for this position, and (2) whether the revision to DOE Standard 5506 will address the broader implications of these concerns, as they are applicable to other DOE sites.

Yours truly,

Thomas A. Summers

Thomas A. Summers
Acting Chairman

Enclosure

c: Mr. Kirk Lachman
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DNFSB/TECH-46

POTENTIAL ENERGETIC CHEMICAL REACTION EVENTS INVOLVING TRANSURANIC WASTE AT LOS ALAMOS NATIONAL LABORATORY

Defense Nuclear Facilities Safety Board

Technical Report

September 2020

DNFSB/TECH-46

POTENTIAL ENERGETIC CHEMICAL REACTION EVENTS INVOLVING TRANSURANIC WASTE AT LOS ALAMOS NATIONAL LABORATORY

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EXECUTIVE SUMMARY

The Department of Energy (DOE) recently experienced two events—one in February 2014 at the Waste Isolation Pilot Plant (WIPP) and another in April 2018 at the Idaho National Laboratory (INL)—in which waste drums released radiological materials due to energetic chemical reactions involving the waste. As a result, the Defense Nuclear Facilities Safety Board (Board) evaluated how DOE analyzes hazards and implements controls at facilities that generate, process, and store nuclear waste. These activities most recently culminated in a letter to the Secretary of Energy dated January 29, 2020, regarding areas of concern in DOE Standard 5506-2007, *Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities.* That letter built upon several efforts, including the Board's public hearing on June 20, 2019, and the Board's Technical Report 43, *Deficiencies in DOE Standard 5506-2007, Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities*, dated March 15, 2018.

These Board products identified a few common themes, including: the need for chemical compatibility evaluations for waste containers stored at waste generator sites that have not yet been certified for shipment to WIPP; the need to develop a defensible release fraction for energetic chemical reaction events based on the amount of material released in recent radiological release events; the need for improvements to control strategies to protect against energetic chemical reactions; and the need to revise DOE Standard 5506 to address these deficiencies.

This technical report provides a site-specific case study on the treatment of energetic chemical reaction hazards in the safety bases for facilities that generate and store transuranic waste at Los Alamos National Laboratory (LANL). These facilities include the Plutonium Facility (PF-4), the Transuranic Waste Facility (TWF), and the Chemistry and Metallurgy Research Facility (CMR)—all operated by Triad National Security, LLC (Triad)—and Area G operated by Newport News Nuclear BWXT-Los Alamos, LLC (N3B). The Board's staff team found that the safety bases for these facilities do not appropriately analyze the hazards from potential energetic chemical reaction events involving transuranic waste.

Some LANL defense nuclear facilities assume inappropriate initial conditions in their accident analyses and do not conservatively estimate the quantity of radioactive material that may be released from an energetic chemical reaction event. As a result, LANL facility safety bases do not contain a bounding analysis that accounts for (1) the types of potential chemicals that could be present in waste drums or (2) the amount of radiological material that could be released from an energetic chemical reaction event. Accordingly, the safety bases may not identify adequate safety controls to protect workers and the public from this type of hazard. Many of these identified concerns stem from inadequate requirements and guidance in DOE Standard 5506. DOE is currently revising this standard.

The staff team identified the following areas of concern with LANL facility safety bases:

Hazard Analyses Lack Systematic Chemical Compatibility Evaluations. In order to fully analyze the hazards from energetic chemical reactions, the Board's staff team has concluded that waste generator sites should incorporate two separate types of evaluations into facility safety bases: (1) a general analysis that assumes that an energetic chemical reaction is possible within waste, without necessarily identifying any specific chemical reaction, and (2) a systematic evaluation of waste streams to identify specific chemical incompatibilities (i.e., a systematic chemical compatibility evaluation).

LANL safety bases include a general analysis. A general analysis is helpful for deriving controls that provide defense-in-depth against unanticipated chemical reactions. As illustrated by DOE's recent events, it is important to defend against unexpected chemical reactions. However, while it is important, a general analysis is not sufficient. The general approach does not lend itself to the creation of robust control sets, including measures for preventing specific chemical interactions, or measures for identifying containers that are particularly at risk of such interactions. Accordingly, a more systematic and detailed approach is also needed to fully analyze energetic chemical reaction hazards and to assign effective controls. While some LANL safety bases currently identify the hazards posed by a specific chemical reaction, LANL safety bases do not systematically evaluate the waste streams to identify a wider spectrum of possible reactions.

DOE requires systematic chemical compatibility evaluations for waste certification prior to accepting containers for disposal at WIPP. However, DOE standards and directives do not explicitly require similar evaluations for waste while it is stored at generator sites. Performing systematic chemical compatibility evaluations at waste generator sites is needed to develop prevention strategies, such as waste compatibility controls. This evaluation could also identify containers at higher risk of undergoing an energetic chemical reaction, allowing such containers to be stored in locations with a more robust control set. There may also be an opportunity to integrate the evaluations required for WIPP into the LANL safety bases to ensure this same level of protection is provided at the point of waste generation.

Some Accident Analyses Assume Inappropriate Initial Conditions and do not Defensibly Estimate Radioactive Material Releases. DOE determined that the amount of radioactive material released from the WIPP accident was significantly higher than the amount DOE standards would have predicted. DOE did not analyze the INL event to determine the amount of radioactive material released, but it also appears to have been higher than the amount that DOE standards would have predicted. DOE has not yet provided complex-wide direction regarding release fractions to its contractors that is informed by the WIPP or INL events. As a result, LANL safety bases do not analyze hazards associated with energetic chemical reactions consistently across facilities:

- The **PF-4** and **CMR** safety bases use a release fraction of 0.07 when analyzing the consequences from an energetic chemical reaction. While this value is less than the 0.205 value that a DOE office derived after the WIPP event, it provides a quantitative estimate for the derivation of safety controls that is more than an order of magnitude higher than other LANL facilities. The PF-4 and CMR safety bases apply this analysis to one specific chemical incompatibility based on the waste constituents of the WIPP event (interactions between nitric acid and polysaccharides). They do not expand the analysis to include other incompatibilities. As demonstrated by the INL event, reactions beyond nitric acid and polysaccharides can lead to significant releases of radioactive materials.

- The **TWF** safety basis uses a release fraction of 0.002 when analyzing the consequences from an energetic chemical reaction event, which is 35 times lower than what is used by PF-4 and CMR. The safety basis inappropriately relies on the waste acceptance criteria to justify the use of a lower release fraction.

- The **Area G** safety basis does not analyze an energetic chemical reaction event resulting in the release of a significant amount of radioactive material. The closest accident type analyzed is a flammable gas deflagration with a release fraction of 0.00054, which is roughly 130 times lower than what is used by PF-4 and CMR. The staff team notes that about 1,500 Area G containers have not undergone a chemical compatibility evaluation, and 2,000 containers do not meet WIPP's waste acceptance criteria and will require remediation. The Area G safety basis is also outdated and was developed in accordance with a DOE standard that requires less rigor for safety bases. N3B has no documented near-term plans to upgrade the safety basis to follow modern DOE requirements.

There is substantial commonality in the waste constituents across LANL facilities; thus the differences in accident types and release fractions are not technically defensible. Further, the appropriate use of elevated release fractions may drive the need for additional safety controls at some of these facilities. The Board's staff team performed an evaluation of the existing inventory at LANL and determined that on the order of 100 transuranic waste containers could release sufficient material to result in a dose consequence that challenges DOE's Evaluation Guideline if an energetic chemical reaction with a release fraction of 0.07 were to occur within those drums. Containers with low risk of undergoing an energetic chemical reaction were excluded from the Board's staff team's evaluation.

Some Facilities Rely Primarily on the Waste Container to Provide Safety. The radiological release events that occurred at WIPP and INL demonstrated the importance of incorporating multiple layers of protection. Some LANL facilities, such as PF-4 and CMR, provide multiple layers of protection including a confinement ventilation system and a fire suppression system to mitigate the consequences of a radiological release event. Other LANL facilities, such as the outdoor transuranic waste storage pads at PF-4 and the fabric domes at Area G, lack these safety systems.

Although preferred, the Board's staff team does not believe that LANL needs to store all transuranic waste containers in facilities with a confinement ventilation system or fire suppression system. Rather, LANL could preferentially store higher-risk waste containers (e.g., poorly characterized waste, waste with high quantities of material-at-risk, waste that has not undergone a chemical compatibility evaluation, or waste with incompatible chemical constituents) in locations with more robust control sets and judiciously apply other types of controls, such as overpack containers, lid restraints, and detection capabilities.

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BACKGROUND AND ANALYSIS

Two recent events in the Department of Energy's (DOE) nuclear weapons complex have illustrated the complexities inherent in chemical interactions involving radioactive waste. In both events, unexpected energetic chemical reactions[1] within the waste resulted in drum breaches and significant releases of radioactive material from the drums.

The first event occurred in February 2014 at the Waste Isolation Pilot Plant (WIPP), where DOE permanently disposes transuranic waste. At WIPP, energetic chemical reactions caused the over-pressurization[2] of a drum, leading to a release of radiological material. This drum was generated at Los Alamos National Laboratory (LANL). Prior to shipment to WIPP, this drum passed chemical compatibility screenings and was incorrectly classified as not ignitable (wastes that can readily catch fire and sustain combustion) [1 – 3]. DOE also determined that the amount of material released during the WIPP event far exceeded what DOE standards would have predicted [1].

The second event occurred in April 2018 at the Idaho National Laboratory (INL), which stores and repackages legacy waste. During this event, reactions occurred in four drums that were inside the Accelerated Retrieval Project V facility. The drums contained recently repackaged legacy waste; INL personnel had relatively little information on the chemical composition of the waste in those specific drums.

The INL contractor-led investigation of the INL event [4, 5] identified several chemical reactions that may have been involved with the release event. First, uranium in the waste underwent oxidation, releasing heat. The increased temperature drove secondary reactions, including the generation of methane from a reaction between beryllium carbide and water. Pressure inside the four drums increased to the point that the drum lids were forcefully ejected, resulting in the spread of radiological material across the facility.

The Need for Chemical Compatibility Evaluations—After the WIPP event, DOE strengthened the process for evaluating potential chemical reaction hazards associated with waste prepared for disposal at WIPP [6 – 8]. This evaluation process is necessary to identify and help prevent energetic chemical reactions that could be caused by the range of possible chemical combinations associated with each waste stream. Personnel of the National Transuranic Program (NTP), whose mission is to ensure that waste shipped to WIPP meets the WIPP waste acceptance criteria, perform this chemical compatibility evaluation. Waste containers may remain at the generator sites indefinitely before NTP personnel perform their evaluation.

Prior to the INL event, a (previous) contractor at INL had performed its own chemical compatibility evaluation of wastes at INL [9, 10] and NTP had yet to perform its analysis of the drums involved in the event. While it is positive that the local contractor performed an evaluation, the evaluation was inadequate and did not identify the hazards involved in the event. Beryllium carbide, which may have been an accident contributor, was not on the list of potential chemicals in the contractor's evaluation.

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[1] Appendix A: *Glossary and Additional Information* defines the term "energetic chemical reaction."
[2] Appendix A: *Glossary and Additional Information* defines the term "over-pressurization."

While other forms of beryllium were listed, the contractor excluded beryllium from further analysis on the grounds that it was only present in “trace” quantities.

These facts demonstrate that conservative decision-making is needed when there is limited knowledge of waste composition, and that “trace” chemicals can play a large role in energetic chemical reactions. Further, the contractor’s evaluation identified hazards posed by the oxidation of uranium [9], but site personnel incorrectly assumed that the hazard did not extend to the form of uranium found in the event drums [4, 11].

Overall, both the WIPP and INL events show that it is not only important for sites to perform chemical compatibility evaluations to identify and reduce the likelihood of potential incompatibilities, but that these evaluations must account for uncertainties in waste composition and chemicals thought to be present in small quantities.

Improvements Needed in DOE Directives—DOE Standard 5506-2007, *Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities* [12], does not explicitly require waste generator sites to perform chemical compatibility evaluations on drums in storage before they enter the certification process for shipment to WIPP. As a result, waste containers can be stored for several years before any chemical compatibility evaluation is performed. The Board’s staff believes that this approach is inconsistent with DOE Standard 3009-94, *Preparation Guide for U. S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, which “requires evaluation of the complete spectrum of hazards and accidents” [13].

DOE Standard 3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis* [14], requires analysts to evaluate events if they have occurred previously within a nonreactor nuclear facility. Specifically, the standard states:

> *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.*** [Emphasis added]

As documented throughout this report, LANL facilities do not perform systematic chemical compatibility evaluations and some facilities do not consider that a WIPP or INL type event that releases a large fraction of material is plausible. Accordingly, DOE Standard 5506 should clarify that (1) waste cannot be stored indefinitely without a chemical compatibility evaluation and (2) facility safety bases should evaluate energetic chemical reactions that release a large fraction of material.

Defense Nuclear Facilities Safety Board Activity—As a result of the INL and WIPP events, the Defense Nuclear Facilities Safety Board (Board) has been evaluating how DOE analyzes hazards and implements controls at facilities that generate, process, and store nuclear waste. The Board held a public hearing and sent multiple letters and a technical report to DOE regarding transuranic waste safety, which include:

- Board letter to DOE dated May 29, 2020, regarding the WIPP documented safety analysis [15].

- Board letter to DOE dated January 29, 2020, regarding areas of concerns with DOE Standard 5506-2007 [16].

- Public hearing on safety management of waste storage and processing in the defense nuclear facilities complex held June 20, 2019 [17].

- Board letter to DOE dated March 12, 2019, regarding flammable gas hazards in waste containers [11].

- Technical Report 43 dated March 15, 2018, which identifies deficiencies found in DOE Standard 5506-2007 [18].

These Board products identified a few common themes, including: the need for chemical compatibility evaluations for waste containers that have not yet been certified for WIPP but remain at generator sites; the need to develop a defensible release fraction for energetic chemical reaction events based on the amount of material released in recent radiological release events; the need for improvements to control strategies to protect against energetic chemical reactions; and the need to revise DOE Standard 5506 to address these deficiencies.

Staff Review Scope and Strategy—The staff team reviewed the safety bases for Area G [19, 20], the Transuranic Waste Facility (TWF) [21, 22], the Plutonium Facility (PF-4) [23, 24], and the Chemistry and Metallurgy Research Facility (CMR) [25, 26]. These safety bases were developed based on the requirements and guidance documented in DOE Standard 5506 and DOE Standard 3009. DOE Standard 5506 supplements DOE Standard 3009 and is used to help support safety basis development for transuranic waste facilities.

The staff team conducted onsite discussions with personnel from the LANL management and operating contractor, Triad National Security, LLC (Triad); the Los Alamos Legacy Cleanup contractor, Newport News Nuclear BWXT-Los Alamos, LLC (N3B); the National Nuclear Security Administration's Los Alamos Field Office (NA-LA); and DOE's Environmental Management Los Alamos Field Office (EM-LA) during the week of November 18, 2019. Triad manages TWF, PF-4, and CMR for NA-LA; and N3B manages Area G for EM-LA.

This report provides a site-specific case study on how energetic chemical reaction hazards involving transuranic waste[3] are analyzed and controlled at PF-4, CMR, TWF, and Area G. PF-4 and CMR generate transuranic waste during normal operations. This waste can be stored at PF-4, CMR, and TWF. Area G stores a variety of transuranic waste above-ground and underground, but is currently not receiving additional transuranic waste. The underground waste is outside of the scope of this report.

[3] Energetic chemical reactions can occur in other types of waste, such as low-level waste, but the focus of this report is on transuranic waste.

INCOMPLETE HAZARD ANALYSES FOR TRANSURANIC WASTE

In order to fully analyze the hazards from energetic chemical reactions, the Board's staff team has concluded that waste generator sites should incorporate two separate types of evaluations into facility safety bases: (1) a general analysis that assumes that an energetic chemical reaction is possible within waste, without necessarily identifying any specific chemical reaction, and (2) a systematic evaluation of waste streams to identify specific chemical incompatibilities (i.e., a systematic chemical compatibility evaluation), similar to what is performed for waste being shipped to WIPP.

A general analysis is needed to derive controls that provide defense-in-depth against unanticipated reactions. The general analysis is particularly important when there is poor characterization data for a waste container and a specific chemical compatibility analysis cannot be adequately performed. Under very limited circumstances (e.g., all containers are grouted or are inert when exposed to a variety of environments), an energetic chemical reaction may not be plausible. In this situation, the safety basis should document the basis for ruling out the hazard.

A systematic chemical compatibility evaluation is needed to identify specific chemical reaction hazards that may be present in existing and new waste in order to develop a complete accident analysis and assign effective controls. This type of analysis is required by WIPP before accepting waste; however, waste can be stored at a generator site for an indefinite period of time without performing such an evaluation. In order to ensure appropriate controls are identified, this analysis should be included as part of facility safety bases. This would allow for the implementation of prevention strategies, such as waste compatibility controls, and for containers at higher risk of undergoing an energetic chemical reaction to be identified and stored in locations with more robust controls. If performed adequately, this evaluation could help prevent future accidents similar to those that transpired at WIPP and INL. A systematic evaluation performed by a waste generator could use the WIPP-approved chemical compatibility evaluation method [6, 8], which is derived from a methodology published by the Environmental Protection Agency [7], or a DOE-approved alternative that is similarly rigorous.

The chemical compatibility evaluations should be able to identify a broad set of adverse conditions, such as generation of heat, gases, corrosive vapors, and shock-sensitive materials. Ideally, an evaluation would consider not just interactions between different chemicals within the waste itself, but also reactions involving the container, air, and moisture. Another consideration is that waste may change over time as it reacts or degrades. Chemicals (including those thought to be only present in trace amounts) should only be excluded from evaluation with technical justification.

Previous Board communications to DOE [11, 16, 17, 18] identified weaknesses in DOE Standard 5506 regarding the evaluation of potential energetic chemical reaction hazards. Specifically, DOE Standard 5506 does not include a process for analyzing energetic chemical reaction hazards, does not provide technically justified release fractions for this accident, and does not include an energetic chemical reaction event in its list of the "minimum set of accident events" required for evaluation in facility safety bases. Accordingly, DOE Standard 5506 does not ensure an appropriate and consistent evaluation of chemical reaction hazards across DOE's defense nuclear weapons complex.

LANL facility safety bases include general chemical hazard analyses in facility safety bases, but some safety bases underestimate the amount of material that could be released (refer to the *Inadequate Accident Analyses of Energetic Chemical Reactions* section for more information). Further, while some LANL safety bases identify a specific chemical reaction hazard, LANL safety bases do not systematically evaluate the full spectrum of chemical incompatibilities that could be present in a waste stream. Not analyzing the full suite of potential hazards and accidents is inconsistent with DOE standards and directives [13, 14] and may lead to an inadequate control set to protect workers and the public.

Specific Reaction Hazards at LANL—The hazard analyses within LANL facility safety bases were developed using simplistic screening methods and do not include systematic chemical compatibility evaluations. Recently, Triad has begun to take a more direct approach toward chemical compatibility hazards in some facilities. Triad declared potential inadequacies of the safety analysis (PISA) at CMR and PF-4 concerning the hazard of an autocatalytic exothermic reaction (a specific type of energetic chemical reaction). Triad declared these PISAs based on information in two reports [27, 28] documenting incompatibilities between polysaccharides (e.g., cheesecloth and starch-based kitty litter) with nitric acid and metal nitrate salts. These types of waste constituents contributed to the WIPP radioactive material release event.

In response to the PISAs, Triad implemented a control that prohibits the commingling of polysaccharides and nitric acid. Triad's analysis and subsequent control of this specific chemical incompatibility is a positive development. However, Triad should expand its evaluation to include other potential chemical incompatibilities (including interactions with elements in trace quantities) that could lead to energetic chemical reactions. As demonstrated by the INL event, reactions beyond nitric acid and polysaccharides can lead to significant releases of radioactive materials.

N3B did not identify any specific chemical incompatibilities (including interactions between polysaccharides and nitric acid) that could lead to an energetic chemical reaction in Area G's hazard analysis. Accordingly, N3B's approach is inappropriate and inconsistent with other LANL facilities that store waste with similar constituents.

Leveraging Existing Initiatives—NTP has established chemical compatibility evaluations for waste streams at LANL. NTP performs these evaluations as part of its process to determine whether waste meets the waste acceptance criteria for WIPP [6]. NTP personnel review records of individual waste containers to ensure that the chemical constituents are included in the established chemical compatibility evaluation for a given waste stream. However, NTP's evaluations are only intended to ensure safety at WIPP, and there are many containers at LANL that NTP has not yet evaluated. Specifically, N3B personnel stated that more than 1,500 containers stored at Area G have not undergone a chemical compatibility evaluation. Triad and N3B could leverage existing NTP evaluations and analyses to help them formally identify chemical compatibility hazards within LANL waste to support facility safety bases.

For example, NTP's chemical compatibility evaluation of a waste stream at PF-4 [29] identified the presence of several chemical constituents that are incompatible and could result in hazards such as explosions or fires, or the generation of flammable gases. NTP notes that spent anion exchange resins in nitrated form are a potential hazard and need to be rendered nonreactive (i.e., cemented) in order to comply with the WIPP waste acceptance criteria. While LANL typically cements spent ion exchange resins, there is no analysis or derived control in the safety basis that requires LANL to cement these resins. Without properly analyzing this hazard or deriving an appropriate control, LANL may inadvertently create incompatible waste.

Work Control Processes and Training—Triad personnel are developing a step in their work control processes to assess waste generation using analysts who are trained and qualified to identify chemical compatibility hazards. These analysts perform visual inspections of waste as it is being packaged to ensure no prohibited items are present, record waste information on a questionnaire, maintain waste stream records, ensure waste items are characterized, and support NTP's evaluation of waste. While this represents a positive step, the Board's staff team identified two areas that can be improved: (1) Triad could structure work control processes to ensure that newly generated waste containers are covered by the analysis and controls within the safety basis, and (2) Triad could strengthen the questionnaire that waste analysts use when they visually inspect materials before they are containerized and officially declared to be waste by tying the questionnaire to chemical compatibility evaluations.

N3B recently developed a chemical compatibility evaluation procedure [30], which is a positive step. However, N3B has not yet developed implementation guidance for this procedure. Further, N3B personnel do not have direct access to all information regarding the above-ground inventory of waste stored at Area G. Instead, they rely on processes defined by a series of agreements [31, 32] that require Triad to transmit waste information to N3B upon request. The lack of direct access to information makes it more difficult for N3B personnel to proactively perform adequate chemical compatibility evaluations of existing waste.

Hazard Analyses Summary. To fully evaluate the hazards from energetic chemical reactions, waste generator sites should incorporate both general chemical hazard analyses and systematic chemical compatibility evaluations of their waste into facility safety bases. The staff team identified that LANL facility safety bases include general chemical hazard analyses in facility safety bases, but some safety bases underestimate the amount of material that is released, as discussed in the *Inadequate Accident Analyses of Energetic Chemical Reactions* section of this report. Further, while some safety bases identify a specific chemical reaction hazard, LANL safety bases do not systematically evaluate the chemical compatibility of an entire waste stream.

A systematic chemical compatibility evaluation is needed in order to develop prevention strategies, such as waste compatibility controls. This evaluation could also identify containers at higher risk of undergoing an energetic chemical reaction that may need to be stored in locations with a more robust control set. Triad and N3B could integrate existing NTP chemical compatibility evaluations into LANL safety bases to ensure that the same level of protection provided at WIPP is also provided at the point of waste generation. Further, N3B should seek to gain direct access to all information regarding the above-ground inventory at Area G.

INADEQUATE ACCIDENT ANALYSES OF ENERGETIC CHEMICAL REACTIONS

The purpose of a hazard analysis is to consider all possible hazards and accidents and to qualitatively assess the consequences. From this analysis, a subset of accidents that can cause high consequences to members of the public are identified. These events are called "design basis accidents" (for new facilities) or "evaluation basis accidents" (for existing facilities) and the consequences are calculated as part of a safety basis' accident analysis [13, 14]. If the safety basis determines that no accidents lead to potentially high consequences, then an accident analysis is not needed.

Some LANL defense nuclear facilities assume inappropriate initial conditions in their accident analyses and do not conservatively estimate the quantity of radioactive material that may be released from an energetic chemical reaction event. As a result, LANL facility safety bases do not contain a bounding analysis that accounts for (1) the types of potential chemicals that could be present in waste drums or (2) the amount of radiological material that could be released from an energetic chemical reaction event. Accordingly, the safety bases may not identify adequate safety controls to protect workers and the public from this type of hazard.

DOE found that a large fraction of waste was released from the drum involved in the energetic chemical reaction event at WIPP [1]. DOE did not analyze the INL event to determine the amount of radioactive material released, but it also appears to have been higher than the amount that DOE standards would have predicted. Until recently, LANL facilities did not analyze an energetic event with a large release fraction in their accident analyses, even though LANL generated the waste drum that caused the WIPP event. Some LANL facilities have recently started addressing this through PISAs, and some have not. None of the facilities at LANL are using the effective release fraction of 0.205 that the Carlsbad Field Office derived after the WIPP event [33], but some are using 0.07. While the 0.07 value used at some LANL facilities is less than the 0.205 value DOE derived for the WIPP accident, it provides a quantitative estimate for the derivation of safety controls that is more than an order of magnitude higher than what is used at other LANL facilities. The Board has previously communicated with DOE regarding the need to develop a defensible release fraction for energetic chemical reactions [11, 16, 17, 18].

Plutonium Facility—As noted above, Triad personnel declared a PISA based on information contained in two reports [27, 28] that documented the possibility of reactive materials (materials unstable under normal conditions that may cause an explosion or violent reaction [2, 3]) being stored together that could lead to an autocatalytic thermal runaway reaction. One report, DWT-RPT-005, *Safety Evaluation of Nitric Acid Reactions with Polysaccharides*, states, "given the degree of uncertainty that encompasses many aspects of the TRU waste process amid the history of recorded events…it is not sufficiently conservative to state unequivocally that an autocatalytic cycle will be prevented in a TRU waste drum (i.e., a potential hazard to the generator site exists)."

The PF-4 safety basis did not previously analyze this type of hazard. Accordingly, Triad developed an evaluation of the safety of the situation (ESS) [34] that included this new accident scenario. This ESS analyzed data in DOE Handbook 3010-94, *Airborne Release Fractions/Rates* *and Respirable Fractions for Nonreactor Nuclear Facilities* [35], and concluded that modeling the event as an over-pressurization event, where a container holding dispersible powder (e.g., powders, granules, soil/gravel, or sand-like materials) ruptures at a pressure greater than 25 psig, bounds other release mechanisms. This release mechanism has an effective release fraction of 0.07.

Chemistry and Metallurgy Research Facility—Initially, CMR personnel evaluated the information from the two reports [27, 28] that describe interactions between polysaccharides, nitric acid, and metal nitrate salts and concluded that this information did not constitute a PISA. However after subsequent analysis, CMR personnel declared a PISA [36] and included a new hazard scenario in the safety basis that is identical to the PF-4 scenario described above.

Area G—The Area G safety basis does not analyze an energetic chemical reaction event that causes a significant release of radioactive material. The closest accident type analyzed in the Area G safety basis is a flammable gas deflagration[4] event involving combustible materials. During discussions with the Board's staff team, Area G safety basis personnel stated that an energetic chemical reaction that causes an accident with a release fraction of 0.07 is not credible due to the constituents of Area G waste. The Board's staff team has not seen sufficient evidence that supports this conclusion and is concerned that the Area G safety basis may not adequately analyze this credible hazard. Further, much of the waste currently stored at Area G originated from CMR and PF-4, and the CMR and PF-4 safety bases both analyze an event with significantly higher release fractions.

According to N3B personnel, approximately 2,000 Area G containers do not meet WIPP's waste acceptance criteria and will require remediation prior to shipment to WIPP. Many of these containers hold prohibited items; several hundred have reactive or ignitable waste characteristics [37]. Of note, NTP issued multiple nonconformance reports for existing waste containers at Area G that cannot be verified to preclude incompatible mixtures of organics and oxidizers. WIPP refused to accept these containers because their contents may be susceptible to energetic chemical reactions and propagating fires. For example, container 69506 is believed to contain 3 kilograms of organic kitty litter and 3 ounces of neutralized nitric acid containing metal nitrates [38]. Organic kitty litter and neutralized nitric acid containing metal nitrates were the main constituents in the energetic chemical reaction that caused the WIPP release event. It is important to note that the quantities of potentially incompatible materials in container 69506 are significantly less than the drum that caused the WIPP event and present a lower risk than the WIPP event drum. N3B personnel reviewed container 69506 [39] and determined that the hazard presented by this drum is "fully bounded by analyses within the Area G BIO [basis for interim operation]." However, as noted throughout this report, the Board's staff team has concerns with the technical basis used to support the analysis in the Area G BIO.

N3B's approach to not analyze an energetic chemical reaction event that causes a significant release of radioactive material is inconsistent with modern DOE directives. Specifically, DOE Standard 3009-2014 [14] allows analysts to exclude events that are not plausible; however, they must analyze an event if it has occurred previously within a nonreactor nuclear facility.

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[4] Appendix A: *Glossary and Additional Information* defines the term "deflagration."

The Area G safety basis is outdated and relies on DOE Standard 3011-2002, *Guidance for Preparation of Basis for Interim Operation (BIO) Documents* [40], which was developed for limited life facilities and requires significantly less rigor compared to DOE Standard 3009-2014. DOE Standard 3011 categorizes a limited life facility as "a facility with an approved deactivation plan calling for cessation of operation within a stated period (i.e., 5 years or less)." Area G will be operational for more than five years, and should not rely on a standard that provides less rigor than DOE Standard 3009.

N3B is currently updating its safety basis using an outdated version of DOE Standard 3011 and has no documented near-term plans to upgrade the safety basis to follow modern DOE requirements (i.e., DOE Standard 3009-2014). The current and planned update of the Area G safety basis may not provide the same level of protection as a modern safety basis. EM-LA and N3B have not generated a gap analysis to quantify the difference in the level of safety between using the two DOE standards.

Transuranic Waste Facility—TWF's safety basis analyzes an over-pressurization event in which a container holding dispersible powder ruptures at a pressure less than 25 psig. The TWF safety basis does not analyze a more severe over-pressurization event leading to the release of radioactive material as an evaluation basis accident. The safety basis [21, 22] states that such an event is precluded by the Material-at-Risk (MAR) Hazardous Chemical Constituents specific administrative control (SAC), which restricts TWF from accepting certain wastes. Successful implementation of this control is an initial condition in TWF's safety analysis.

While the chemical constituents SAC is an important control that can help prevent an energetic chemical reaction event, a safety basis should not treat this SAC as an initial condition that prevents analyzing the full suite of hazards. Relying on this initial condition circumvents the control selection process. Therefore, the Board's staff team is concerned that additional controls at TWF may be warranted.

DOE Standard 3009 normally does not allow analysts to credit administrative controls as an initial condition in the accident analysis. While the standard allows some exceptions, these are typically for controls that specify radiological inventories or concentrations. Radiological inventories can be measured and are needed to define meaningful accident scenarios. Identifying the presence of chemically reactive waste is more difficult, requires extensive analysis and evaluation, and is vulnerable to error or misjudgment.

Further, it is not prudent to assume that the waste generation facility correctly identifies all potential incompatibilities, as the identification process is difficult and susceptible to human error. In some cases, the documentation for the waste may be incomplete, making it difficult to perform a systematic evaluation. In recent years, LANL waste generation facilities have taken steps to improve this documentation, but older wastes may retain some vulnerability. Even if the composition of the waste is well understood, analysts at the generation facility may incorrectly conclude that a given waste type is not reactive.

Based on the information presented above, the staff team has concluded that the approach used by Triad at TWF to credit the chemical constituents SAC as an initial condition is inappropriate. In order to ensure that the hazard and accident analyses are thorough and address the "complete spectrum of hazards and accidents" [13], the safety basis should include a chemical reaction event that causes a drum over-pressurization greater than 25 psig, similar to the event analyzed at PF-4 and CMR.

Radiological Dose Consequences. As noted above, LANL facility safety bases use inconsistent, and in some cases inappropriate, effective release fractions when calculating the radiological dose consequences from accidents involving reactive waste. To illustrate these differences, the Board's staff team calculated the theoretical dose consequences for PF-4, CMR, TWF, and Area G using the effective release fractions listed in each safety basis and a common quantity of MAR. The staff team used 80 plutonium-239 equivalent curies (PE-Ci) for this analysis because it is the maximum quantity of MAR that WIPP will accept under its waste acceptance criteria for a direct-loaded standard 55-gallon drum [6]. Some LANL facilities have transuranic waste containers with greater amounts of MAR; others have no containers as high as 80 PE-Ci. The Board's staff team then calculated what the consequences would be if TWF and Area G used the same effective release fraction as PF-4 and CMR. Table 1 summarizes the results of this analysis. Appendix B provides a full description of the methodology used to develop Table 1.

Table 1. *Postulated Unmitigated Dose Consequences for an 80 PE-Ci Container*

Responsible Organizations	NA-LA & Triad		EM-LA & N3B
Facility	**PF-4 & CMR**	**TWF**	**Area G**
Accident Mechanism*	**Over-pressurization > 25 psig**	**Over-pressurization < 25 psig**	**Flammable gas deflagration**
Assumed Material Type*	**Dispersible Powders**	**Dispersible Powders**	**Combustible Materials**
Release Fraction*	**.07**	**0.002**	**0.00054**
Collocated Worker Dose (rem TED†) [Using Release Fraction from Safety Basis]	**760**	**22**	**5.9**
Collocated Worker Dose (rem TED) [Using Release Fraction = 0.07]	**Same as above‡**	**760**	**760**
Public Dose (rem TED) [Using Release Fraction from Safety Basis]	**PF-4: 24 CMR: 53**	**0.94**	**2.3**
Public Dose (rem TED) [Using Release Fraction = 0.07]	**Same as above‡**	**33**	**300**

* As assumed in facility safety bases.

† Total effective dose.

‡ PF-4 and CMR already use an effective release fraction of 0.07 in their safety bases.

As shown in Table 1, PF-4 and CMR used a significantly higher effective release fraction compared to what TWF and Area G used to calculate the dose consequences from an energetic chemical reaction event leading to the release of radioactive material.

TWF relies on an initial condition SAC to limit the severity of this event. As noted earlier, the Board's staff team has concluded that this approach is inappropriate. If TWF modeled this event in a manner similar to PF-4 and CMR, the theoretical dose consequences to the public would be 33 rem TED, and the dose consequences to the worker would be 760 rem TED. These values exceed DOE's Evaluation Guideline of 25 rem to the public and DOE's limit of 100 rem to the collocated worker [13, 14]. Consequently, TWF may need to implement additional controls to protect workers and the public.

The Area G safety basis models energetic chemical reaction events as a flammable gas deflagration involving combustible materials. Modeling this accident as a deflagration involving combustible materials underestimates the amount of material that may be released during an energetic chemical reaction and is inconsistent with the approach used by other LANL facilities, which store waste containers with similar contents. Use of an effective release fraction equivalent to what is used at PF-4 and CMR would increase the theoretical radiological dose consequences at Area G by more than a factor of 100. Specifically, the dose consequences to the public would increase to 300 rem TED, and the dose consequences to the worker would increase to 760 rem TED. These calculated consequences also exceed DOE's thresholds for identifying safety controls to protect the public and workers [13, 14].

Facility Inventory. The radiological dose consequences to the public, as listed in Table 1, are based on theoretical transuranic waste containers containing 80 PE-Ci of material. The majority of the transuranic waste containers stored at LANL contain significantly smaller quantities of MAR. Accordingly, the staff team reviewed transuranic waste container inventories at LANL facilities to determine how many containers could release sufficient material to result in an estimated dose consequence that challenges the Evaluation Guideline based on an analysis that uses an effective release fraction of 0.07. DOE Standard 3009-2014 defines a challenge to the Evaluation Guideline as "unmitigated off-site doses between 5 rem and 25 rem" and sets these as the criteria between which "SC [safety class] controls should be considered…."

To estimate how many containers present the potential for an elevated release fraction, the Board's staff team evaluated waste drums from waste streams that contain combustible waste, and excluded: containers with cemented waste (regardless of MAR content); containers with remediated and unremediated nitrate salt wastes that have been rendered non-reactive; containers buried underground; waste contained in a pipe overpack container or a standard waste box; and containers that NTP has certified for shipment to WIPP. The basis for these exclusions are: (1) the risk of a cemented drum undergoing an energetic release is sufficiently low, and cemented waste is not readily dispersible; (2) the remediated and unremediated nitrate salt waste containers have been treated with inerting material to render the waste non-reactive, which prevents this type of accident; (3) transuranic waste drums that are buried underground pose a significantly lower risk of airborne release to workers and members of the public; (4) overpacking provides additional protection that could reduce the consequences; and (5) the NTP analysis provides an extra layer of assurance that reduces the likelihood of this event.

Based on these exclusions, the staff team estimates that on the order of 100 transuranic waste containers stored at LANL could release sufficient material to result in a dose consequence estimate that challenges the Evaluation Guideline [13, 14] if an energetic reaction with a release fraction of 0.07 occurred within those drums. The Board's staff team concludes that there is insufficient detail in the safety bases to rule out the possibility of this type of accident, and additional evaluation may be warranted. Such an evaluation may conclude that these drums are non-reactive and that the existing control set is adequate to protect the public or the worker. Alternatively, LANL may determine that some containers present an elevated risk and implement additional controls.

It is important to note that even drums that do not have the potential to release sufficient material to result in a dose consequence that challenges DOE's Evaluation Guideline need multiple layers of controls to prevent or mitigate a release of radioactive material, consistent with DOE directives. This defense-in-depth concept is described in the *Facility Safety Posture and Control Strategy* section of this report.

Accident Analyses Summary. All transuranic waste generation and storage facilities at LANL should evaluate an energetic chemical reaction event that occurs within a waste container as an evaluation basis accident because of the complex chemical behavior exhibited by some waste (as demonstrated by the INL and WIPP events) and the existence of waste stored at LANL that exhibits reactive or ignitable characteristics.

DOE has not provided updated direction to reflect the consequences from an energetic chemical reaction event. As a result, LANL safety bases do not analyze hazards associated with energetic chemical reactions appropriately or consistently across facilities. PF-4 and CMR use a release fraction value of 0.07, TWF uses a value of 0.002, and Area G uses a value of 0.0054. There is substantial commonality in the waste constituents across all of these facilities; thus the differences in accident types and release fractions are not technically defensible. The appropriate use of elevated release fractions may drive the need for additional safety controls at some of these LANL facilities.

The Board's staff team performed an evaluation of the existing transuranic waste inventory at LANL (excluding containers with low risk of undergoing an energetic chemical reaction) and determined that on the order of 100 containers could release sufficient material to result in a dose consequence that challenges DOE's Evaluation Guideline [13, 14] if an energetic reaction with a release fraction of 0.07 occurred within those drums.

FACILITY SAFETY POSTURE AND CONTROL STRATEGY

Many transuranic waste generation and storage facilities rely on administrative controls as their first line of defense to prevent energetic chemical reactions from occurring within waste containers. These controls typically include waste acceptance criteria or other similar controls that prevent the commingling of specific reactive materials in a waste drum. While these administrative controls are important, their implementation relies on human performance, which adds uncertainty and reduces reliability.

DOE recognizes the importance of not relying on a single control to prevent or mitigate specific accidents and incorporates this "defense-in-depth" concept into its safety directives. As described in DOE Standard 3009-2014, "Defense-in-depth is a fundamental approach to hazard control for nuclear facilities that is based on several layers of protection to prevent the release of radioactive or other hazardous materials to the environment. These protective layers are generally redundant and independent of each other to compensate for unavoidable human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon." The standard requires that the "identification of hazard controls shall incorporate a defense-in-depth approach that builds layers of defense against release of radioactive or other hazardous materials so that no layer by itself, no matter how effective, is completely relied upon."

The radiological releases at WIPP and INL demonstrated the importance of incorporating multiple layers of protection to mitigate the dose consequences from an energetic chemical reaction. WIPP and INL relied on layers of protection, including confinement ventilation, to reduce the radiological dose consequences to workers and the public. Not all facilities in DOE's nuclear weapons complex have layers of controls to protect against energetic chemical reactions that may occur in waste containers. The Board has previously communicated with DOE regarding the need for improvements to control strategies to protect against this type of event [11, 16, 17].

The safety posture varies among LANL facilities that store transuranic waste. Some LANL facilities have established a robust control set with multiple engineered controls, whereas others rely solely on the waste containers. Table 2 summarizes the most applicable controls available at each facility to detect a release and to mitigate the dose consequences from an energetic chemical reaction event inside a waste container. The staff team notes that in addition to the controls listed in Table 2, LANL facilities overpack some drums and TWF imposes a waste acceptance criteria via a SAC, which would help mitigate or prevent the consequences of an energetic chemical reaction.

Among the controls listed in Table 2, confinement ventilation would provide the most protection for the collocated worker and the public against energetic chemical reaction events. A fire suppression system may provide some protection against fires that could initiate an energetic chemical reaction event or take place after an energetic chemical reaction event occurs. Detection of a release of radioactive material is important to allow for the timely initiation of emergency response. Detection would also help protect workers from inadvertently entering an area where a release occurred, especially in situations where there may not be obvious visual indications of a release. However, detection capabilities, such as continuous air monitors, must be appropriately sited, may not be effective in all situations, and should not be relied on as a primary control for mitigation. Additional controls such as overpack containers could help reduce the consequences of a release. Lid restraints and blast shields could also be employed to protect the facility worker from the physical impacts of this event.

Table 2. *Controls at LANL Transuranic Waste Storage Facilities*

Control		NA-LA & Triad				EM-LA & N3B
		PF-4		CMR	TWF	Area G
		Outdoor Pads	Inside			
Mitigation	Confinement Ventilation	No	Yes	Yes	No	No
	Fire Suppression	No	Yes	Yes	Yes	Varies*
Detection	Continuous Air Monitoring	No	Yes	Yes	No	No
	Frequency of Contamination Surveys During Storage	None	Monthly	Monthly	Quarterly	Weekly

* Several Area G storage domes have general service fire suppression capabilities.

CMR and Indoor Storage at PF-4—Transuranic waste containers can be stored inside the PF-4 and CMR buildings. These buildings provide a more robust storage area for transuranic waste compared to other facilities at LANL. LANL established many of the engineered controls available at CMR and PF-4 to mitigate the potential consequences due to other hazards. However, these controls are also effective at mitigating the radiological consequences from an energetic chemical reaction event.

Outdoor Storage at PF-4—Transuranic waste can be stored at two outdoor locations in Technical Area 55 outside PF-4: the high-efficiency neutron counter (HENC) pad (Figure 1) and the hazardous waste pad. Each waste pad can store up to 10.26 kg plutonium-239 equivalent waste for an indefinite period of time. As Table 2 and Figure 1 illustrate, the outdoor storage pads at PF-4 do not provide layers of controls to detect or mitigate the dose consequences from a release of radioactive material.

Figure 1. *LANL's HENC Pad Located Outside PF-4*

Transuranic Waste Facility—TWF stores, characterizes, and performs intra-site shipping of newly generated transuranic waste. This facility, which began operations in late 2017, stores waste inside multiple buildings. Each building has a fire suppression system that could help mitigate the dose consequences from an energetic chemical reaction, however the buildings do not have continuous air monitoring or a confinement ventilation system.

Area G—Area G does not have multiple layers of protection to prevent or mitigate a chemical reaction event. Area G stores transuranic waste in domes that typically consist of an aluminum frame with a fabric shell (Figure 2). While several storage domes have general service fire suppression capabilities, the Area G safety basis allows transuranic waste to be stored in domes that lack a fire suppression system. Area G personnel perform weekly radioactive contamination monitoring; however, the storage domes do not have continuous air monitors. Further, Area G personnel recently rolled back the Area G radiological buffer area, and associated radiological work permits no longer require workers to perform a radiological survey prior to exiting Area G.

Figure 2. *Area G Dome 49*

Facility Safety Posture and Control Strategy Summary. Some LANL facilities do not provide multiple layers of protection to prevent or mitigate the consequences of an energetic chemical reaction in a waste container. Given the complex chemical behavior exhibited by some waste (as demonstrated by the INL and WIPP events), additional controls beyond the waste container may be necessary to ensure the protection of workers and the public.

Although preferred, the Board's staff team does not believe that LANL needs to store all transuranic waste containers in facilities with confinement ventilation or fire suppression systems. Rather, LANL could preferentially store higher-risk waste containers (e.g., poorly characterized waste, waste with high quantities of MAR, waste that has not undergone a chemical compatibility evaluation, or waste with incompatible chemical constituents) in locations with more robust control sets. Further, other types of controls, such as overpack containers, lid restraints, blast shields, and detection capabilities could be used to mitigate the consequences of such an event. At a minimum, LANL should evaluate the existing control sets at all transuranic waste storage and generation facilities to determine if the facilities have adequate controls in place to protect workers and the public from energetic chemical reaction events that may occur in transuranic waste containers.

CONCLUSIONS

An energetic chemical reaction event, similar to those that occurred at WIPP and INL, can occur at transuranic waste generation, storage, or processing facilities due to the complex behavior exhibited by waste chemical constituents. Accordingly, each waste generation facility should appropriately analyze such an event in its hazard and accident analyses. From these analyses, the facility can then implement adequate controls, including multiple layers to provide defense-in-depth, to protect workers and the public.

The Board's staff team reviewed the PF-4, CMR, TWF, and Area G safety bases and concluded that the hazard and accident analyses do not appropriately analyze energetic chemical reaction hazards involving transuranic waste. As a result, LANL facilities may not have appropriate controls to protect workers and the public. Further, DOE directives do not provide adequate guidance and requirements for analyzing and controlling energetic chemical reaction events at waste generator sites. DOE should consider addressing this gap as it revises DOE Standard 5506.

REFERENCES

[1] Department of Energy, Office of Environmental Management, *Accident Investigation Report Phase 2, Radiological Release Event at the Waste Isolation Pilot Plant, February 14, 2014*, 2015.

[2] Code of Federal Regulations, Title 40, Part 261, *Identification and Listing of Hazardous Waste*, July 1, 2016.

[3] Environmental Protection Agency, *Hazardous Waste Characteristics: A User-Friendly Reference Document*, October 2009.

[4] Idaho Cleanup Project, *Formal Cause Analysis for the ARP V (WMF-1617) Drum Event at RWMC*, RPT-1659, Rev 1, April 2019.

[5] Idaho Cleanup Project, *Technical Analysis of Drum Lid Ejections-ARP V*, RPT-1662, November 2018.

[6] Department of Energy, *Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, Revision 9, October 18, 2018.

[7] Hatayama, H.K., J.J. Chen, and E.R. de Vera, *A Method for Determining the Compatibility of Hazardous Wastes,* Environmental Protection Agency, EPA-600/2-80-076, 1980.

[8] Department of Energy, *U.S. Department of Energy Implementation of Chemical Evaluation Requirements for Transuranic Waste Disposal at the Waste Isolation Pilot Plant*, DOE-EM-4.21-01, July 2017.

[9] Idaho Cleanup Project, *Chemical Compatibility and Inventory Evaluation for the Accelerated Retrieval Project*, EDF-5307, Rev 2, October 16, 2014.

[10] Advanced Mixed Waste Treatment Project, *Acceptable Knowledge Document for Pre-1980 INL-Exhumed SDA Waste*, RPT-TRUW-91, Rev 2, February 05, 2014, p. 46.

[11] Defense Nuclear Facilities Safety Board, *Idaho Waste Drums with Elevated Methane Concentrations*, Letter to Energy Secretary James R. Perry, March 12, 2019.

[12] Department of Energy, *Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities*, DOE-STD-5506-2007, April 2007.

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

[14] Department of Energy, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, DOE-STD-3009-2014, November 2014.

[15] Defense Nuclear Facilities Safety Board, *Waste Isolation Pilot Plant Documented Safety Analysis Review*, Letter to Energy Secretary Dan Brouillette, May 29, 2020.

[16] Defense Nuclear Facilities Safety Board, *Areas of Concern Related to DOE Standard 5506*, Letter to Energy Secretary Dan Brouillette, January 29, 2020.

[17] Defense Nuclear Facilities Safety Board, *Safety Management of Waste Storage and Processing in the Defense Nuclear Facilities Complex*, Public Hearing with the Department of Energy, June 20, 2019.

[18] Defense Nuclear Facilities Safety Board, *Deficiencies in DOE Standard 5506-2007, Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities*, DNFSB/TECH-43, 2018.

[19] Los Alamos National Laboratory, *Basis for Interim Operation for Technical Area 54, Area G*, ABD-WFM-001, Rev. 5.0, September 27, 2017.

[20] Los Alamos National Laboratory, *Technical Safety Requirements (TSRs) for Technical Area 54, Area G*, ABD-WFM-002, Rev. 5.0, September 27, 2017.

[21] Los Alamos National Laboratory, *Transuranic Waste Facility (TWF) Documented Safety Analysis*, DSA-TWF-001-R2.3, October 30, 2018.

[22] Los Alamos National Laboratory, *Technical Safety Requirements for Transuranic Waste Facility (TWF)*, TSR-TWF-002-R2.3, October 30, 2018.

[23] Los Alamos National Laboratory, *TA-55 Documented Safety Analysis*, TA55-DSA-2018-R0, August 6, 2018.

[24] Los Alamos National Laboratory, *TA-55 Technical Safety Requirements (TSRs)*, TA55-TSR-2018-R0, August, 6, 2018.

[25] Los Alamos National Laboratory, *Chemistry and Metallurgy Research Facility Documented Safety Analysis*, CMR-DSA-001-R8, December 2018.

[26] Los Alamos National Laboratory, *Chemistry and Metallurgy Research Facility Technical Safety Requirements (TSRs)*, CMR-TSR-002-R8, December 2018.

[27] Los Alamos Field Office Carlsbad Operations, *Safety Evaluation of Nitric Acid Reactions with Polysaccharides*, DWT-RPT-005-R1, Carlsbad, NM, January 23, 2019.

[28] Los Alamos National Laboratory Carlsbad Operations, *Safety Evaluation of Remediated Nitrate Salt Waste*, DWT-RPT-006-R0, Carlsbad, NM, April 15, 2019.

[29] Schoen, James M., *Chemical Compatibility Evaluation for Waste Stream LA-MHD01.001 Full Waste Stream (AK Source Document CCE18)*, AK-TA55-1257, June 27, 2019.

[30] Los Alamos National Laboratory, *Waste Compatibility*, N3B-AP-TRU-2009, R.0, July 30, 2020.

[31] Los Alamos National Laboratory, *Waste Services*, SAWA M&O-008, Revision 3, September 2019.

[32] Los Alamos National Laboratory, *Business Management Services*, SAWA M&O-007, Revision 3, September 2019.

[33] Hunt, S.W., *DOE Carlsbad Field Office Letter to P. Breidenbach, Nuclear Waste Partnership, regarding Corrective Actions and Bounding Exothermic Event Evaluation*, 2015.

[34] Los Alamos National Laboratory, *Evaluation of the Safety of the Situation TA-55 Nitric Acid and Polysaccharide Interaction*, ESS-TA55-130-R1, October 4, 2019.

[35] Department of Energy, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, Change Notice 1, Washington DC, March 2000, Reaffirmed 2013.

[36] Los Alamos National Laboratory, *CMR Nitric Acid and Polyol Interaction: Further Information Bounding Respirable Release Parameter*, NI-CMR-3103, December 13, 2019.

[37] Defense Nuclear Facilities Safety Board, *Resident Inspector Weekly Report: Los Alamos National Laboratory*, November 1, 2019.

[38] Greenwood, Trey, *Basis of Knowledge Criteria Evaluation for Containers in Waste Stream LA-MHD03.001*, June 25, 2019.

[39] Los Alamos National Laboratory, *Initial Confirmatory Process Form: Area G TRU Waste Drums May Contain Nitrates Absorbed with Organic Polyol*, IC-AREAG-19-001, Rev 1, June 17, 2020.

[40] Department of Energy, *Guidance for Preparation of Basis for Interim Operation (BIO) Documents*, DOE-STD-3011, December 2002.

APPENDIX A—Glossary and Additional Information

Deflagration. A type of explosion involving the ignition and combustion of a flammable gas or vapor. Nuclear waste often emits hydrogen, but other gases or vapors can also present a hazard. A deflagration can occur if the flammable gas is present in a sufficient concentration together with sufficient oxygen or other oxidizer and an ignition source. The flame propagates rapidly, but at less than the speed of sound. There are many possible sources of the flammable gas or vapor, such as radiolysis, chemical reactions, microbial activity, evaporation of solvents, and leaks of stored gas.

Energetic chemical reaction. A chemical reaction with the potential to cause adverse effects due to the release of heat or gases. Possible adverse effects include fires in process areas or over-pressurization of waste containers.

Over-pressurization. Any event that causes the pressure inside a waste container to increase to the point that the container fails in some way, leading to a release of radiological material. DOE Standard 5505-2007, *Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities*, states that the "pressure buildup may be due to radiolysis…, thermal expansion of material/gases inside the container, or chemical reactions inside the container." While a deflagration can also cause the over-pressurization of a container, DOE Standard 5506-2007 treats deflagrations as a distinct type of accident.

APPENDIX B—Radiological Dose Consequences across LANL Facilities

Background and Objective. The safety bases for facilities that store transuranic waste at Los Alamos National Laboratory (LANL) calculate the radiological dose consequences from energetic events involving reactive waste differently. Specifically, the Plutonium Facility (PF-4) and the Chemistry and Metallurgy Research Facility (CMR) model this event as an over-pressurization event, where a container holding dispersible powder (e.g., powders, granules, soil/gravel, or sand-like materials) ruptures at a pressure greater than 25 psig. The Transuranic Waste Facility (TWF) models this event as an over-pressurization where a container holding dispersible powder ruptures at a pressure less than 25 psig. Area G models this event as a flammable gas deflagration involving a drum containing combustible waste. While a deflagration can also cause the over-pressurization of a container, DOE Standard 5506-2007, *Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities* [B-1], treats deflagrations as a distinct type of accident. The different models result in effective release fractions that vary by more than a factor of 100, which directly affects the radiological dose consequence calculations. This can have a major impact on the resulting control set used to protect workers and the public.

The objectives of this calculation are to: (1) show how different LANL facilities calculate the radiological dose consequences from accidents involving reactive waste, and (2) show how changes in the effective release fraction for reactive waste accidents impact the calculated dose consequences in LANL safety analyses. To illustrate these differences, the Defense Nuclear Facilities Safety Board's (Board) staff team calculated the radiological dose consequences for PF-4, CMR, TWF, and Area G using the same quantity of material-at-risk (MAR). The staff team then calculated what the consequences would be if TWF and Area G used the same effective release fraction as PF-4 and CMR.

The staff team used facility-specific relative airborne concentration values to calculate the radiological dose consequences to the public. This parameter, χ/Q', represents the dilution of the radioactive plume via dispersion and deposition as it travels from the facility during an accident. The χ/Q' value differs for each facility as it depends on the distance between the release point and the site boundary, and other factors. The staff team used the Department of Energy (DOE) default χ/Q' value to calculate the consequences to the collocated worker. The collocated worker consequences are calculated at 100 m from the release point, regardless of where the facility is located. The staff team selected this value to highlight the impact that the effective release fraction has on the calculated dose consequences without introducing additional variables.

Limitations. The staff team's calculation uses the methodologies and assumptions made in the facility-specific safety bases, except as noted below. In order to compare dose consequences consistently across facilities, the staff team used ground-level release conditions when selecting facility-specific χ/Q' values. The staff team did not evaluate whether the assumptions used to calculate the χ/Q' values were technically justified.

Assumptions and Input Parameters. A list of assumptions and input parameters that the staff team used to support this calculation appear below. This section is split into two parts: (1) Common Parameters across LANL Facilities, and (2) Facility Specific Parameters and Parameters used for Comparison Purposes.

Common Parameters across LANL Facilities.

Material-at-Risk:

80 Plutonium-239 Equivalent Curies (PE-Ci)

Basis: The staff team selected this value because it is the maximum amount of MAR that the Waste Isolation Pilot Plant (WIPP) will accept under its waste acceptance criteria (WAC) for a direct loaded standard 55-gallon drum [B-2]. Note: some LANL facilities have transuranic waste containers with greater quantities of MAR; others have no containers as high as 80 PE-Ci.

Relative Airborne Concentration (χ/Q') [Collocated Worker]:

3.5E-03 s/m^3

Basis: DOE uses this default χ/Q' value to calculate the radiological dose consequences to the collocated worker [B-3]. Note: the facility-specific collocated worker χ/Q' value may differ per facility; however, for comparison purposes, the staff team selected the DOE default value.

Leak Path Factor (LPF):

1

Basis: DOE uses this LPF, as documented in DOE Standard 3009-2014 [B-3] and DOE Standard 3009-94 [B-4].

Dose Conversion Factor (DCF):

1.85E+08 rem/PE-Ci [public]

1.18E+08 rem/PE-Ci [collocated worker]

Basis: DOE Standard 3009-2014 states that DCFs (or dose coefficients) published by the International Commission on Radiological Protection (ICRP) "shall be used." In particular, the standard specifies the use of ICRP Publication 68 for estimates of worker dose [B-5], and Publication 72 for dose to the public [B-6].

ICRP presents different DCF values for different lung clearance types (F, M, and S). Different chemical forms of the radionuclides are assigned to different types, depending on their behavior inside the body. The choice of clearance type should be consistent with the assumptions for MAR. In this staff calculation, MAR is expressed in terms of PE-Ci, as defined in Appendix B of the WIPP WAC [B-2]. The WAC states that the PE-Ci concept is based on plutonium-239 with "a weekly [W] pulmonary clearance class." The WAC uses an older system of conversion factors; according to the ICRP [B-5], clearance types F, M, and S correspond "broadly" to the older classes D, W, and Y, respectively. The staff team thus selected dose conversion factors for type M Pu-239.

For the worker, ICRP 68 tabulates factors for different particle sizes: 1 micron and 5 microns, activity mean aerodynamic diameter. ICRP 68 recommends the 5 micron value as a default [B-5]. Accordingly, the staff team selected the 5 micron value as a default.

Based on the discussion above, the staff team selected the following values from the relevant ICRP publications:

- For the public, 5.0E-05 Sieverts (Sv)/Becquerel (Bq).
- For the worker, 3.2E-05 Sv/Bq.

To be consistent with the units used in this calculation, the staff team converted these coefficients to units of rem/curie as follows:

$$\left(5.0\text{E-05 } \frac{\text{Sv}}{\text{Bq}}\right) \times \left(100 \ \frac{\text{rem}}{\text{Sv}}\right) \times \left(3.7\text{E+10 } \frac{Bq}{\text{Ci}}\right) = 1.85\text{E+08} \frac{\text{rem}}{\text{Ci}} \text{ (for public)}$$

$$\left(3.2\text{E-05 } \frac{\text{Sv}}{\text{Bq}}\right) \times \left(100 \ \frac{\text{rem}}{\text{Sv}}\right) \times \left(3.7\text{E+10 } \frac{Bq}{\text{Ci}}\right) = 1.18\text{E+08} \frac{\text{rem}}{\text{Ci}} \text{ (for worker)}$$

Breathing Rate (BR):

3.3E-04 m^3/s

Basis: Area G [B-7], TWF [B-8], PF-4 [B-9], and CMR [B-10] safety bases use a breathing rate of 3.3E-04 m^3/s. DOE Standard 3009-2014 and DOE Standard 5506-2007 also list this as the default breathing rate.

Facility Specific Parameters and Parameters used for Comparison Purposes.

Area G:

Relative Airborne Concentration (χ/Q') [Public]:

8.66E-04 s/m^3

Basis: The Area G safety basis uses this value for a release from TA-54-033. The staff team selected the "spill release." This value corresponds to a release that does not credit plume meander, which is consistent with the release methodology used at other LANL facilities. See page 3-78 of the Area G Basis for Interim Operation [B-7].

Effective Release Fraction – Deflagration [ARFxRFxDR]:

5.4E-04

Basis: DOE Standard 5506, Appendix B, page 51, lists this value as the overall effective release fraction for a flammable gas deflagration event involving a drum containing combustible waste. The effective release fraction is a combination of the airborne release fraction (ARF), the respirable fraction (RF), and the damage ratio (DR). The Area G safety basis also uses this combined value for the deflagration event scenario, see page 3-157 [B-7].

Effective Release Fraction – Pressurized Release >25 psig [ARFxRFxDR]:

7.0E-02

Basis: PF-4 and CMR use this effective release fraction value for accidents involving a drum containing dispersible powder that could undergo a runaway exothermic reaction (the technical basis for this value is defined in the PF-4 and CMR sections below). The staff team used this value with Area G specific parameters for comparison purposes to determine the consequences to workers and the public if a similar accident occurred at Area G.

TWF:

Relative Airborne Concentration (χ/Q') [Public]:

9.59E-05 s/m^3

Basis: The TWF safety basis uses this value to determine the potential dose consequences to the public. See page 3-80 [B-8].

Effective Release Fraction – Pressurized Release <25 psig [ARFxRFxDR]:

2.0E-03

Basis: The TWF safety basis states, "For internal pressure mechanisms causing a failure of a container associated with Event 12 [a waste over-pressurization event] from DOE-STD-5506-2007, the ARF × RF value from DOE-HDBK-3010-94 for pressurized releases less than 25 psig is the most appropriate value to use; the ARF value for this event is 5E-03 and the RF is 0.4, for a combined ARF × RF value of 2E-03." See page 3-78 [B-8]. This effective release fraction value is for "powders, granules, soil/gravel, or sand-like materials."

Effective Release Fraction – Pressurized Release >25 psig [ARFxRFxDR]:

7.0E-02

Basis: PF-4 and CMR use this effective release fraction value for accidents involving a drum containing dispersible powder that could undergo a runaway exothermic reaction (the technical basis for this value is defined in the PF-4 and CMR sections below). The staff team used this value with TWF specific parameters for comparison purposes to determine what the consequences to workers and the public would be if TWF modeled a similar accident.

PF-4:

Relative Airborne Concentration (χ/Q') [Public]:

7.13E-05 s/m^3

Basis: The PF-4 documented safety analysis (DSA) uses this χ/Q' value for ground-level releases, see page 3-127 [B-9]. Note: an elevated release provides a more conservative χ/Q'; however, for comparison to other facilities, the staff team selected the ground-level release value.

Effective Release Fraction – Pressurized Release >25 psig [ARFxRFxDR]:

7.0E-02

Basis: The PF-4 evaluation of the safety of the situation (ESS) [B-11] identifies an ARFxRF value of 7.0E-02 for a runaway exothermic reaction in a drum. The ESS indicates that DOE Standard 5506 does not list effective release fraction values for this type of event. Instead, the ESS uses an effective release fraction value from related phenomena. Specifically, the ESS uses a value of 0.07, which is based on the pressurized venting of dispersible powders (e.g., soil/gravel, powder, granules) at pressures greater than 25 psig, and is consistent with DOE Handbook 3010 [B-12].

CMR:

Relative Airborne Concentration (χ/Q') [Public]:

1.55E-04 s/m^3

Basis: The atmospheric dispersion calculation [B-13] used to support the CMR DSA uses this χ/Q' value for ground-level releases. Note: an elevated release provides a more conservative χ/Q'; however, for comparison to other facilities, the staff team selected a ground-level release.

Effective Release Fraction – Pressurized Release >25 psig [ARFxRFxDR]:

7.0E-02

Basis: CMR safety basis personnel declared a potential inadequacy of the safety analysis (PISA) [B-14] and developed a subsequent ESS [B-15]. The PISA concluded that the CMR safety basis did not include an evaluation of an autocatalytic chemical reaction in a transuranic waste container and that the consequences from such an event could exceed what was previously analyzed. The ESS indicates that DOE Standard 5506 does not list effective release fraction values for this type of event. Instead, the ESS uses an effective release fraction value from related phenomena. Specifically, the ESS uses a value of 0.07, which is based on the pressurized venting of dispersible powders (e.g., soil/gravel, powder, granules) at pressures greater than 25 psig, and is consistent with DOE Handbook 3010 [B-12].

Analytical Methods and Computations. As described in DOE Standard 3009-14 and in DOE Standard 5506-2007, the radiological dose is calculated as follows:

$$Source\ Term\ (ST) = MAR \times DR \times ARF \times RF \times LPF$$
$$Dose = ST \times \frac{\chi}{Q'} \times DCF \times BR$$

Area G Deflagration:

$$ST = MAR \times DR \times ARF \times RF \times LPF$$
$$ST = (80PE\text{-}Ci) \times (1) \times (5.4E\text{-}04) \times (1)$$
$$= 4.3E\text{-}02\ \ PE\text{-}Ci$$

$$Dose = ST \times \frac{\chi}{Q'} \times DCF \times BR$$

Public Dose

$$=(\ 4.3\text{E-}02\ \text{PE-Ci})\times\left(8.66\text{E-}04\frac{\text{s}}{\text{m}^3}\right)\times\left(1.85\text{E+}08\frac{\text{rem}}{\text{PE-Ci}}\right)\times\left(3.3\text{E-}04\frac{\text{m}^3}{\text{s}}\right)$$

$=2.3$ rem

Collocated Worker Dose

$$=(\ 4.3\text{E-}02\ \text{PE-Ci})\times\left(3.5\text{E-}03\frac{\text{s}}{\text{m}^3}\right)\times\left(1.18\text{E+}08\frac{\text{rem}}{\text{PE-Ci}}\right)\times\left(3.3\text{E-}04\frac{\text{m}^3}{\text{s}}\right)$$

$=5.9$ rem

Area G Pressurized Release >25 psig:

$$ST = MAR \times DR \times ARF \times RF \times LPF$$
$$ST = (80PE\text{-}Ci) \times (1) \times (7.0E\text{-}02) \times (1)$$
$$= 5.6\ PE\text{-}Ci$$

$$Dose = ST \times \frac{\chi}{Q'} \times DCF \times BR$$

Public Dose

$$=(\ 5.6\ \text{PE-Ci})\times\left(8.66\text{E-}04\,\frac{\text{s}}{\text{m}^3}\right)\times\left(1.85\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right)\times\left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$

$=300$ rem

Collocated Worker Dose

$$=(\ 5.6\ \text{PE-Ci})\times\left(3.5\text{E-}03\,\frac{\text{s}}{\text{m}^3}\right)\times\left(1.18\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right)\times\left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$

$=760$ rem

TWF Pressurized Release <25 psig:

$$ST = MAR \times DR \times ARF \times RF \times LPF$$
$$ST = (80PE\text{-}Ci) \times (1) \times 2E\text{-}03 \times (1)$$
$$= 1.6E\text{-}01\ PE\text{-}Ci$$

$$Dose = ST \times \frac{\chi}{Q'} \times DCF \times BR$$

Public Dose

$$=(\ 1.6\text{E-}01\ \text{PE-Ci})\times\left(9.59\text{E-}05\,\frac{\text{s}}{\text{m}^3}\right)\times\left(1.85\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right)\times\left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$

$=0.94$ rem

Collocated Worker Dose

$$=(\ 1.6\text{E-}01\ \text{PE-Ci})\times\left(3.5\text{E-}03\,\frac{\text{s}}{\text{m}^3}\right)\times\left(1.18\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right)\times\left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$

$=22$ rem

TWF Pressurized Release >25 psig:

$$ST = MAR \times DR \times ARF \times RF \times LPF$$
$$ST = (80PE\text{-}Ci) \times (1) \times (7.0E\text{-}02) \times (1)$$
$$= 5.6\ PE\text{-}Ci$$

$$Dose = ST \times \frac{\chi}{Q'} \times DCF \times BR$$

Public Dose

$$=(5.6\ \text{PE-Ci}) \times \left(9.59\text{E-}05\,\frac{\text{s}}{\text{m}^3}\right) \times \left(1.85\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right) \times \left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$
$$=33\ \text{rem}$$

Collocated Worker Dose

$$=(\ 5.6\ \text{PE-Ci}) \times \left(3.5\text{E-}03\,\frac{\text{s}}{\text{m}^3}\right) \times \left(1.18\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right) \times \left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$
$$=760\ \text{rem}$$

PF-4 Pressurized Release >25 psig:

$$ST = MAR \times DR \times ARF \times RF \times LPF$$
$$ST = (80PE\text{-}Ci) \times (1) \times (7.0E\text{-}02) \times (1)$$
$$= 5.6\ PE\text{-}Ci$$

$$Dose = ST \times \frac{\chi}{Q'} \times DCF \times BR$$

Public Dose

$$=(5.6\ \text{PE-Ci}) \times \left(7.13\text{E-}05\,\frac{\text{s}}{\text{m}^3}\right) \times \left(1.85\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right) \times \left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$
$$=24\ \text{rem}$$

Collocated Worker Dose

$$=(\ 5.6\ \text{PE-Ci}) \times \left(3.5\text{E-}03\,\frac{\text{s}}{\text{m}^3}\right) \times \left(1.18\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right) \times \left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$
$$=760\ \text{rem}$$

CMR Pressurized Release >25 psig:

$$ST = MAR \times DR \times ARF \times RF \times LPF$$
$$ST = (80PE\text{-}Ci) \times (1) \times (7.0E\text{-}02) \times (1)$$
$$= 5.6\ PE\text{-}Ci$$

$$Dose = ST \times \frac{\chi}{Q'} \times DCF \times BR$$

Public Dose

$$=(5.6\ \text{PE-Ci}) \times \left(1.55\text{E-}04\,\frac{\text{s}}{\text{m}^3}\right) \times \left(1.85\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right) \times \left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$
$$=53\ \text{rem}$$

Collocated Worker Dose

$$=(\ 5.6\ \text{PE-Ci}) \times \left(3.5\text{E-}03\,\frac{\text{s}}{\text{m}^3}\right) \times \left(1.18\text{E+}08\,\frac{\text{rem}}{\text{PE-Ci}}\right) \times \left(3.3\text{E-}04\,\frac{\text{m}^3}{\text{s}}\right)$$
$$=760\ \text{rem}$$

Results and Conclusions. Table B-1 illustrates that LANL facilities calculate the consequences from energetic chemical reactions differently from each other. Specifically, PF-4 and CMR model this event as an over-pressurization in which a container holding dispersible powder (e.g., powders, granules, soil/gravel, or sand-like materials) ruptures at a pressure greater than 25 psig. TWF models this event as an over-pressurization in which a container holding dispersible powder ruptures at a pressure less than 25 psig. Area G models this event as a flammable gas deflagration involving a drum containing combustible waste. If Area G and TWF modeled this type of event consistently with PF-4 and CMR, the calculated radiological dose consequences could exceed the evaluation guideline of 25 rem to the public and the DOE limit of 100 rem to the collocated worker. As a result, these facilities may require additional controls to protect workers and the public. Note: The staff team did not evaluate whether the assumptions used to calculate the facility-specific or DOE-default χ/Q’ values, which are used in the final dose consequence calculation, were technically justified.

Table B-1. *Postulated Unmitigated Dose Consequences for an 80 PE-Ci Container*

Responsible Organizations	NA-LA & Triad		EM-LA & N3B
Facility	**PF-4 & CMR**	**TWF**	**Area G**
Accident Mechanism*	**Over-pressurization > 25 psig**	**Over-pressurization < 25 psig**	**Flammable gas deflagration**
Assumed Material Type*	**Dispersible Powders**	**Dispersible Powders**	**Combustible Materials**
Release Fraction*	**.07**	**0.002**	**0.00054**
Collocated Worker Dose (rem TED†) [Using Release Fraction from Safety Basis]	**760**	**22**	**5.9**
Collocated Worker Dose (rem TED) [Using Release Fraction = 0.07]	**Same as above‡**	**760**	**760**
Public Dose (rem TED) [Using Release Fraction from Safety Basis]	**PF-4: 24 CMR: 53**	**0.94**	**2.3**
Public Dose (rem TED) [Using Release Fraction = 0.07]	**Same as above‡**	**33**	**300**

* As assumed in facility safety bases.

† Total effective dose.

‡ PF-4 and CMR already use an effective release fraction of 0.07 in their safety bases.

Appendix B References

[B-1] Department of Energy, *Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities*, DOE-STD-5506-2007, April 2007.

[B-2] Department of Energy, *Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, Revision 9, October 18, 2018.

[B-3] Department of Energy, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, DOE-STD-3009-2014, November 2014.

[B-4] Department of Energy, *Preparation Guide for U. S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, DOE-STD-3009-94, Change Notice 3, March 2006.

[B-5] International Commission on Radiological Protection, *Dose Coefficients for Intakes of Radionuclides by Workers*, ICRP Publication 68, 1994.

[B-6] International Commission on Radiological Protection, *Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients*, ICRP Publication 72, 1996.

[B-7] Los Alamos National Laboratory, *Basis for Interim Operation for Technical Area 54, Area G*, ABD-WFM-001, Rev. 5.0, September 27, 2017.

[B-8] Los Alamos National Laboratory, *Transuranic Waste Facility (TWF) Documented Safety Analysis*, DSA-TWF-001-R2.3, October 30, 2018.

[B-9] Los Alamos National Laboratory, *TA-55 Documented Safety Analysis*, TA55-DSA-2018-R0, August 6, 2018.

[B-10] Los Alamos National Laboratory, *Chemistry and Metallurgy Research Facility Documented Safety Analysis*, CMR-DSA-001-R9, January 7, 2020.

[B-11] Los Alamos National Laboratory, *Evaluation of the Safety of the Situation TA-55 Nitric Acid and Polysaccharide Interaction*, ESS-TA55-130-R1, October 4, 2019.

[B-12] Department of Energy, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, Change Notice 1, Washington DC, March 2000, Reaffirmed 2013.

[B-13] Los Alamos National Laboratory, *Chemistry and Metallurgy Research (CMR) Building Atmospheric Dispersion Parameter – 2012, 2014, 2015, 2017, 2018 CY Meteorological Data*, SBD-CALC-CMR-133, November 2019.

[B-14] Los Alamos National Laboratory, *CMR Nitric Acid and Polyol Interaction: Further Information Bounding Respirable Release Parameter*, NI-CMR-3103, December 13, 2019.

[B-15] Los Alamos National Laboratory, *Evaluation of the Safety of the Situation CMR Nitric Acid and Polysaccharide Interaction*, ESS-CMR-136, January 23, 2020.