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**DEFENSE NUCLEAR FACILITIES
SAFETY BOARD**

Washington, DC 20004-2901



September 15, 2021

The Honorable Jennifer Granholm
Secretary of Energy
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-0701

Dear Secretary Granholm:

The Defense Nuclear Facilities Safety Board reviewed the documented safety analysis (DSA) for Hanford's Tank Farms facility. The Board found that the Tank Farms DSA is based upon a dated methodology and lacks sufficient documentation to support its conclusions regarding risk to the workers and the public. It does not present a thorough and rigorous analysis for key operational upset conditions, and therefore does not meet the requirements and guidance set out in DOE Standard 3009-1994, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*. Consequently, the Board is concerned that the DSA does not provide DOE with sufficient information to accurately assess the consequences of accidents that could affect the public. The enclosed report summarizes the Board's findings.

A modern, updated DSA will be necessary to ensure a smooth transition to the next phases of Tank Farm operations, which will involve changing tank waste conditions and an increased operational tempo as the Tank Farms mission expands and the Waste Treatment and Immobilization Plant's Low Activity Waste Facility starts up in late 2023. While the Board understands that significant effort would be required to revise the Tank Farms DSA to address the issues outlined, we believe it is important that DOE do so in the near term. A revision prior to the start of the Tank Farms' support of the Hanford Site Direct Feed, Low-Activity Waste mission would allow DOE to ensure that those operations are supported by rigorous and conservative hazard control methods and decisions based on current information, improved analytical methods, and updated criteria resulting in greater assurance for public and worker protection.

Lastly, the Board notes that DOE most recently revised Standard 3009 in 2014. However, the current Tank Farms DSA is written to the 1994 version of the standard. The safety analyses in the DSA would benefit from the additional rigor and structure of the 2014 revision of

the standard. It would be prudent for DOE to take this opportunity to update the safety analysis methodology within the Tank Farms DSA in accord with DOE's own most current guidance.

Sincerely,

A handwritten signature in cursive script that reads "Joyce L. Connery".

Joyce L. Connery
Chair

Enclosure

c: Mr. William I. White
Mr. Brian Vance
Mr. Joe Olencz

HANFORD TANK FARMS SAFETY BASIS REVIEW

Defense Nuclear Facilities Safety Board Technical Report



SEPTEMBER 2021

HANFORD TANK FARMS SAFETY BASIS REVIEW



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EXECUTIVE SUMMARY

Members of the Defense Nuclear Facilities Safety Board's (Board) staff reviewed the Tank Farms documented safety analysis (DSA) [1] to evaluate its compliance with the requirements of Title 10, Code of Federal Regulations, Part 830, *Nuclear Safety Management* (10 CFR 830) [2], and associated standards, including DOE Order 420.1B, *Facility Safety* [3], and DOE-STD-3009-1994-CN3, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses* [4]. The staff team developed lines of inquiry and discussed them with the Department of Energy (DOE)-Office of River Protection (ORP) and Washington River Protection Solutions (WRPS) in December 2018, March 2019, and April 2019.

The scope of the staff team's review included the safety basis and hazard controls that DOE had approved at the time of the review. As a result of this review, the staff team concluded that the Tank Farms DSA lacks sufficiently rigorous technical content pertaining to the selection and analysis of some important design basis accident scenarios. In addition, some controls important to safety do not have the expected level of formality or classification per DOE standards.

Of particular note, the consequence analyses for design basis accidents related to accumulation of flammable gases in the tanks are dated and neither DOE nor WRPS were able to provide some of the supporting documentation. Additionally, the basis for assumptions that support the analyses lack adequate technical justification. Lastly, the methods used lack the transparency necessary to validate the conservatism of DOE's approach. Although the expert elicitation process used by DOE may have been the most viable method at the time (1990s), modern DOE guidance (such as DOE-STD-3009-1994-CN3 and its successor document, DOE-STD-3009-2014) suggests a more rigorous and quantitative process should be used for hazard and accident analyses.

The DSA does not provide DOE with sufficient information to accurately assess the consequences of accidents that could affect the public. DOE needs this information to validate that the contractor has selected appropriate controls, and to ensure adequate protection of the public and workers. The body of this report details the deficiencies identified. Unless such issues are addressed, the Tank Farms DSA does not align with requirements and/or guidance in either DOE-STD-3009-1994-CN3 or its successor document, DOE-STD-3009-2014.¹

¹ The code of record for the Tank Farms DSA lists the 1994 version of DOE-STD-3009, rather than the 2014 version, so the staff team compared the DSA to the former from a requirements perspective. However, the staff notes that DOE intended the 2014 version to be a clarification of the requirements in the 1994 version, rather than an expansion of them. Consequently, it is still instructive to compare and contrast the DSA to both standards.

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INTRODUCTION

Members of the Defense Nuclear Facilities Safety Board's (Board) staff reviewed the Tank Farms documented safety analysis (DSA) [1] to evaluate its compliance with the requirements of Title 10, Code of Federal Regulations, Part 830, *Nuclear Safety Management* (10 CFR 830) [2], and associated standards, including DOE Order 420.1B, *Facility Safety* [3], and DOE-STD-3009-1994-CN3, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses* [4]. The staff team developed lines of inquiry and discussed them with the Department of Energy (DOE)-Office of River Protection (ORP) and Washington River Protection Solutions (WRPS) in December 2018, March 2019, and April 2019.

The scope of the staff team's review included the safety basis and hazard controls that DOE had approved at the time of the review. Because the code of record for the Tank Farms DSA lists the 1994 version of DOE-STD-3009, rather than the 2014 version, the staff team compared the DSA to the former from a requirements perspective. However, the staff notes that DOE intended the 2014 version to be a clarification of the requirements in the 1994 version, rather than an expansion of them. Consequently, it is still instructive to compare and contrast the DSA to both standards.

BACKGROUND

The Hanford Site Tank Farms house 177 tanks, which hold over 56 million gallons of very high hazard mixed radiological and chemical waste. The tanks are either past or approaching the end of their design life. The oldest tanks were built in the 1940s and the newest in the 1980s. The Tank Operations Contractor, Washington River Protection Solutions (WRPS), is responsible for the safe and efficient management of the hazardous waste stored in the tanks, and for preparing to deliver the tank waste to the Waste Treatment and Immobilization Plant for vitrification. DOE is also considering other tank waste disposal options. This important mission is expected to last more than 40 years and will be conducted using the aging tanks and support systems that exist in the tank farms, as well as temporary systems, such as hose-in-hose waste transfer systems that support individual mission activities. WRPS performs this mission using hazard controls identified in the Tank Farms documented safety analysis (DSA) [1]. The DSA was developed using the methods and requirements defined in DOE-STD-3009-1994, *Preparation Guide for U. S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses* [4].

The hazards associated with the Hanford tank farms are significant and the Board has had a long-standing history of working with DOE to control these hazards to protect workers and the public. Previous efforts by both organizations have resulted in significant improvements that prevent potential deflagrations or detonations in tanks by ensuring that flammable gases do not routinely collect in tank head spaces. However, these established methods for controlling the hazards cannot fully prevent events that could result from episodic releases of flammable gases that have become trapped and thus accumulated below the tank surface. For the most part, DOE has accepted this risk based on limited information that appears to indicate that the potential impact to the public is relatively low. Since 2010, the Board and DOE have conducted an extensive dialogue on this topic¹, including Board Recommendation 2012-2 [5][6][7][8].

Separately, DOE issued DOE-STD-3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, in November 2014 [9]. DOE's stated goal for the revised standard was "to provide clearer criteria and guidance to support effective and consistent DSAs based upon lessons learned in implementing DOE-STD-3009-1994." DOE has not yet directed the Tank Farms Operations Contractor to adopt the standard as a basis for the Tank Farms DSA (though, as noted in various places in this report, the DSA would benefit from changes driven by the additional clarity provided by the 2014 revision of the standard).

The tank farms will soon be required to operate in support of the Hanford Site Direct Feed, Low-Activity Waste mission. This will entail an increase in the frequency and scope of high-hazard operations involving tank waste and will also require implementation of new methods for retrieving and pre-processing waste. Unless the DSA is upgraded, the Tank Farms will operate for another half century in this higher risk environment using outdated information, criteria, and potentially inadequate controls.

¹ The references to this material are included here for the interested reader; however, the discussions and analyses in these historical references are not intended to drive the content of this report. Instead, this report is meant to convey new Board analysis of the relevant issues.

INADEQUATE JUSTIFICATION OF ASSUMPTIONS RELATED TO DESIGN BASIS ACCIDENTS (DBA)

One of the most important DBAs documented in the Tank Farms DSA is a flammable gas accident; that is, a deflagration or detonation inside a tank. The initiator for this accident, as discussed in the DSA, can be external (e.g., earthquake) or internal (e.g., mixing, retrieval, or spontaneous release). The bounding accident of this type analyzed in the DSA is a detonation in one double shell tank (DST), with analyzed consequences of 7 rem total effective dose (TED) to the public.

DOE-STD-3009-1994-CN3 states that the purpose of a hazards analysis is to “present a comprehensive evaluation of potential process related, natural events, and man-made external hazards that can affect the public, workers, and the environment due to single or multiple failures.” Further, the standard states that “the intent is that [source term and dose consequence calculations] be based on reasonably conservative estimates of the various input parameters.” The Tank Farms DSA does not include adequate justification for the assumptions behind analysis of this DBA. Consequently, the DSA does not provide sufficient information to determine whether appropriate controls have been selected, or whether the public and workers are properly protected. The staff team is particularly concerned with inadequate justifications for the source terms used in the accident analysis, inadequate assumptions related to the percentage of flammable gas inventory released, and the lack of justification for excluding certain common-cause events. Appendix A provides additional technical background related to these concerns.

Inadequate Justification for Selected Source Terms. The radioactive source term used to calculate the dose consequences of DBAs was based on information from an expert elicitation process conducted in the early 1990s [10]. Each expert provided the cumulative probability distribution for the respirable mass of waste (i.e., the radioactive source term) released for various accident scenarios. The contractor (i.e., a predecessor to WRPS) then aggregated the experts’ values into a single distribution for each scenario. For the purposes of dose consequence calculations, the contractor selected a source term of 100 kg for detonation events, and a source term of 1 kg for deflagration events. The highest postulated dose consequence to the public calculated using the above values was 7 rem TED.

The Tank Farms DSA asserts that these source term values, which lie at approximately the 80th and 50th percentiles of their respective aggregate distribution curves, are “reasonably conservative,” but does not explicitly include any technical justification to support the conclusion.

A consequence analysis document [11] cited in the DSA provides some justification of the source term selected for the detonation event. The reference presents an evaluation that determined that the 100 kg value is a reasonably conservative estimate of the mass of respirable material released because the value encompasses the release estimates provided by seven of nine experts in the elicitation noted above. The evaluation noted that one of the remaining expert’s assumed aerosol densities were extremely high and would result in considerable agglomeration and deposition during transport. The evaluation also stated that the other remaining expert’s estimate was very conservative, since it was developed using the trinitrotoluene (TNT)-

equivalent model from DOE-HDBK-3010-1994, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities* [12]. Based on this information, the evaluation asserts that the 100 kg value is reasonably conservative.

The cited document does not provide any additional evidence to support the assumptions related to the source term, other than a comparison to studies related to material suspension in deflagration events. This justification is not adequate for the purpose of accident analysis; additional technical evaluation is required to show clearly that the source term values are appropriately conservative. Therefore, the assumptions underpinning the dose consequence calculations in the Tank Farms DSA do not meet DOE-STD-3009-1994-CN3 requirements (see Appendices A and B for further justification of this position).

To better understand the potential magnitude of this concern, the staff team calculated (see Appendix C) postulated dose consequences using a source term corresponding to the 95th percentile (a commonly-used value in conservative safety analyses) from the aggregate expert elicitation distributions. Using this value, the postulated dose consequence to the public exceeds the Evaluation Guideline of 25 rem TED for detonation accidents in DSTs. Further, the postulated dose consequence for deflagration accidents in single shell tanks (SSTs) also exceeds the Evaluation Guideline, though this accident is not quantitatively evaluated as a design basis accident in the DSA. A calculated dose consequence of this magnitude would require the identification of safety-class controls per DOE-STD-3009-1994-CN3.

The relative sensitivity of consequences near the evaluation guideline indicated by comparing the DSA calculation with the staff team's calculation shows that relatively small differences in source term can have significant implications for the classification of safety-related controls per DOE-STD-3009-1994-CN3. Therefore, it is imperative that the source term values be properly understood and justified. The Tank Farms DSA does not include adequate information in this regard and thus the DSA does not align with the accepted methodology laid out in DOE-STD-3009-1994-CN3, and that the source terms selected for the analysis of the seismic DBA (and other flammable gas accidents) are not adequately justified.

DOE's failure to identify a clear technical justification for the assumptions that underpin critical safety basis calculations is a significant flaw in the approved safety analysis. In particular, it is not clear how the analysis contained in the Tank Farms DSA meets DOE-STD-3009-1994-CN3, which states that a DSA "needs to present information at a level that is considered sufficient for the review and approval of the DSA." Without an adequately documented analysis of the hazards associated with Tank Farms operations, DOE cannot fully understand the risk and ensure adequate protection of the public and workers. The appendices of this document provide additional support for the staff team's conclusions.

Inadequately Justified Assumptions Related to Percentage of Flammable Gas Inventory Released. RPP-10006, *Methodology and Calculations for the Assignment of Waste Groups for the Large Underground Waste Storage Tanks at the Hanford Site* [13], states that 17 DSTs and 38 SSTs are designated as either Group A or Group B. By definition, these tanks have sufficient entrained gas to reach 100 percent of the lower flammability limit (LFL) should all

entrained gas be released into the tank headspace.² Given this, each of these tanks should be analyzed for potential deflagration or detonation scenarios during a seismic event, unless sufficient evidence exists to the contrary.

However, ORP and WRPS have concluded that not all tanks need to be analyzed in this regard. The Tank Farms DSA includes only limited language on this subject:

Although a design basis earthquake may cause multiple flammable gas accidents (i.e., deflagrations), it is not reasonable to expect that flammable gas accidents occur in all Waste Group A and B tanks.

During the review interaction, ORP and WRPS personnel provided qualitative and limited quantitative reasoning to support their decision. They stated that is not reasonable to expect release of 100 percent of the entrained gas in a given tank during a design basis seismic event. They further elaborated that historical data³, combined with engineering judgment, led them to the conclusion that 50 percent is a more realistic estimate for the proportion of gas released. If this conclusion is accepted, it narrows the pool of “at risk” tanks to seven total (out of the possible fifty-five with flammable gas inventories large enough to reach the LFL). However, WPRS and ORP did not demonstrate the applicability of historical event conditions to seismic event conditions. The staff team does not consider the additional information provided by ORP and WRPS to be sufficient to resolve the deficiency in the DSA; therefore, the assumed limits on the release of entrained gas, and subsequent reduction in the number of at-risk tanks, is not adequately supported.

Lack of Analysis for a Simultaneous Multiple Tank Event. Flammable gas accidents resulting from seismic activity are potentially common-cause events. An earthquake has the potential to cause similar events in more than one waste tank, especially if conditions in several tanks are conducive to this type of event. Other initiators for common cause events can be postulated. However, the Tank Farms DSA considers a detonation in only one DST as the bounding scenario for accident analysis purposes, and the DSA inappropriately omits the possibility of flammable gas events occurring simultaneously (or nearly simultaneously) in more than one tank. The Tank Farms DSA includes the following language to justify this reasoning:

The MOI [maximally-exposed offsite individual] doses from the postulated flammable gas accidents (i.e., deflagrations) and waste transfer leaks are not directly additive because the accidents occur at different locations within the tank farms.

The offsite radiological consequences of the bounding natural event, a design basis earthquake, are qualitatively judged not to challenge the...Evaluation Guideline.

² Group A tanks have properties that allow spontaneous release of gas, whereas Group B tanks do not. However, both groups are subject to the risk of gas release during a seismic event or other external initiator.

³ These data come primarily from DST SY-101, which experienced several spontaneous gas release events in the past. Conditions in that tank have since changed, such that those events are no longer possible.

The staff team disagrees with this argument as presented in the DSA. Per DOE's latest estimate, seven DSTs contain sufficient entrained gas to exceed the LFL if 50 percent of that gas is released⁴. Three of those tanks (AN-103, AN-104, and AN-105) are collocated within the same tank farm. In addition, the distance of the site boundary from the tank farms is such that if each of these tanks undergoes a simultaneous (or near-simultaneous) deflagration or detonation, the public receptor could be subjected to a cumulative dose consequence from material from multiple tanks. Consequently, the staff team disagrees with the reasoning outlined in the Tank Farms DSA to not include simultaneous (or near-simultaneous) tank events and concludes that there is a gap in the accident analysis.

Without a justifiable technical basis to select only one DST for the accident analysis, DOE should define a bounding multiple tank case for the design basis seismic event. This gap is especially consequential when considered in conjunction with the source term concerns mentioned earlier, since staff team analysis shows the potential for even deflagration accidents (which are more likely than detonation accidents) to result in consequences that exceed the Evaluation Guideline. DOE-STD-3009-1994-CN3 requires that "the range of accident scenarios analyzed in a DSA should be such that a complete set of bounding conditions to define the envelope of accident conditions to which the operation could be subjected are evaluated and documented." Due to this gap, the Tank Farms DSA is not aligned with DOE-STD-3009-1994 (nor is it aligned with the 2014 version of the standard).

⁴ Though 50 percent is the value DOE currently works to, as discussed above, the staff team does not agree that this value has been adequately determined. This term is simply used here for sake of argument.

FORMALITY OF CONTROL DESIGNATION

The Tank Farms DSA and technical safety requirements (TSRs) [14] do not strictly follow the guidance and requirements in DOE standards. The following are items identified by the staff team:

Use of Contractual Direction. WRPS was originally prohibited from creating additional Group A tanks through a 2013 letter of direction [15] from ORP. This letter is included as part of the Tank Farms contract and is referenced in the Tank Farms DSA, but there is no corresponding specific administrative control (SAC) that explicitly covers this prohibition. This ambiguity and level of control appear to be inconsistent with the intent of DOE requirements and guidance. The staff team notes that it may better align with the intent of DOE standards to designate such controls as SACs to clear up the ambiguity as to the control strategy or implications stemming from potential violations. In particular, the new version, DOE-STD-1186-2016, *Specific Administrative Controls*, states that “where necessary and feasible, SACs should be used to control or limit material-at-risk (MAR) and other important physical attributes” [16]. This logic could apply to controls on Group A tank creation, since tank group designation is an important physical attribute underpinning the analysis in the Tank Farms DSA.

Classification of Engineered Features Supporting SACs. SAC 5.8.5, *Waste Transfer System Overpressure and Flow Transient Protection*, protects the waste transfer system from over-pressurization. This SAC requires evaluation of each waste transfer system design to avoid over-pressurization and ensure it is adequately mitigated if it occurs. However, key features of the system design (e.g., pump characteristics) are not identified as safety-related engineered controls. Similarly, although the hose in hose transfer line (HIHTL) pump hydraulic units are outfitted with high temperature shutoffs (i.e., a support system that could prevent HIHTL rupture in the event of pump failure or deadhead), the high temperature shutoffs are not identified as safety-significant. This is inconsistent with DOE-STD-1186-2004, *Specific Administrative Controls*, which states that “instrumentation and controls and equipment that support a SAC should meet performance requirements consistent with the importance of the safety function of the Specific AC [administrative control]” [17].

Use of TSR Key Elements. WRPS excludes tank AZ-101 sludge from consideration as potential MAR when determining the unmitigated consequences for bounding detonation events in the tank farms. WRPS justifies this exclusion by presuming that the supernatant covering the sludge will not be removed, and will therefore provide a barrier to protect the sludge layer from detonations in the tank headspace⁵. The exclusion is used as an initial condition to reduce the source term for the analyses, and DOE protects this initial condition by prohibiting WRPS from performing waste transfers that uncover the sludge layer in tank AZ-101. However, instead of using a SAC to prevent an inappropriate transfer, WRPS uses a TSR administrative control key element requiring that certain characteristics be evaluated prior to each waste transfer as part of a safety management program. Regarding MAR controls for DST AZ-101, the DSA states the following:

⁵ For general reference, AZ-101 (a ~1000kgal DST) contains approximately 50kgal of sludge but over 800kgal of supernatant. These numbers do not fluctuate much, due to the prohibitions on transfers discussed in this paper.

The selection of the bounding waste layer excludes the sludge layers at the bottom of DST 241-AZ-101 because there are no plans to remove the supernatant and uncover the sludge in DST 241-AZ-101 and, therefore, the detonation material release mechanisms do not involve these sludge layers. This exclusion is protected by the decision rules in HNF-SD-WM-OCD-015, Tank Farms Waste Transfer Compatibility Program, Section 3.1.1.4, "DST Controls for Uncovering or Dissolving Solids (AC 5.8.1)," which do not allow transfers from DST 241-AZ-101 that could uncover solids in the tank. The decision rule further states that if a transfer from DST 241-AZ-101 that could uncover solids in the tank is needed, an evaluation of the changes to the consequence analysis of the flammable gas accident in the headspace of a DST is required.

The language in the associated TSRs does not explicitly discuss this prohibition, but the language in the Waste Transfer Compatibility Program does.

While on site, the staff team asked whether a violation of this control (i.e., performing an improper evaluation or initiating an unauthorized transfer) would constitute a TSR violation. DOE-STD-1186-2004 states that "a TSR violation of a safety management program can only result from a gross program failure, significant enough to render the DSA assumptions invalid." This statement leaves ambiguity as to whether a failure of one of these controls, which are only one aspect of a safety management program, would qualify as a violation. DOE and WRPS personnel agreed that if they failed to adhere to this requirement in the Waste Transfer Compatibility Program, it would sufficiently undermine the analysis underpinning the Tank Farms DSA such that it would be a programmatic breakdown, and therefore a TSR violation.

This ambiguity and level of control appear to be inconsistent with the intent of DOE requirements and guidance. It may be appropriate to designate these controls as SACs to clear up ambiguity as to the control strategy or implications stemming from potential violations. In particular, the new version of DOE-STD-1186-2016 states that "where necessary and feasible, SACs should be used to control or limit [MAR] and other important physical attributes." Since controls to exclude AZ-101 sludge from source term consideration are effectively controls on MAR, this language from the standard suggests that they should be considered for explicit inclusion as SACs.

OTHER OBSERVATIONS

Over the course of the review, the staff team noted other elements of the Tank Farms DSA that would benefit from revisions for clarity and content, in order to better align with the intent of current DOE guidance. Overall, the DSA would benefit from the additional rigor and structure suggested by modern standards such as DOE-STD-3009-2014. Items specifically related to hose-in-hose transfer lines can be found in Appendix D. Other items are contained in Appendix E.

CONCLUSIONS

The Tank Farms DSA lacks a sufficient technical basis to adequately justify the values used in some DBA analyses and does not adequately justify the selection and analysis of DBA scenarios. Without sufficient technical detail, the accident analysis and control designation methodologies are correspondingly inadequate. In addition, some controls important to safety do not have the expected level of formality or classification per DOE standards, and that several areas of the DSA would benefit from revisions for clarity and content to better align with modern DOE guidance. DOE should address these deficiencies to ensure that the Tank Farms DSA provides sufficient information to make safety-related decisions.

Of particular note, the consequence analyses for design basis accidents related to accumulation of flammable gases in the tanks are dated and neither DOE nor WRPS were able to provide some of the supporting documentation. Additionally, the basis for assumptions that support the analyses lack adequate technical justification. Lastly, the methods used lack the transparency necessary to validate the conservatism of DOE's approach. Although the expert elicitation process used by DOE may have been the most viable method at the time (1990s), modern DOE guidance (such as DOE-STD-3009-1994-CN3 and its successor document, DOE-STD-3009-2014) suggests a more rigorous and quantitative process should be used for hazard and accident analyses.

The DSA does not provide DOE with sufficient information to accurately assess the consequences of accidents that could affect the public. DOE needs this information to validate that the contractor has selected appropriate controls, and to ensure adequate protection of the public and workers. The body of this report details the deficiencies identified. Unless such issues are addressed, the Tank Farms DSA does not align with requirements and/or guidance in either DOE-STD-3009-1994-CN3 or its successor document, DOE-STD-3009-2014.⁶

⁶ The code of record for the Tank Farms DSA lists the 1994 version of DOE-STD-3009, rather than the 2014 version, so the staff team compared the DSA to the former from a requirements perspective. However, the staff notes that DOE intended the 2014 version to be a clarification of the requirements in the 1994 version, rather than an expansion of them. Consequently, it is still instructive to compare and contrast the DSA to both standards.

REFERENCES

- [1] Washington River Protection Solutions, LLC, *Tank Farms Documented Safety Analysis, Rev. 7-G*, RPP-13033, September 2017.
- [2] Department of Energy, *Nuclear Safety Management*, Title 10, Code of Federal Regulations, Part 830.
- [3] Department of Energy, *Facility Safety*, DOE Order 420.1B, December 22, 2005.
- [4] Department of Energy, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, DOE-STD-3009-1994-CN3, July 1, 1994.
- [5] Winokur, Peter, Chairman, Defense Nuclear Facilities Safety Board, *Letter to Secretary of Energy Inés Triay regarding analytical and implementation deficiencies in the Hanford Tank Farms Documented Safety Analysis*, August 5, 2010.
- [6] Triay, Inés, Secretary of Energy, U. S. Department of Energy, *Letter to Chairman Peter Winokur regarding changes to the Hanford Tank Farm Documented Safety Analysis and associated technical basis in response to the Board's letter of August 5, 2010*, October 18, 2010
- [7] Winokur, Peter, Chairman, Defense Nuclear Facilities Safety Board, *Letter to Secretary of Energy Steven Chu forwarding Recommendation 2012-2, Hanford Tank Farm Flammable Gas Strategy*, September 28, 2012.
- [8] Chu, Steven, Secretary of Energy, U. S. Department of Energy, *Letter to Chairman Peter Winokur accepting Recommendation 2012-2, Hanford Tank Farm Flammable Gas Strategy*, January 7, 2013.
- [9] Department of Energy, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, DOE-STD-3009-2014, November 2014.
- [10] Duke Engineering and Services Hanford, Inc., *Flammable Gas Project Expert Elicitation Results for Hanford Site Double-Shell Tanks*, HNF-2577, Rev. 0, July 9, 1998.
- [11] CH2MHILL Hanford Group, *Offsite Radiological Consequence Analysis for the Bounding Flammable Gas Accident*, RPP-13470, Rev. 2, 2005.
- [12] Department of Energy, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-1994, 1994.
- [13] Washington River Protection Solutions, LLC, *Methodology and Calculations for the Assignment of Waste Groups for the Large Underground Waste Storage Tanks at the Hanford Site*, RPP-10006, 2017.
- [14] Washington River Protection Solutions, LLC, *Tank Farms Technical Safety Requirements*, HNF-SD-WM-TSR-006, Rev. 8-C, September 2017.
- [15] Office of River Protection, *ORP Letter of Direction from Smith, K.W. to M.D. Johnson*, 13-NSD-0002, 2013.
- [16] Department of Energy, *Specific Administrative Controls*, DOE-STD-1186-2016, August 2016.

[17] Department of Energy, *Specific Administrative Controls*, DOE-STD-1186-2004, August 2004.

Appendix A: Technical Background and Additional Information for Seismic Design Basis Accident (DBA)

Source Term Used in the Tank Farms Documented Safety Analysis (DSA). The Department of Energy (DOE) used an expert elicitation process to facilitate development of the hazard and accident analyses in the Tank Farms DSA. A number of experts in the field were individually asked to develop a cumulative probability distribution for the respirable mass of waste released in a flammable gas explosion (i.e., the source term for dose consequence analysis). For example, an expert would estimate that there was a 10 percent chance of X kg being released, 50 percent chance of Y kg being released, and so on. DOE proposed five scenarios for the experts to consider:

- Headspace burn, no high-efficiency particulate air (HEPA) filter failure,
- Headspace burn, HEPA failure, peak pressure < 20 psig, no dome failure,
- Headspace burn, HEPA failure, peak pressure > 20 psig, no dome failure,
- Headspace deflagration, dome failure, and
- Headspace detonation, dome failure.

For each accident scenario, the individual experts' distributions were then aggregated into a single distribution, resulting in five total aggregate distributions (one for each accident scenario).

The source term for the design basis flammable gas accident (a detonation in a double shell tank [DST]) was selected using data from this method and is given in the DSA as 100 kg. To support selection of this value, section 3.4.2.1.2 includes the following text:

It is estimated that 100 kg of respirable waste would be released by a detonation in an SST [single shell tank] or DST [double shell tank] that results in partial dome collapse. This estimate is based on information contained in HNF-2577, Flammable Gas Project Expert Elicitation Results for Hanford Site Double-Shell Tanks.

For the purposes of calculating the offsite radiological consequences of a detonation in an SST or DST, a value of 100 kg is selected as being a reasonably conservative estimate of the mass of respirable material released.

The DSA does not contain further discussion on the basis for why this value is “reasonably conservative.” The methodology behind the selection of the 100 kg value is not explicitly discussed in the DSA (i.e., there is no obvious technical basis in the DSA for this number), but can be determined by carefully examining and interpolating Figure C-16 of HNF-2577. The 100 kg value discussed in the DSA corresponds to the 80th percentile value of the aggregate distribution (i.e., a distribution created by averaging all of the expert’s resultant distributions) of the most severe postulated scenario (i.e., headspace detonation and dome failure).

The analyzed dose to the public receptor for the design basis flammable gas accident (within the headspace of a double or single shell tank) is estimated in the DSA to be 7 rem total effective dose (TED), which approaches but does not exceed the evaluation guideline of 25 rem for consideration of safety-class controls. The DSA does not identify any safety-class controls.

The DSA considers a deflagration accident to be more likely but less severe than the detonation accident. As such, the DSA does not evaluate the deflagration accident for off-site consequences, in part because the consequences of the detonation accident are assumed to bound the consequences of the deflagration accident (i.e., deflagrations are not evaluated as separate design basis accidents). It does, however, identify a source term of 1 kg for this accident. This value corresponds to the 50th percentile value of the aggregate distribution for the second-most severe postulated scenario (i.e., headspace deflagration and dome failure).

During the review interaction, DOE and Washington River Protection Solutions (WRPS) personnel restated their position that the analyses for these accidents are reasonably conservative. The staff team disagrees with this position and concludes that it is not supported by an adequate technical basis.

Guidance in DOE Standards on “Reasonably Conservative” Values. DOE-STD-3009-1994-CN3, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, states that “the intent is that [source term and dose consequence] calculations be based on reasonably conservative estimates of the various input parameters.” While the standard does not mandate a particular method for determining the source term, Appendix A of the standard states that “source term is typically estimated as the product of five factors: (1) MAR [material at risk], (2) damage ratio, (3) airborne release fraction, (4) respirable fraction, and (5) leakpath factor.” Colloquially this is known as the “five factor formula.” The standard does not define “reasonably conservative” explicitly, leaving some amount of judgment up to the safety basis analyst; however, several passages within the standard elucidate the intent behind this term for certain parameters. For example:

- The standard states that the value for MAR used in calculations “should represent documented maxima for a given process or activity.”
- On the subject of airborne release fractions (ARF) and respirable fractions (RF), which are used to calculate radioactive source terms, the standard states that “bounding estimates...for a wide variety of MAR and release phenomena are systematically presented in DOE-HDBK-3010, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*,” implying that these (i.e., bounding) are the preferred values to be used for such parameters.
- In a section dedicated specifically to atmospheric dispersion parameters, the standard states that “the 95th percentile of the distribution of doses to the [maximally exposed offsite individual], accounting for variations in distance to the site boundary as a function of direction, is the comparison point for assessment against the EG [Evaluation Guideline].”

Further evidence for the intent of DOE-STD-3009-1994-CN3 can be found in the updated version of this standard, DOE-STD-3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*. The new version of the standard states the following:

Calculations shall be made based on technically-justified input parameters and underlying assumptions such that the overall consequence calculation is conservative. Conservatism is assured by the selection of bounding accident scenarios, the use of a conservative analysis methodology, and the selection of source term and input parameters that are consistent with that methodology.

For some input parameters, this section identifies default or bounding values that may be used without further justification. Unless otherwise stated for a particular input value, this section allows use of alternative values when supported by an adequate technical basis. When an input parameter used is not a default or bounding value, an acceptable technical basis of the value describes why the value selected is appropriate for the physical situation being analyzed, and references relevant data, analysis, or technical standards. The completeness and level of detail in the technical basis should increase as the parameters depart from default or bounding values.

The 2014 version of the standard goes on to discuss the “five factors,” which are MAR, damage ratio (DR), ARF, RF, and leak path factor (LPF). The suggested values for these parameters are often bounding. For example, the 2014 version of the standard states that “a DR of 1.0 shall be used unless there is an applicable standard or technical basis for a different value.” For ARFs and RFs, the standard also states that “the bounding estimates [provided in DOE-HDBK-3010-1994] shall be used unless a different value is provided in an applicable standard or is otherwise technically justified.”

The staff team recognizes that the code of record for the tank farms DSA calls out the 1994 version of DOE-STD-3009, rather than the revised version. However, the staff team notes that the revision to DOE-STD-3009 was not meant to constitute new requirements but was meant to clarify the intent behind existing requirements. As DOE stated in a letter to the Board dated October 18, 2014:

The new revision of DOE-STD-3009 is an update to: (1) reflect best practices and lessons learned in application of the Standard over the last 20 years; (2) clarify which elements of DOE-STD-3009 must be met to fully implement the safe harbor methodology; (3) clearly address the use of the 25 rem Evaluation Guideline and provide requirements if mitigated off site dose estimates exceed the Evaluation Guideline; and (4) make it consistent with the criteria and guidance for development of a Preliminary DSA identified in DOE-STD-1189.

Therefore, as stated in point (2), the language in DOE-STD-3009-2014 should be interpreted as the intent behind the original requirements of DOE-STD-3009-1994-CN3. As such, any analysis included as part of the Tank Farms DSA should strive to align with the new

revision to comply with the safe harbor methodology; otherwise, any deviation from this guidance must be adequately justified.

Given this discussion, the staff team concludes that DOE's decision to use the 80th percentile value from the source term distributions, without adequate technical justification, is not supported by DOE-STD-3009-1994-CN3.

Staff Team Calculation of Implicit ARF*RF Values. To understand how the source terms for the seismic DBA compare the against typical DOE-STD-3009 methodology, the staff team deconstructed the source term into the five factors discussed in the standard. As detailed in Appendix B, the staff team estimated the combined ARF*RF value, as implied in the seismic DBA analysis, to be 5.49e-5. This is significantly less (i.e., between approximately one and four orders of magnitude less) than the values suggested by DOE-HDBK-3010-1994, which, as discussed above, is the resource explicitly suggested by both versions of DOE-STD-3009. Consequently, the staff team concludes that, without further justification as to its adequacy, the source term for the seismic DBA does not meet the intent of DOE-STD-3009-1994-CN3.

Implications of More Conservative Source Term Values. As alluded to in the body of this report, the source term selected for the seismic DBA is in a region where the specific values chosen can have large implications for the required control strategy per DOE-STD-3009-1994-CN3. To quantitatively understand these implications, a member of the staff team calculated (see Appendix C) postulated dose consequences associated with the 95th percentiles of the source term distributions, rather than the 80th or 50th percentiles. Using such values results in a postulated dose consequence to the public for the detonation accident of at least 34 rem TED. Dose consequences of this magnitude would require the identification of safety-class controls per DOE-STD-3009-1994-CN3. As discussed above, the staff team is not asserting that the 95th percentile of the expert elicitation aggregate curves represents the only correct source term, but simply reports this value to make the point that relatively nearby source term values can result in significantly different control requirements. It is therefore imperative that the source term values be properly understood and justified.

Furthermore, the staff team's independent analysis indicates that the SST deflagration accident posited in the DSA (i.e., a deflagration in a single tank) also exceeds the evaluation guideline of 25 rem TED when the expert elicitation results are analyzed using the same approach. Not only would this accident scenario require safety-class controls per DOE-STD-3009-1994-CN3, a scenario involving simultaneous seismically induced deflagrations in multiple tanks could have dose consequences significantly exceeding the Evaluation Guideline, and could be properly identified as a stand-alone design basis accident since it may necessitate a different set of controls. As discussed in previous sections of this paper, the staff team does not consider that DOE has adequately considered the possibility of this accident; larger dose consequences would make proper analysis of this accident scenario even more imperative.

Appendix B: Back Calculation of Dose Consequence Calculation Parameters

This section documents a staff team effort to calculate factors relevant to dose consequence calculations at Hanford's Tank Farms facility, and a comparison to values discussed in Department of Energy (DOE) standards.

Background. As noted in previous sections of this paper, DOE chose to select source terms for detonation accidents using data from an expert elicitation process. DOE's decision to define the source term as a whole, and not as a series of parameters used to calculate a resultant source term, is atypical. While DOE-STD-3009-1994-CN3, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, does not mandate a particular method for determining the source term, Appendix A of the standard states that "source term [ST] is typically estimated as the product of five factors: (1) MAR [material at risk], (2) damage ratio [DR], (3) airborne release fraction [ARF], (4) respirable fraction [RF], and (5) leakpath factor [LPF]." The standard further states that, regarding dose consequence calculations, "the intent is that calculations be based on reasonably conservative estimates of the various input parameters." While the source term is described in the Tank Farms documented safety analysis (DSA) as "reasonably conservative" (although, as noted in the body of this paper, there is no solid technical basis to support that assertion), the staff team notes that the requirement per the standard is not just that the *source term* be reasonably conservative, but that each of the *input parameters* be reasonably conservative.

The usual method for calculating a source term would be to define the parameters listed above, select reasonably conservative values for those parameters, and justify how those values meet the criteria in the standard. The expert elicitation process combined these steps. For example, the fact that the accident scenario is pre-defined as a tank dome collapse means there are embedded assumptions regarding leak path factor and damage ratio. Additionally, the fact that DOE's request was for the experts to determine the respirable mass means there are embedded assumptions regarding the respirable fraction that, though they underpin the selection of the source term, are not transparently discussed. HNF-2577, *Flammable Gas Project Expert Elicitation Results for Hanford Site Double-Shell Tanks*, does not definitively elucidate the selection process or meaning of these assumptions, or include any discussion as to why they are reasonably conservative. Therefore, by its nature, the source term selection process (i.e., the designation of a value by the Tank Farms contractor, using input from the expert elicitation) makes it difficult to deconstruct the end result (i.e., the source term value) and determine whether it is based on "reasonably conservative estimates of the various input parameters" as prescribed by DOE-STD-3009-1994-CN3.

ARF*RF Calculation. The radioactive source term calculation for use in accident analyses, Appendix A of DOE-STD-3009-1994-CN3, is represented mathematically below:

$$ST = MAR * DR * ARF * RF * LPF$$

DOE elected to use an expert elicitation method to define the source term, such that the individual factors listed above are not clearly identified, but the source term selection is still beholden to the criteria in that standard, which states that "the intent is that [source term]

calculations be based on reasonably conservative estimates of the various input parameters.” Given this language, the staff team sought to back-calculate values for some of these parameters in order to determine whether they meet the “reasonably conservative” standard set forth in DOE-STD-3009-1994-CN3.

As discussed in the body of this paper, the source term selected for the detonation event in a double shell tank (DST) is 100 kg; this value corresponds to the 80th percentile value of the most conservative of the five distributions discussed in HNF-2577. Because of the postulated severity of the scenario underpinning the distribution in question (i.e., tank dome failure), the staff team considers it is appropriate to assume that both DR and LPF that underpin this source term are bounding (i.e., set to one). This is appropriate, conservative, and aligned with the intent of DOE-STD-3009-1994-CN3¹. The equation above therefore simplifies to:

$$ST = MAR * ARF * RF$$

To back-calculate ARF*RF (henceforth expressed as a single term) from the source term, one simply has to divide by the material at risk:

$$ARF * RF = \frac{ST}{MAR}$$

Where the ST is a selected value (100 kg). In this case, since the accident scenario is a detonation in a single tank, MAR (the independent variable) is defined as all material in that tank. This is consistent with guidance in DOE-STD-3009-1994-CN3, which states that MAR values “should represent documented maxima for a given process or activity.” This can be calculated as follows:

$$MAR = V * \rho$$

Where V is volume of the waste and ρ is density of the waste.

Volume is not necessarily known in this case, so a range of possible volumes is presented here. For the purposes of this calculation, the range of possible volumes of waste in the tank was informed using actual tank waste levels from HNF-EP-0182, Rev. 377, *Waste Tank Summary Report for Month Ending May 31, 2019*. The emptiest² DST is listed as AP-102, with 372,000 total gallons of waste. The fullest DST is listed as AP-105, with 1,233,000 total gallons of waste. Applying margin on either side, an appropriate volume range for analysis purposes is 200,000 gallons to 1,300,000 gallons³. To account for density differences in waste forms, source

^{B-1} DOE-STD-3009-1994-CN3 states that the LPF “should be set to unity” and that DR should be “that fraction of material actually impacted by the accident generating conditions.” During a detonation scenario, it is appropriate to assume that the explosive force would have an effect on all material in the tank, and therefore setting DR to one is appropriate. While other values for these two parameters may be appropriate in certain cases, those other values would need to be justified.

^{B-2} Excluding DST AY-102, which has been retrieved.

^{B-3} This floor value is appropriate for a scoping analysis, since this section and calculation deal only with hazards related to spontaneous releases of gas. For this accident, there must be sufficient gas retained in the waste to support

term calculations in the tank farms DSA use generic, aggregated values for density⁴. As discussed in section 3.4.2.1.3 of the tank farms DSA, the generic waste density assumed for dose consequence calculations is 1.6 kg/L, or roughly 6.06 kg/gal. The MAR, therefore, can range from 1.21e6 to 7.88e6 kg.

Using the equation for ARF*RF given earlier, and the fixed source term of 100 kg, the ARF*RF implied in the source term calculation is between 1.27e-5 and 8.25e-5. It is important to note that there is not actually a range of ARF*RF values that may underpin the source term calculations in the DSA; instead, this range is an artifact of the fact that MAR is not known, and the calculation is only intended to show the possible range of values. For the purposes of this calculation, the most conservative possible value of ARF*RF is selected⁵ to compare against guidance given in DOE literature. Therefore, the ARF*RF value assumed for the purposes of this calculation is **8.25e-5**.

ARF*RF Values Discussed in Standards. DOE-HDBK-3010-1994, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, is intended to “provide a compendium and analysis of experimental data from which airborne release fractions (ARFs) and respirable fractions (RFs) may be derived.” This handbook is explicitly referenced in DOE-STD-3009-1994-CN3 as an appropriate resource for such data. Section 3.2.2.1 of the handbook discusses shock effects on liquid sources due to detonations and lists several possible values for ARF*RF derived from “empirical correlation to experimental data on the fragmentation of metals and aqueous solution by detonations.” This section is often referred to as the “TNT equivalent model,” since it relates the source term to the mass of TNT-equivalent that would result in a detonation of a given size. The explicitly discussed ARF*RF values, which vary depending on considerations related to mathematical and physical conservatism, range from **3e-4 to 2e-1**.

Conclusion. The most conservative possible value for ARF*RF underpinning the selection of the source term used for tank farms detonation scenarios is still significantly less conservative than all recommended values from DOE-HDBK-3010-1994 regarding shock effects on liquids from detonations.

a flammable atmosphere in the tank headspace, should that gas be released. At Hanford, tanks designated as Group A or Group B meet this definition. Using HNF-EP-0182, Rev. 377, and cross referencing with RPP-10006, *Methodology and Calculations for the Assignment of Waste Groups for the Large Underground Waste Storage Tanks at the Hanford Site*, we find that the Group A or B DST with the smallest waste inventory is SY-103, with 732,000 gallons (~63 percent capacity). For Group A or B SSTs, U-111 has the smallest inventory at 219,000 gallons (~41 percent capacity). These conditions are relatively stable, particularly in SSTs, and unlikely to change drastically. Hence, for the purposes of this scoping analysis, we have selected a 200,000 gallon floor value, or ~17 percent capacity for a DST or ~38 percent for an SST.

^{B-4} This appendix is concerned only with the calculation of the source term that is an input into dose consequence calculations. Dose consequence calculations account for differences in waste characteristics, such as conservatism related to radioactivity, by employing a unit liter dose method; therefore, there is no need to take those waste characteristics into account for this calculation.

^{B-5} It is also important to note that only by making very non-conservative assumptions regarding MAR is the ARF*RF value allowed to be this conservative, since given a fixed source term, MAR and ARF*RF are inversely proportional to each other. In a proper DSA analysis, both MAR and ARF*RF would need to be conservative simultaneously. This calculation has been optimized to uncover the most conservative possible value for ARF*RF.

The staff team recognizes that the calculated ARF*RF reported here is subject to certain assumptions. As noted above, setting DR to unity is a very conservative assumption, which may not necessarily be physically meaningful in all cases. Indeed, the relevant sections of DOE-HDBK-3010-1994 include discussion related to the mass ratio (i.e., MAR to TNT equivalent) assumed for the correlations in the text; mass ratios, which serve a similar function to DR, can have a large effect on the reported ARF*RF values.

The staff team is not asserting that the ARF*RF reported in this calculation is the only value that could be considered “reasonably conservative.” Rather, the staff team displays this scoping calculation to illustrate the ARF*RF that results from simple, bounding assumptions—assumptions that require no further justification as to their conservatism. It is certainly plausible that less conservative values of ARF*RF could be selected, providing that adequate technical justification exists and is documented. However, such justification is not present in the Tank Farms DSA. Therefore, absent further technical justification, it is not clear that the source term value in the Tank Farms DSA meets the “reasonably conservative” standard set by DOE-STD-3009-1994-CN3.

Appendix C: Independent Analysis of the Seismic Design Basis Accident (DBA)

Background. As discussed in the body of this report, a key DBA in the Hanford Tank Farms documented safety analysis (DSA) is a flammable gas detonation within the headspace of a double shell tank (DST) or single shell tank (SST). The analyzed dose to the public receptor for this accident is 7 rem total effective dose (TED), which approaches but does not exceed the evaluation guideline of 25 rem TED, above which safety-class controls are required. The DSA considers a flammable gas headspace deflagration accident to be more likely, but less severe, than the detonation accident, and concludes the dose to the facility worker is also below the guideline. The DSA does not evaluate the deflagration accident for off-site consequences.

The Defense Nuclear Facilities Safety Board's (Board) staff team concluded that these analyses are not consistent with Department of Energy (DOE)-STD-3009-1994-CN3, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, due to selection of non-conservative input parameters from distributions. As discussed previously in this paper, DOE-STD-3009-1994-CN3 requires selection of bounding scenarios and provides a methodology for performing a conservative analysis using bounding handbook input parameter values or otherwise reasonably conservative input parameters. The specific wording in DOE-STD-3009-1994-CN3 contains some ambiguity concerning this intent; however, any ambiguity was clarified with the issuance of DOE-STD-3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, which makes clear that a conservative analysis is required.

Parameters Represented by Distributions. When a parameter is represented by a distribution of potential values, the median or 50th percentile represents the best estimate since half of the potential values are lower than the median and half are higher. There is no standard definition of what percentile represents a reasonably conservative value, however the 95th percentile is often used in the sciences to represent a conservative estimate. The dispersion coefficient is an input parameter represented by a distribution of values, and DOE-STD-3009-1994-CN3 recommends the use of the 95th percentile value in dose consequence analyses. DOE has previously provided specific guidance regarding dose consequence evaluations where input parameters are represented by distributions of potential values.

From 2000 to 2001, the Board and DOE exchanged letters regarding the use of a proposed statistical method for determining the dose to the public for comparison to the Evaluation Guideline. The method involved using input parameter distributions, then taking the 95th percentile of the resulting source term. DOE took issue with this and in its final letter from the Secretary of Energy to the Board [C-1] included an attached report of the DOE Office of Nuclear and Facility Safety Policy's (ONFSP) review of the proposed statistical method. The attached report stated that the proposed statistical method included "selecting a dose result at the 95th percentile level of the distribution as 'a reasonably conservative' value for use in comparison with the Evaluation Guideline for Safety Class SSCs [structures, systems, and components]." The report then stated that "this is in contrast to the method described in Appendix A to DOE-STD-3009-1994-CN3, which specifies the use of reasonably conservative values of each parameter." Later in the report, DOE stated "it is quite clear that the methodology is not consistent with that of DOE-STD-3009-1994-CN3, especially in the context of the

proposed use in classifying Safety Class SSCs. Appendix A to DOE-STD-3009-1994-CN3 is quite explicit on the method to be used...the central difference is that DOE-STD-3009-1994-CN3 specifies ‘that calculations be based on reasonably conservative estimates of the various input parameters,’ rather than on statistical distributions of limited data.”

Based on this guidance from DOE and DOE-STD-3009-1994-CN3, together with common practice in the engineering sciences, the Board’s staff team concluded that a parameter value in the 95th percentile of a distribution is a reasonably conservative estimate of the value. Additionally, each input parameter should be reasonably conservative (i.e., the 95th percentile value), as opposed to taking the 95th percentile of the product of parameters.

Expert Elicitation Results. The technical bases for the analyzed doses are documented in [C-2] and [C-3]. A key input into the calculations is the amount of respirable mass released as a result of a detonation or deflagration in a vessel headspace. To estimate these releases, an expert elicitation process was used. Figure C-1 below shows an example of the estimated respirable mass released due to a detonation in the headspace of a DST that results in the vessel dome failing [C-4]. Probability distributions elicited from nine experts are shown. The solid curve is the aggregate mean of the nine distributions. The vertical axis is the estimated probability that the actual value of mass released is less than a given mass on the horizontal axis. Similar curves were generated for flammable gas accidents in SSTs for which seven experts were elicited [C-5]. The DSA utilizes these aggregate mean distributions for selecting values used in dose consequence analysis.

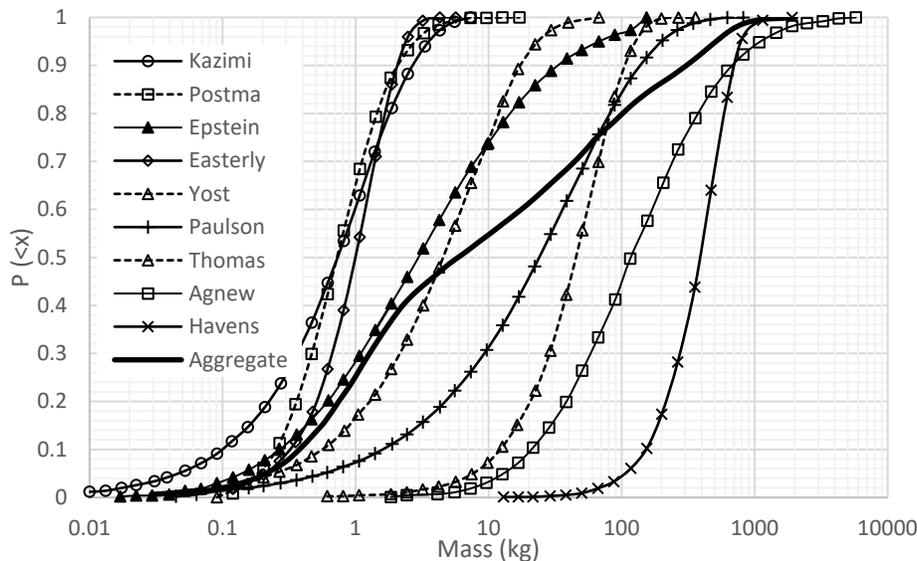


Figure C-1. Mass of respirable waste released from a DST by a headspace detonation that causes dome failure. Recreated from Figure C-16 in [C-4].

Figure C-2 below shows the expert elicitation results for aggregate mean mass released¹ for deflagration accidents in DSTs and SSTs. In applying this information to compute on-site dose estimates, the DSA used the 50th percentile estimated value of mass released. These are the

¹ For SSTs, the expert elicitation referred to mass suspended, whereas in the case of DSTs it was referred to as mass released. For purposes of dose consequence calculations in the DSA, the two are treated the same.

red lines shown in Figure C-2, corresponding to a mass of 1.0 kg for DSTs² and 5.7 kg for SSTs (which the DSA rounds up to 6 kg). The 50th percentile is the median value of a distribution and is typically considered to be the best estimate given an uncertain range of potential values. The masses corresponding to the reasonably conservative 95th percentile values of the median aggregate curves in Figure C-2 are 58 kg for DSTs and 455 kg for SSTs (blue lines in Figure C-2). These values are approximately 58 – 76 times larger than that the values used in the DSA.

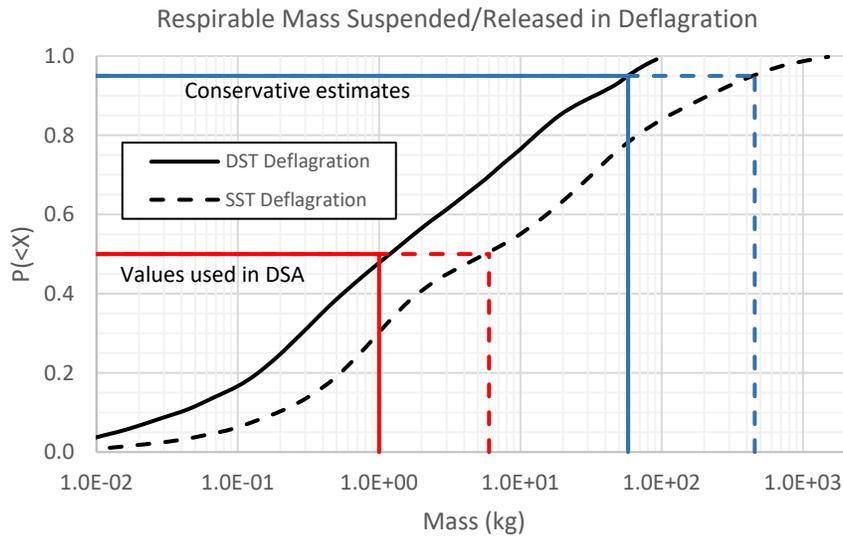


Figure C-2. Aggregate mean respirable mass suspended/released from a deflagration accident in Hanford Waste Tanks used for on-site dose consequence analysis in DSA. DST data recreated from Figure C-15 in [C-4]. SST data recreated from Figure A3-A16 in [C-5].

Figure C-3 below shows the aggregate mean respirable mass suspended/released for detonation accidents in an SST or DST. In applying this information to compute off-site dose estimates, the DSA used a mass of 100 kg, which is approximately the 80th percentile (the red line shown in Figure C-3) [C-3]. While the 80th percentile is a more conservative estimate than the 50th percentile used for on-site dose estimates, 20 percent of the potential values still exceed this value. The mass corresponding to the 95th percentile conservative estimate in Figure C-3 is 513 kg, which is about a factor of 5 higher than the value used in the DSA.

^{C-2} The staff team’s analysis of the distribution of aggregate mean respirable mass for SSTs indicates the 50th percentile value is 1.2 kg, which is larger than the value of 1.0 kg reported in the DSA.

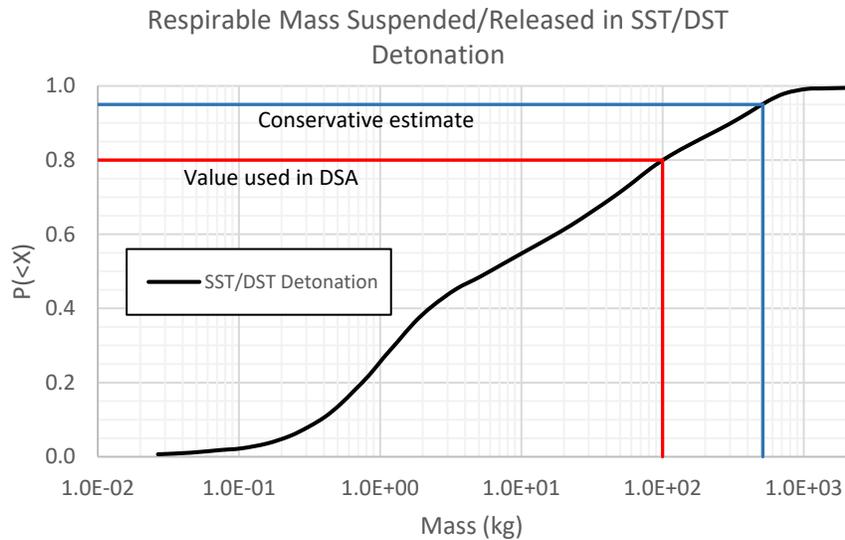


Figure C-3. Aggregate mean respirable mass suspended/released from a detonation accident in a Hanford single or double shell tank from Figure C-16 in [C-4].

Independent Conservative Parameters. In addition to requiring the use of conservative parameter inputs for dose consequence analysis, DOE-STD-3009-1994 requires that *each* input be conservative, as previously discussed. Particularly, both the source term/release fraction and the respirable fraction should be independently and conservatively selected. The dose consequence calculations in the DSA use distributions for respirable mass. These distributions are the product of separate distributions for total mass released and respirable fraction generated during the expert elicitation process. Therefore, it would be consistent with DOE requirements to use conservative individual values for total mass released and respirable fraction when computing doses.

To illustrate the degree of non-conservatism resulting from using distributions for respirable mass, consider Figure C-4 below, which shows the individual distributions of total mass released and respirable fraction for deflagration events in SSTs. The respirable mass for this accident used in the DSA was shown in Figure C-2 to be 5.7 kg. The 50th percentiles for total mass released (40 kg) and respirable fraction (0.17) are shown in red in the Figure C-4. When these values are multiplied together, the respirable mass is about 6.8kg, which is close to the median value from the aggregate respirable mass distribution, suggesting the DSA effectively used median values for both total mass and respirable fraction. From Figure C-4, the 95th percentile conservative value of total mass released is 1260 kg, and the 95th percentile conservative value of respirable fraction is 0.67. A conservative estimate of respirable mass released is obtained by the product of these two conservative values³, resulting in a respirable mass released of about 840 kg. Note the additional conservatism in this result compared with the 95th percentile of the respirable mass distribution shown in Figure C-2, which was 455 kg. This additional conservatism is achieved when conservative values for each input parameter are selected, consistent with the requirements in DOE-STD-3009-1994.

^{C-3} It is assumed that the aggregate distributions for total mass released and release fraction are independent.

A similar analysis could not be shown for DSTs since distributions for respirable fraction were not provided in the expert elicitation report [C-4]. The individual experts specified distributions of both total mass and respirable fraction, however aggregate mean distributions for respirable fraction were not provided in the report. Regardless, had the individual distributions for total mass and respirable fraction been published, it is clear that using conservative values for each would result in a more conservative (larger) amount of respirable mass, and subsequently a larger corresponding dose.

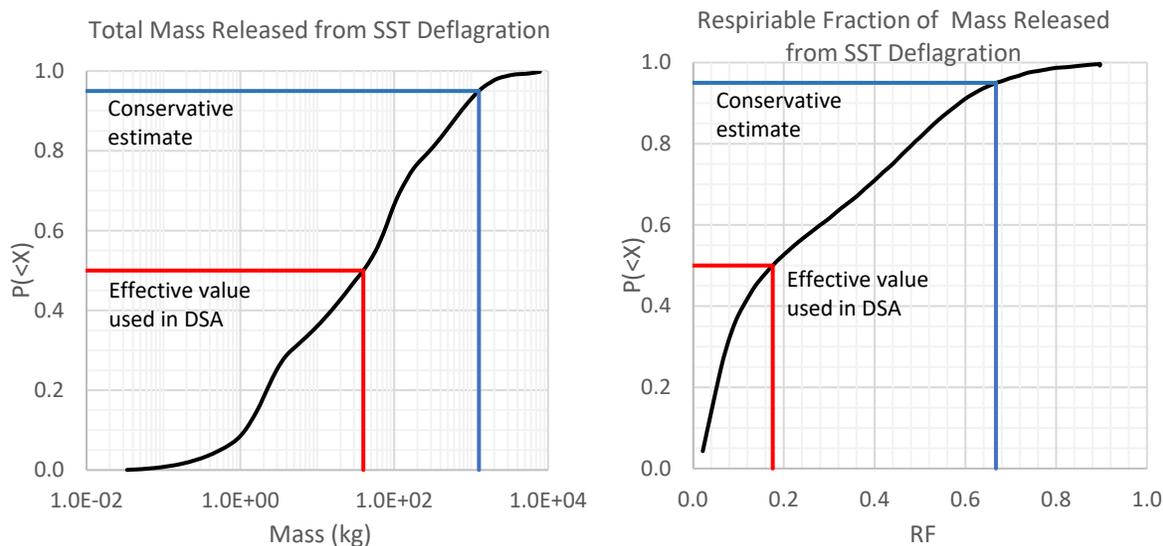


Figure C-4. Expert elicitation results for total mass suspended (left) and respirable fraction (right) for the deflagration accident in Hanford single shell tanks. From Figures A3-A16 and A3-A17 in [C-5].

Dose Consequence Analysis. A summary of the input parameters taken from the various distributions is shown in Table C-1 below. The values are considered to be accurate to within about 5 percent of the originally published values.

Table C-1. Conservative input parameters taken from distributions.

Scenario	95 th percentile respirable mass, <i>RM</i> (kg)	95 th percentile total mass, <i>TM</i> (kg)	95 th percentile respirable fraction, <i>RF</i>
DST Deflagration	58	NA	NA
SST Deflagration	455	1260	0.67
DST/SST Detonation	513	NA	NA

The other input parameters required for dose consequence analysis are shown in Tables C-2 and C-3, along with references to their source documents.

Table C-2. *Input parameters used in onsite dose consequence calculations.*

Scenario	Waste density, ρ (kg/L)	Dispersion rate, χ/Q (s/m³)	Breathing rate, BR (m³/s)	Unit liter dose, ULD (Sv/L)	Reference
DST Deflagration	1.4	3.73E-03	3.33E-04	9.0E+04	[C-2]
SST Deflagration	1.6	2.06E-03	3.33E-04	1.30E+05	[C-2]
DST/SST Detonation	1.4	3.73E-03	3.33E-04	1.30E+05	[C-2]

Table C-3. *Input parameters used in offsite dose consequence calculations.*

Scenario	Waste density, ρ (kg/L)	Dispersion rate, χ/Q (s/m³)	Breathing rate, BR (m³/s)	Unit liter dose, ULD (Sv/L)	Reference
SST Deflagration	1.6	2.10E-05	3.33E-04	1.30E+05	[C-2]
DST/SST Detonation	1.6	2.22E-05	3.33E-04	1.50E+05	[C-3]

Doses are calculated according to:

$$Dose = V \times \frac{\chi}{Q} \times BR \times ULD$$

Where:

$$V = RM/\rho = TM \times RF/\rho.$$

Here V is the volume of waste suspended (L), ρ is the waste density (kg/L), RM is the respirable mass suspended (L), and TM is the total mass suspended (L). The results of the calculation are in units of the Sievert, which is equivalent to 100 rem.

Results. The staff team's calculations using reasonably conservative parameter values conclude the dose to the public for the detonation accident would exceed 36 rem TED had conservative individual values for total mass released and respirable fraction been used for analysis. Further, the Board's staff team's analysis indicates the flammable gas deflagration accident, which is a more likely accident but was not evaluated for off-site consequences in the DSA, also exceeds the guideline of 25 rem TED for the dose to the public. A summary of the Board's staff team's results and values used in the DSA are shown in Table C-4.

Table C-4. *Dose consequence estimates using conservative input parameters.*

Scenario	Estimated consequences for scenarios evaluated in DSA		Staff analysis using 95 th percentile respirable mass		Staff analysis using 95 th percentile total mass & respirable fraction	
	On-site dose (rem)	Off-site dose (rem)	On-site dose (rem)	Off-site dose (rem)	On-site dose (rem)	Off-site dose (rem)
DST Deflagration	7.8	NA	460	NA	NA	NA
SST Deflagration	34	NA	2500	26	4700	48
DST/SST Detonation	81	7	5900	36	NA	>38

References

- [C-1] Department of Energy, *Letter to the Defense Nuclear Facilities Safety Board regarding alternate methodologies in preparing documented safety analyses*, September 4, 2001.
- [C-2] Washington River Protection Solutions LLC, *Flammable Gas Technical Basis Document*, RPP-13510, Rev. 11, 2013.
- [C-3] CH2MHILL Hanford Group, *Offsite Radiological Consequence Analysis for the Bounding Flammable Gas Accident*, RPP-13470, Rev. 2, 2005.
- [C-4] Fluor Daniel Hanford, Inc., *Flammable Gas Project Expert Elicitation Results for Hanford Site Double-Shell Tanks*, HNF-2577, Rev. 0, 1998.
- [C-5] Sandia National Laboratories, *Safety Controls Optimization by Performance Evaluation (SCOPE) Expert Elicitation Results for Hanford Site Single-Shell Tanks*, HNF-SD-WM-ES-412, Rev. 0, 1997.

Appendix D: Staff Observations on Hose-in-Hose Transfer Lines (HIHTL)

The following are additional observations from the Defense Nuclear Facilities Safety Board's (Board) staff team related to HIHTLs. These observations do not rise to the level of safety issues, but are presented for the Department of Energy's (DOE) information and use:

Hose-in-Hose Transfer Line Lifespan. HIHTL degradation is controlled via limits on shelf life and storage life of fully assembled HIHTLs. RPP- 6711, *Evaluation of Hose-in-Hose Transfer Line Service Life*, forms the basis for the total lifespan of HIHTLs [D-1]. The staff team identified two observations regarding the HIHTL limits on life and adequacy of conditions supporting the limits on life.

Total Life. Washington River Protection Solutions (WRPS) purchases HIHTLs from the vendor, River Bend Hose Specialty (RBHS). Granford Manufacturing, Inc. (GMI), a former subsidiary of Goodyear Tire and Rubber Co., manufactures the primary hose components in HIHTLs. In developing the limits on total life for HIHTLs, the tank operations contractor (TOC) received input from both companies over the course of several years. A series of emails in RPP-6711 provide the basis for the shelf life and service life, as follows [D-1]:

- The original shelf life discussion cites letters from RBHS, dated in June and November of 2000.
- The discussion of service life cites a 2007 email from GMI, which clarifies that service life and shelf life are exclusive of each other, and the total lifespan of HIHTLs is the combination of shelf life and storage life. This 2007 email does not cite values for the service life and shelf life, and from the information provided in the email and clarified in discussions with site personnel, the staff team could not verify that GMI was aware of the previous discussions that established the shelf and storage lifespan limits.

Given the length of time between discussions, differing company contacts, and lack of cited values in the 2007 email, the staff team believes there is a credible chance of miscommunication in development of the total lifespan. Therefore, the basis for the total lifespan of HIHTLs may not be fully supported.

Shelf Life. Per procedure, WRPS is allowed to store HIHTLs up to seven years prior to use. The seven-year storage time is maintained through in-service-inspections and based on GMI and RBHS recommendations. The manufacturer and vendor both specify additional recommended storage criteria to support the seven-year storage length; these criteria are assumed to be met in order for the seven-year storage length to remain valid. In the staff team's opinion, protection of these storage requirements must be commensurate to protection of the lifespan limit

itself. Since the lifespan protects against HIHTL failure as a technical safety requirements (TSR) level control, the storage requirements for HIHTLs should be protected similarly.

WRPS does not meet the entirety of the storage recommendations, and these recommendations are not controlled via TSRs. Among other guidelines, GMI recommends:

- Storage areas should be relatively cool and dark, and free of dampness/mildew.
- Hoses should not be stored in conditions of high or low humidity.
- Hoses should be exposed to a maximum temperature of 100°F.
- Coils should be stored in a horizontal plane.
- Protection from insects, rodents, ozone, and sunlight should be provided.

RBHS provides similar, but often conflicting storage recommendations as follows:

- Storage areas should *optimally* be relatively cool and dark, and free of dampness/mildew.
- Ambient temperatures of up to 120°F should not be destructive to hoses.
- HIHTLs should be stored in either horizontal or vertical position.
- Exposure to direct sunlight should be avoided.
- If the HIHTL is stored outdoors, the packing and shipping material should be intact and covered with a tarpaulin or other protective covering.
- Ends of HIHTLs should be covered to prevent rodent/insect intrusion.

WRPS maintains the condition of the storage areas using the procedure *Material and Equipment Staging Area Control* [D-2]. The procedure includes a list of item storage requirements but does not specifically call out HIHTLs or the manufacturer's recommendations. The staff team noted that a large number of the manufacturer's recommendations, and several of the vendor's recommendations, may not be met through the current storage conditions. See below for a picture of storage conditions of HIHTLs.



Figure D-1. *HIHTL outdoor staging.*

Unanalyzed HIHTL Conditions. The safety basis does not include an analysis of an accident combining high-pressure and high-temperature for HIHTLs or primary piping systems. DOE personnel stated that this condition may be bounded by the individual analyses of high-temperature and high-pressure conditions. The staff team could not determine whether this position is adequately justified, since the tensile strength of rubber decreases at high temperatures, and such a change could impact the assumed burst pressures. The staff team additionally notes that while RPP-6711 includes an analysis of temperature versus lifespan, the temperatures included do not bound the potential temperatures to which the HIHTLs could be subjected during high-pressure/high-temperature failures such as pump deadhead accidents.

Limitations of HIHTL Test Plans. WRPS recently developed a test plan aimed at enhancing the basis for the allowable service life of HIHTLs. On April 26, 2011, the Board sent a letter to DOE that included the issue, “Deficiencies in the methodology for extending the service life of hose-in-hose transfer lines.” DOE responded that it understood the value of enhancing the technical basis for extending the service life of the HIHTLs and committed the TOC to developing a test plan outlining some experiments. While a test plan was developed, the test plan was never implemented due to lack of funding. The planned HIHTL tests will address the same concerns present in the 2011 Board letter. Specifically, the TOC is currently planning to conduct a two-part test of HIHTL degradation, including 1) inspections of retrieved sections of HIHTLs and 2) degradation tests of unused hose samples.

The staff team identified several limitations related to WRPS's plans to test HIHTLs, specifically related to *Test Plan for the Laboratory Analysis of Hose-In-Hose Waste Transfer Pipe, WRPS-1802769* [D-3], including:

- The equipment does not allow the operator to perform tests for temperatures over 50°C. However, HIHTL may experience temperatures exceeding 68°C. The current service life basis document indicates that temperature may be the largest contributor to HIHTL degradation; subsequently, the service life basis document anticipates a reduced lifespan dependent on temperature. TOC personnel understand this limitation and may use additional information from the current service life basis document to supplement data from the test.
- The tests do not focus on determining synergistic effects between temperature, caustic solutions, and radiation. However, the tests do include a combination of caustic solution and archived tank waste that could provide information on synergistic effects.
- The proposed test plan will mainly provide qualitative data focusing on visual inspection and scanning electron microscopy/energy dispersive spectrometry, but the TOC has not defined a pass/fail criterion for the HIHTLs to support this methodology.
- WRPS personnel indicated they are unable to perform burst testing due to worker hazards and a lack of the necessary volume of waste or simulant.
- WRPS does not have a clear plan on how the test data will be used to inform the technical basis for HIHTL lifespan.

The staff team has requested the final test report and will review it upon completion of testing and publication of the report.

References

- [D-1] Washington River Protection Solutions, LLC, RPP-6711, *Evaluation of Hose-in-Hose Transfer Line Service Life*, July 6, 2017.
- [D-2] Washington River Protection Solutions, LLC, *Material and Equipment Staging Area Control*, TFC-BSM-FPM-PR-C-24, February 7, 2018.
- [D-3] Special Analytical Services, *Test Plan for the Laboratory Analysis of Hose-in-Hose Waste Transfer Pipe*, WRPS-1802769, October 17, 2018.

Appendix E: Additional Staff Observations

The following are additional observations from the Defense Nuclear Facilities Safety Board's (Board) staff team. None of these observations alone rise to the level of a safety issue. They are provided here to support the staff team's conclusion that the Tank Farms safety basis documents would benefit from revisions for clarity and content:

Complexity of Safety Basis Documentation Structure. The staff team raised questions regarding whether documents supporting safety basis controls get the appropriate level of scrutiny. For example, the staff team noted that additional details on administrative controls, including specific administrative controls (SAC), are contained in the supporting document HNF-IP-1266, *Tank Farms Operations Administrative Controls* [E-1], as opposed to the technical safety requirements (TSR). Washington River Protection Solutions (WRPS) personnel indicated that they (not the Department of Energy [DOE]) managed HNF-IP-1266, but if a revision to that document required changes to the TSRs, an amendment would need to be submitted to the DOE Office of River Protection (ORP). WRPS has a specific procedure for change control of HNF-IP-1266 to ensure configuration management with the safety basis is maintained (e.g., the change request is reviewed against the safety basis). Further, WRPS personnel indicated that their unreviewed safety question (USQ) process applies to the majority of engineering documents. They rely on the USQ process to capture the complete list of documents that would need to be updated. DOE noted that safety system oversight personnel generally review technical evaluations even though they are not part of the approval chain.

Radiological and chemical source terms are developed and maintained via supporting references rather than the documented safety analysis (DSA) or the TSR. The staff team raised questions regarding whether changes to the source terms would be captured in the safety basis and the supporting documents in a timely manner. WRPS indicated that the limiting unit liter dose value rarely changes and it was aware of only one change in the past 10 years. This may change the time to the lower flammability limit, which would then lead to an amendment for surveillance frequencies. The site also indicated that protective action criteria values do not change very often anymore, and if there were a change, it would be included as part of the Hanford Tank Farms DSA annual update.

Unintended Consequences of Certain Limiting Conditions for Operation (LCO) Formats. The TSR contains the following statement on SAC 5.8.8, *Waste Transfer System Freeze Protection*: “the air temperature in the waste transfer-associated structures shall be monitored, and the lowest temperature shall be VERIFIED to be > 32°F” and “the monitoring frequency shall be prior to removing the administrative lock on the ACTIVE WASTE TRANSFER PUMP [...] AND once per 8 hours thereafter.” It also states that “if the above temperature requirement is not met in the waste transfer-associated structures, the WASTE TRANSFER PUMP shall be placed UNDER ADMINISTRATIVE LOCK within 3 hours.”

SACs with specific limits and actions with completion times to be taken when limits are exceeded lend themselves to being written as LCOs. DOE-STD-1186-2004, *Specific Administrative Controls*, states that the LCO format “should be used when the SAC is well defined, clear corrective actions are available, and conditions supporting the SAC can be easily

surveilled.” SACs that essentially serve as LCOs but are written as directive actions may cause confusion as to what the entry and exit conditions are and whether a TSR violation has occurred. WRPS noted that personnel can create an action request in the site’s issues management system if errors are identified that do not rise to the level of a TSR violation. The request would be evaluated by the Plant Review Committee, consisting of personnel from facility/operations management, engineering, nuclear safety, project contractor assurance, and other personnel as needed.

Atmospheric Dispersion Modeling. RPP-13482, *Atmospheric Dispersion Coefficients and Radiological/Toxicological Exposure Methodology for Use in Tank Farms*, describes the model used for a rapid venting of an underground tank [E-2]. DOE-STD-3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, while not in the tank operations contract, offers additional insight on the topic. For codes that do not contain fixed values or calculate the parameters internally, one of the parameters that shall be used for ensuring conservative calculations of offsite doses in accordance with DOE-approved toolbox codes is a “non-buoyant, ground level, point source release.” If a site- or facility-specific modeling protocol is used instead, the method “should make use of DOE-approved toolbox codes and DOE-approved methods for determining site-specific parameters, where available and applicable.” When this option is used, “the modeling protocol shall address the appropriateness of the model to the site-specific situation, show that the overall result (i.e., radiological dose consequence) is conservative, and be submitted to the DOE Safety Basis Approval Authority for approval prior to use.”

The facility used the GXQ code, which is not a DOE toolbox code and which the site no longer has, to calculate the atmospheric dispersion coefficient (χ/Q') values used in its accident analyses. The methodology for calculating onsite consequences uses a puff model (i.e., a ground level, volumetric source release). The report describes how χ/Q' was calculated for a source with a diameter equal to the diameter of the largest tanks (75 feet) and a source height related to the volume vented. WRPS personnel defended the puff model by stating that venting is expected to happen rapidly during an internal deflagration or detonation and a less severe failure (i.e., resulting in a smaller, but perhaps more concentrated puff volume) would release less material. WRPS personnel further indicated that if they had used a point source χ/Q' instead, the calculated dose consequences for the worst-case scenario would increase by a factor of 8.8, which would not require additional controls. DOE-STD-3009-2014 suggests the use of DOE-approved toolbox codes employing a “non-buoyant, ground level, point source release” to ensure conservative calculations of offsite doses. The staff team raised questions focused on whether this model meets the intent of DOE-STD-3009-1994-CN3 (the version in the Tank Farm’s code of record) regarding atmospheric dispersion modeling.

Inactive Miscellaneous Underground Storage Tanks (IMUSTs). The contents, isolation status, and potential presence of ignition sources in IMUSTs are unknown. Tank Farms’ personnel believe they do not pose a nuclear safety issue if they are not disturbed. While the DSA does not specifically prohibit operations involving IMUSTs, DOE emphasized that any activity not described in the DSA is assumed to be prohibited, and a process hazard analysis would be completed for work involving IMUSTs.

References

- [E-1] Washington River Protection Solutions, LLC, *Tank Farms Operations Administrative Controls*, HNF-IP-1266, September 2017.
- [E-2] Washington River Protection Solutions, LLC, RPP-13482, *Atmospheric Dispersion Coefficients and Radiological/Toxicological Exposure Methodology for Use in Tank Farms*, September 8, 2015.