Preliminary Documented Safety Analysis Assessment for the Hanford Site High-Level Waste Facility

June 2021

Office of Enterprise Assessments
U.S. Department of Energy

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Acronyms

BDBA	Beyond Design Basis Accident
BNI	Bechtel National, Incorporated
C5V	Confinement Ventilation System
CW	Co-located Worker
DBA	Design Basis Accident
DOE	U.S. Department of Energy
EA	Office of Enterprise Assessments
EG	Evaluation Guideline
HLW	High-Level Waste
LCO	Limiting Condition for Operation
MAR	Material at Risk
MOI	Maximally Exposed Offsite Individual
NPH	Natural Phenomena Hazards
ORP	Office of River Protection
PAC	Protective Action Criteria
PDSA	Preliminary Documented Safety Analysis
PrHA	Process Hazard Analysis
SAC	Specific Administrative Control
SBRT	Safety Basis Review Team
SC	Safety Class
SER	Safety Evaluation Report
SRD	Safety Requirements Document
SS	Safety Significant
SSCs	Structures, Systems, and Components
TSR	Technical Safety Requirement
WTP	Waste Treatment and Immobilization Plant

Preliminary Documented Safety Analysis Assessment for the Hanford Site High-Level Waste Facility November 2020 through March 2021

Summary

Scope:
This assessment evaluated the preliminary documented safety analysis (PDSA) and corresponding safety evaluation report (SER) for the Hanford Site Waste Treatment and Immobilization Plant High-Level Waste (HLW) Facility. The HLW Facility will be used for vitrification of high-activity waste currently stored in the Hanford Site tank farms.

Significant Results for Key Areas of Interest:
The HLW PDSA complies with DOE-STD-3009-94 Change Notice 3, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, and the SER complies with DOE-STD-1104-2016, *Review and Approval of Nuclear Facility Safety Basis and Safety Design Basis Documents*.

Preliminary Documented Safety Analysis
The PDSA adequately documents integration of safety into the design of the HLW Facility as demonstrated by the following:

- The hazard evaluation includes an appropriately detailed, conservative process hazard analysis and provides a sound basis for control selection and functional classification.
- The selection of hazard controls follows the DOE-STD-3009-94 preferred control hierarchy to ensure adequate protection for workers and the public.
- The functional classification of safety structures, systems, and components is appropriate, and the safety functions, functional requirements, and performance criteria are adequate.
- The specific administrative control evaluations demonstrate that safety functions will be met.
- The descriptions of operating modes, limiting conditions for operation, and design features are adequate to support future derivation of technical safety requirements.

Federal Review and Approval
The SER meets the requirements of DOE-STD-1104-2016, adequately documents the basis for approving the PDSA, and appropriately concludes that the design and safety basis provide reasonable assurance of adequate protection of the public, workers, and the environment from HLW Facility operations. The SER identified one condition of approval requiring the next revision of the PDSA to provide a basis for administrative controls that are used in place of engineering controls. The SER also identified five directed actions to correct editorial errors and ensure consistency within the PDSA.

Best Practices and Findings
There were no best practices or findings identified in this assessment.

Follow-up Actions:
The PDSA identifies 25 planned design and operational safety improvements. The Office of Enterprise Assessments will continue to review PDSA revisions and facility design development as both activities continue to mature.

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) Office of Nuclear Engineering and Safety Basis Assessments, within the independent Office of Enterprise Assessments (EA) conducted an assessment of the preliminary documented safety analysis (PDSA) and safety evaluation report (SER) for the High-Level Waste (HLW) Facility at the Hanford Site Waste Treatment and Immobilization Plant (WTP). This assessment, conducted primarily from November 2020 to March 2021, is part of an ongoing effort to conduct independent oversight of high-hazard nuclear facility construction projects, as required by DOE appropriations legislation.

This assessment was conducted in accordance with the *Plan for the Assessment of the Hanford Site High-Level Waste Facility Preliminary Documented Safety Analysis, November 2020*. The scope of this assessment encompassed review of the hazard and accident analyses, including hazard controls, design basis accidents (DBAs), and beyond design basis accidents (BDBAs); safety structures, systems, and components (SSCs) and specific administrative controls (SACs); and the preliminary derivation of technical safety requirements (TSRs) associated with the HLW Facility.

Bechtel National, Incorporated (BNI) manages the WTP under the direction and oversight of the DOE Office of River Protection (ORP). BNI is responsible for design, construction, and commissioning of the WTP.

The purpose of the HLW Facility is to process high-level liquid radioactive waste into a stable glass form and package it for final disposal. The HLW Facility is one of three major processing facilities (including the Pretreatment Facility and the Low-Activity Waste Facility) within the WTP. The HLW vitrification process includes several major activities. Pretreated waste is transferred to receipt vessels in the HLW Facility using underground lines from the Pretreatment Facility. After receipt, two parallel and redundant processing systems are used to prepare waste for vitrification. The waste is then added to one of two normally operating joule-heated melters. Finally, the molten waste/glass mixture is discharged from the melter into stainless-steel canisters. The radioactive liquid waste and effluents generated from vitrification and support processes are transferred to the Pretreatment Facility for treatment, recycling, or disposal. The HLW Facility is designed for a 40-year nominal service (operating) life.

2.0 METHODOLOGY

The DOE independent oversight program is described in and governed by DOE Order 227.1A, *Independent Oversight Program*, which is implemented through a comprehensive set of internal protocols, operating practices, assessment guides, and process guides. This report uses the terms "best practices, deficiencies, findings, and opportunities for improvement" as defined in the order.

As identified in the approved plan, this assessment considered requirements included in EA Criteria and Review Approach Document (CRAD) 31-29, Rev. 1, *Review of Nuclear Facility Safety Design Basis Development*. WTP construction began before DOE issued the standard for integrating safety into the design of nuclear facilities (DOE-STD-1189-2008, *Integration of Safety into the Design Process*). As a result, neither the standard nor its 2016 successor version is applicable to the BNI contract. The methodology that BNI followed for developing the PDSA is DOE-STD-3009-94 Change Notice 3, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety*

Analyses. In accordance with the assessment plan, the assessment team selected relevant criteria from CRAD 31-29, taking into account these considerations. The assessment team evaluated the ORP SER for compliance with DOE-STD-1104-2016, *Review and Approval of Nuclear Facility Safety Basis and Safety Design Basis Documents*.

The assessment team focused on aspects of nuclear safety essential to ensuring adequate protection of workers and the public. The assessment team examined key supporting documents, including the process hazard analysis (PrHA), the preliminary fire hazards analysis, accident analysis calculations, design calculations, procurement specifications, and engineering drawings. The assessment team attended key hazard analysis and design review meetings and conducted meetings with BNI personnel and ORP safety basis review team (SBRT) members responsible for developing and reviewing the safety design basis documents. Since April 2020, the assessment team has been conducting all WTP oversight activities remotely. The members of the assessment team, the Quality Review Board, and EA management responsible for this assessment are identified in Appendix A.

The assessment team used a comment and response process to address issues identified during its review. The team provided comments on the PDSA to ORP during the in-process review draft stages and received written responses. When necessary, follow-on discussions among the assessment team, ORP, and BNI were conducted to resolve issues. Comments were resolved by either adequate comment responses or changes incorporated into the PDSA, SER, and supporting documents.

No items from previous assessments required follow-up in this assessment.

3.0 RESULTS

3.1 Preliminary Documented Safety Analysis

Revision 0 of the HLW PDSA was approved in 2002. Since then, BNI has regularly revised the document based on the progress of design and construction. EA has been performing field oversight activities associated with this safety design basis development since 2014 and formally reviewed a change to the PDSA (Revision 6) based on the redesign of the radioactive liquid waste disposal system in late 2015. The results of that review are documented in *Office of Enterprise Assessments Targeted Assessment of the Waste Treatment and Immobilization Plant High-Level Waste Facility Radioactive Liquid Waste Disposal System Safety Basis Change Package – May 2016*. Revision 7, issued in late 2017, was a major change to the PDSA based on a new hazard analysis. BNI has continued to systematically refine the hazard analysis. This assessment evaluated Revisions 8 and 9 of the PDSA, which incorporated new hazard analyses of the melter feed process, canister handling, and melter offgas systems; incorporated design changes to the confinement ventilation system (C5V); and deleted controls associated with chemical hazards outside the process stream.

3.1.1 Hazard and Accident Analyses (Chapter 3)

The objective of the assessment of Chapter 3 of the PDSA was to evaluate hazard identification and evaluation for the HLW Facility, including the designation of hazard controls. The assessment team reviewed hazard events related to fires, explosions, loss of confinement, and external causes, both man-made and from natural phenomena hazards (NPH).

3.1.1.1 Hazard Identification and Characterization

A hazard identification checklist was used to systematically document hazards for each process area in the HLW Facility. The PrHA events were developed using the What-if/Checklist process to identify

potential abnormal conditions and accidents. Worker safety hazards are appropriately identified. The material at risk (MAR) is based on the HLW feed from the Pretreatment Facility. The HLW slurry feed consists of a mixture of liquids and solids. The bounding flow streams include the melter feed process system, radioactive liquid waste disposal system, melter process system, and melter offgas treatment process system. Maximum values for radionuclide concentration are derived from these feeds. The MAR is appropriately described in terms of quantity and form and includes fissile isotopes. The PDSA adequately identifies and characterizes the HLW Facility hazards.

The hazard categorization of the HLW Facility is appropriately identified as Hazard Category 2 in accordance with DOE-STD-1027-92 Change Notice No. 1, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*. The estimated inventory exceeds the Hazard Category 2 threshold shown in DOE-STD-1027-92 for strontium-90, cesium-137, and plutonium-239 when based on the volume of the feed and feed preparation vessels.

3.1.1.2 Hazard Evaluation

The assessment team reviewed the hazard analysis to determine whether it appropriately evaluates the HLW Facility processes under normal, abnormal, and accident conditions. The assessment team examined the analyzed hazard scenarios and potential effects of postulated events to verify that the estimated event frequencies and consequences for workers and the public are conservative.

The HLW PrHA is divided into a series of nodes allowing a systematic approach for developing accident scenarios, identifying boundaries and interfaces, and establishing the applicable MAR. The hazard evaluation analyzes normal operations and maintenance processes, as well as abnormal and accident conditions (i.e., fires, loss of confinement, explosions, man-made external events, and NPH events).

The HLW Facility hazard evaluation process appropriately includes hazard screening, hazard evaluation, unmitigated and mitigated consequence/frequency estimation, and hazard control selection. Hazard event consequences are evaluated against a radiological consequence threshold of 100 rem to the co-located worker (CW) and the Evaluation Guideline (EG) of 25 rem to the maximally exposed offsite individual (MOI) for the selection of safety SSCs. In accordance with an ORP letter of direction on safety basis development, the PDSA considers the threshold for challenging the EG for the MOI to be 5 rem. The PDSA categorizes events that exceed this threshold as having a consequence level of "High." Chemical consequences are evaluated against toxicological Protective Action Criteria level 3 (PAC-3) values for the CW and PAC-2 values for the MOI for the selection of safety SSCs. The revised control strategy proposes to manage chemical hazards (sodium hydroxide and nitric acid) prior to their introduction into a radioactive material waste stream through a chemical safety management program instead of safety significant (SS) SSCs. The PDSA includes a planned design and operational safety improvement to develop the HLW chemical safety management program. Selection of safety SSCs for protection of the public, CW, and facility worker is adequate based on the requirements of DOE-STD-3009-94.

The PDSA provides bounding accident analyses for four event types (i.e., fires, explosions, loss of confinement, and NPH events). There are no accidents with high unmitigated radiological consequences (i.e., greater than or equal to 5 rem) to the public. However, multiple accidents have a high unmitigated risk rank (group I) for the CW or a medium unmitigated risk rank (group II) for the public. The bounding accident involving a hydrogen explosion in a melter feed vessel results in radiological dose consequences of 3.4 rem to the public and 660 rem to the CW. The accident analysis demonstrates that all accident events are adequately prevented or mitigated.

The PDSA provides an analysis of four BDBAs, including full facility fires, seismic events greater than the design basis earthquake, and post-seismic or ashfall hydrogen explosions involving multiple vessels. The estimated dose consequences for the analyzed BDBAs do not result in significantly higher

consequences than the analyzed accidents. The consequence analysis methodology and associated parameters are conservative. Safety class (SC) and SS SSCs and SACs are appropriately identified and functionally classified for each DBA based on the consequences and risk rankings.

Although the bounding seismic event consequences are moderate to the public, SC controls are identified due to the inherent uncertainties in the safety analysis. The SC seismic response includes termination of hazardous material transfers in identified lines and isolation of utility systems which, upon failure, may challenge the C5V.

The potential for an inadvertent criticality event in the HLW Facility is determined as not credible, assuming compliance with the HLW waste acceptance requirements. The HLW waste acceptance criteria, which are protected by a SAC, limit the ratio of fissile material to neutron absorbing materials in waste feed, precluding a criticality event.

The hazard evaluation addresses a thorough set of hazard events. Initiating event frequencies and radiological and chemical consequences are conservatively estimated. The accident analysis adequately evaluates an appropriate set of representative and unique DBAs derived from the hazard evaluation. The consequence analysis methodology and associated parameters are conservative.

3.1.1.3 Hazard Control Selection

The assessment team reviewed the accident analysis in Chapter 3 of the PDSA to evaluate the selection and classification of hazard controls. Chapter 3 identifies controls for the protection of workers from potential hazard events, exclusive of standard industrial hazards. Safety SSCs and SACs are identified to prevent or mitigate DBAs with potential consequences exceeding or challenging the EG or PAC-2 to the MOI, or 100 rem or PAC-3 to the CW, and to protect the facility worker.

The postulated design basis seismic event assumes a complete facility structural collapse causing the bounding release involving all significant MAR in the facility. The SS HLW structure reduces the probability of a release of radiological and chemically hazardous material by maintaining structural stability under dynamic loads. The SS seismically qualified C5V, in combination with the structure, ensures a filtered release. An SC seismic switch and its necessary support systems (the seismic monitoring system, programmable protection system, and uninterruptible power supply electrical system) are selected to mitigate the consequences of a seismic event by terminating transfers.

Credited SS SSCs for DBA fire events include passive fire barriers. Hydrogen explosion events are prevented by vessel mixing and headspace air purge and are mitigated by a vented vessel design and the C5V. Loss of confinement events predominately rely on primary confinement (e.g., vessels, melter shells, piping) for prevention and a suite of controls for mitigation (e.g., C5V, process interlocks, melter pressure relief device).

The PDSA and PrHA provide a sufficiently detailed hazard analysis summarizing the hazard events, including the event description, summary of causes, and frequency/consequences. For each DBA, the accident analysis provides an adequate discussion of scenario development, source term, initiating frequency, radiological consequences, chemical consequences, comparison to thresholds, and control selection. Hazard controls are properly identified and selected, with clear traceability to the hazard events, and include the safety functions and associated functional requirements. The selection of hazard controls follows the DOE-STD-3009-94 preferred control hierarchy and is adequate to prevent or mitigate the analyzed DBAs.

3.1.1.4 Defense in Depth

The PDSA effectively incorporates the principles of defense in depth described in DOE-STD-3009-94. SSCs and administrative controls provide preventive or mitigative functions so that multiple independent barriers are available for protection of the public, workers, and the environment. The fundamental aspects of defense-in-depth controls were addressed during the hazard analysis activities. For example, the defense in depth for transfer piping is implemented by a primary (inner) and secondary (outer) confinement design. Primary confinement for waste storage and processing systems consists of process system piping, vessels, melters, offgas components, and containers. Secondary confinement consists of the facility structure, export casks, overpacks, and the active C5V. Safety management programs provide sufficient assurance of abnormal condition detection and notification, response processes, procedures, and training for facility workers and the CW.

3.1.2 Hazard Controls (Chapter 4)

The objective of the assessment of Chapter 4 of the PDSA was to verify that the safety functions of SSCs and SACs are aligned with the hazard analysis and that the functional requirements and performance criteria are adequate to ensure that the safety functions can be met.

3.1.2.1 Safety Structures, Systems, and Components

The safety functions of SSCs are clearly described and are appropriately based on the hazard and accident analyses. The functional requirements and system evaluations, including performance criteria, are adequately developed in Chapter 4 and provide a thorough evaluation of how the controls effectively prevent or mitigate DBAs. NPH design requirements are appropriately included in the system evaluations.

3.1.2.2 Specific Administrative Controls

Chapter 4 of the PDSA identifies 12 SACs for protecting initial conditions, preserving analysis assumptions, or preventing or mitigating hazardous events. For most SACs, the PDSA provides their safety functions, descriptions, and functional requirements; however, there is insufficient design information to fully develop the Fire Protection Water SAC. This action is being tracked as a planned design and operational safety improvement in the PDSA. The PDSA also includes an evaluation section, with performance criteria, that assesses the ability of the SAC to meet its safety functions.

SACs are appropriately chosen as controls when safety SSCs cannot feasibly be used (e.g., waste acceptance criteria, combustible controls), where operator action is required (e.g., critical lifts, cask torquing requirements), or where actions are very infrequent and there is considerable time for the action to take place (e.g., ashfall response, transfers between melter cells). The SACs are sufficiently developed to support the PDSA and final design of the HLW Facility. The safety functions of the SACs are consistent with those identified in the hazard and accident analyses. The functional requirements and SAC evaluations sufficiently describe how the SACs meet their safety functions.

3.1.2.3 Hazard Control Design

The objectives of the assessment of the final design and supporting design documentation were to verify that the nuclear safety design criteria of DOE Order 420.1B, *Facility Safety* (the revision of the order that is applicable to the WTP Project), are adequately addressed and to evaluate implementation of the functional design criteria established for the HLW Facility. The assessment focused on the adequacy of the design and major processes to support the safety functions, functional requirements, and performance criteria of safety SSCs.

The reviewed safety requirements document (SRD), final design documents, calculations, and drawings adequately reflect the building structure and process systems during this stage of the project. The SRD provides formal documentation of the safety requirements and implementing codes and standards for the HLW Facility. The approach to meeting the nuclear safety design criteria of DOE Order 420.1B is adequately described in the SRD using a tailored approach, with no identified exceptions to the order. The PDSA appropriately invokes the requirements of the SRD. Applicable design codes and standards are referenced, including the code of record, procurement specification, final design documents, and applicable NPH design criteria.

3.1.3 Derivation of Technical Safety Requirements (Chapter 5)

The objective of the assessment of Chapter 5 of the PDSA was to evaluate the derivation of TSRs and to verify accurate translation of credited SSCs and performance requirements into a set of formal and implementable requirements for the facility. These requirements preserve the identified safety functions, functional requirements, and performance criteria developed in Chapters 3 and 4 of the PDSA.

Modes and mode restrictions for process areas are clearly defined in Chapter 5 of the PDSA. Three facility modes—operations, maintenance, and shutdown—are established, and the descriptions are complete. Proposed limiting conditions for operation (LCOs) for safety SSCs are consistent with the control development in Chapter 4, and surveillance requirements are appropriately identified. SACs are adequately described as LCOs. Design features are adequately described with appropriate in-service inspection and configuration management requirements. The PDSA TSR derivation meets the requirements of DOE-STD-3009-94.

3.1.4 Preliminary Documented Safety Analysis Conclusion

The PDSA meets the requirements of DOE-STD-3009-94 and comprehensively identifies and evaluates the hazards associated with the HLW Facility. The hazard analysis appropriately addresses hazardous materials and energy sources and postulates an adequate set of hazard events. The identified controls are adequate to ensure protection for workers and the public. The safety functions and functional requirements for SSCs and SACs are sufficiently defined to meet the hazard control requirements derived in the hazard analysis. The system evaluation of the SSCs and SACs ensure that safety functions will be met. The design criteria in DOE Order 420.1B are adequately described in the SRD. The identified operational modes, LCOs, and design features are adequate to support the derivation of TSRs.

3.2 Federal Review and Approval

The assessment team reviewed the SERs for Revisions 8 and 9 of the PDSA to determine their adequacy as the approval bases for the PDSA changes as required by DOE-STD-1104-2016. The ORP SBRT followed the *Safety Basis Review Plan for Waste Treatment and Immobilization, High-Level Waste Facility* and used the lines of inquiry to ensure the thoroughness of the review. These SERs focus on the changes to the PDSA in each revision and are identified as addenda to the SER written for Revision 7 of the PDSA.

The SBRT included members with appropriate subject matter expertise in nuclear safety, criticality safety, and safety systems oversight. The SBRT concluded that the PDSA presents sufficient information to support the final design and acceptably resolves SBRT (and EA) comments. Based on this assessment, the SBRT recommended approval of the HLW Facility PDSA.

The SER addresses the approval bases identified for review in DOE-STD-1104-2016, which include verification that the design requirements of DOE Order 420.1B are met, verification that the PDSA design is based on the safety functions identified in the hazard analysis, and confirmation that the appropriate

design criteria are identified. For each approval basis, the SER provides a satisfactory basis for recommending approval of the PDSA. There is one condition of approval requiring the next revision of the PDSA to provide a basis for administrative controls that are used in place of engineering controls. The SER for Revision 9 also identified five directed actions to correct editorial errors and ensure consistency within the PDSA.

Overall, the PDSA and SER appropriately conclude that there is reasonable assurance of adequate protection of the public, workers, and the environment from HLW Facility operations.

4.0 BEST PRACTICES

There were no best practices identified as part of this assessment.

5.0 FINDINGS

There were no findings identified as part of this assessment.

6.0 DEFICIENCIES

There were no deficiencies identified as part of this assessment.

7.0 OPPORTUNITIES FOR IMPROVEMENT

There were no opportunities for improvement identified as part of this assessment.

8.0 ITEMS FOR FOLLOW-UP

The PDSA includes 25 open planned design and operational safety improvements. EA will continue to review the PDSA revisions and monitor the WTP Project as these improvements are incorporated.

Appendix A
Supplemental Information

Dates of Assessment

November 2020 – March 2021

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