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Design Calculation or Analysis Cover Sheet

Complete only applicable items.

1. QA: QA

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5. Title

HLW/DOE SNF Co-Disposal Waste Package Design Report

6. Group

Thermal/Structural Analysis

7. Document Status Designation

☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled/Superseded

8. Notes/Comments

None.

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1) CACN-001, DATED 02/29/2008

Attachments	Total Number of Pages
None	

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Initial Issue This design report supersedes and revises the previous document ANL-DDC-ME-000001 REV 00 to report the results of the finite element analyses and evaluations for the latest HLW/DOE SNF Co-Disposal waste package designs. The changes are extensive and all pages are affected.	97	97	T.A. Schmitt 3/2/04	A.K. Scheider 3/2/04	N/A [EGS signature not required when 00A was issued]	M.J. Anderson 3/2/04
00B	Revised Section 7.1.2.2.9 to include results of the revision of calculation 000-00C-DS00-00100-000-00B, 5 DHLW/DOE SNF – Short Waste Package 10-Degree Oblique Drop with Slap Down. Updated references to current versions and made minor modifications to be consistent with the revised references.	98	98	T.A. Schmitt 7/1/04	A.K. Scheider 7/1/04	N/A [EGS signature not required when 00B was issued]	M.J. Anderson 7/1/04
ECN1	Document status changed to committed	1	1	T.A. Schmitt 8/12/05	M. Mullin 8/12/05	N/A	M.J. Anderson 8/12/05
CACN 001	Corrected minor errors and omissions per CA 8293-004 and CA 8293-001	1	1	D. Mecham 12/7/06	K. Jaquay 12/7/06	N/A	M.J. Anderson 12/7/06 T. Mulkey 12/7/06
00C	Major revision to reflect change in scope of design report. Updated references and formatted to new procedures. All pages are affected.	61	61	Mohan Durani/ Daniel Wang 10/30/07	Del Mecham 10/30/07	M. J. Anderson 10/30/07	M.J. Anderson 10/30/07
00D	Administrative wording change. Page 11 only.	61	61	Daniel Wang 11/7/07	N/A	N/A	M.J. Anderson 11/7/07
00E	Revision to incorporate Design basis change to 2.0 kW/m linear heat load in drift. Extensive minor wording changes. All pages are affected.	63	63	Daniel Wang 2/12/08	Jason Viggato 2/12/08	Jason Viggato 2/12/08	M.J. Anderson 2/12/08
00F	Documented that the maximum thermal power in DHLW canisters results in maximum DOE waste package thermal power of 5,570 *watts* which satisfies all temperature limits. Extensive revision. All pages are affected.	63	63	Del Mecham [signature] 2/21/08	Daniel Wang [signature] 2/21/08	Jason Viggato [signature] 2/21/08	M. J. Anderson [signature] 2/22/08

DISCLAIMER

The calculations contained in this document were developed by Bechtel SAIC Company, LLC (BSC) and are intended solely for the use of BSC in its work for the Yucca Mountain Project.

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ACRONYMS

ASME	American Society of Mechanical Engineers
B&PV	Boiler and Pressure Vessel
BOD	Basis of Design
CSNF	Commercial Spent Nuclear Fuel
DHLW	Defense High-Level (radioactive) Waste
DOE	U.S. Department of Energy
EM	Environmental Management
EWA	Element Wall-Averaged
FLIP	Fuel Life Improvement Program
GMAW	Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
HLW	High-Level Waste
HVAC	Heating, Ventilation, and Air-Conditioning
IED	Information Exchange Document
IICD	Integrated Interface Control Document
INEEL	Idaho National Engineering and Environmental Laboratory
INL	Idaho National Laboratory (formerly INEEL)
IPWF	Immobilized Plutonium Waste Form
ITS	Important To Safety
ITWI	Important To Waste Isolation
LaBS	Lanthanide Borosilicate
LA	License Application
MCNP	Monte Carlo N-Particle

MCO	Multicanister Overpack
MTHM	Metric Tons of Heavy Metal
NSDB-LA	Nuclear Safety Design Bases for License Application
NSNFP	National Spent Nuclear Fuel Program
OCB	Outer Corrosion Barrier
OD	Outer Diameter
PCSA	Preclosure Safety Analyses
PDC	Project Design Criteria
QA	Quality Assurance
RPM	Repository Project Management
SI	Stress Intensity
SNF	Spent Nuclear Fuel
SNL	Sandia National Laboratory
SRS	Savannah River Site
SS	Stainless Steel
SSC	Structures, Systems, and Components
TAD	Transportation, Aging, and Disposal
TEV	Transport and Emplacement Vehicle
TRIGA	Training, Research, Isotope, General Atomics
UNS	Unified Numbering System for Metals and Alloys
WP	Waste Package
WVDP	West Valley Demonstration Project
YMP	Yucca Mountain Project

1. PURPOSE

A design methodology has been developed for the waste packages (WP) that satisfies the requirements of the Yucca Mountain Project (YMP). The practicability of this design methodology has been demonstrated in this report. This report provides a description of the design requirements and cites the specific evaluations as the basis for meeting those requirements.

The purpose of this report is to document how the design methodology has been applied to the 5–DHLW/DOE SNF co-disposal waste package configurations. The design methodology is described in the *Waste Package Component Design Methodology Report* (Reference 2.2.40) as augmented by the *Execution Plan for the Thermal-Structural Discipline Workflow for Design, Design Revisions, and Prototyping of Waste Packages and Related Components* (Reference 2.2.30). The design methodology is intended to provide designs that satisfy the safety and operational requirements of the YMP. Three waste package configurations have been selected to illustrate the application of the methodology during the License Application (LA) process. These three configurations are the Transportation, Aging, and Disposal (TAD) canister bearing waste package, the 5–Defense High-Level Waste (DHLW)/United States Department of Energy spent nuclear fuel (DOE SNF) short (5–DHLW/DOE SNF Short) co-disposal waste package, and the naval canistered SNF long (Naval SNF Long) waste package. Design work for the other four waste packages will be completed at a later date using the same design methodology. These include the TAD canister bearing long waste package, the 5–DHLW/DOE SNF long co-disposal waste package, the DOE 2–Multi-Canister Overpack/2–Defense High-Level Waste (2–MCO/2–DHLW) co-disposal waste package, and the naval canistered SNF short (Naval SNF Short) waste package.

This report demonstrates that the design methodology can be applied successfully to the configurations and supports the License Application for construction of the repository. This report summarizes design features that show the designs are in compliance with applicable design requirements. Design requirements are contained in the *Basis of Design for the TAD Canister-Based Repository Design Concept* (BOD) (Reference 2.2.24) and the *Project Design Criteria Document* (PDC) (Reference 2.2.39). Additional design requirements are derived from the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25), which defines credible preclosure event sequences during normal operations.

It is important to note that the design authority's responsibility is limited to implementing the controlled design requirements such that compliance can be demonstrated (with the use of performance confirmation data as necessary) only up to the time of repository closure. The responsibility for demonstrating any future postclosure state with respect to compliance with design requirements rests with Sandia National Laboratory the YMP Lead Laboratory. Further, the Lead Laboratory retains responsibility for demonstrating how and to what extent compliance with the design requirements contributes to barrier capability.

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2.3 DESIGN CONSTRAINTS

None

2.4 DESIGN OUTPUTS

This document provides the basis for the 5-DHLW/DOE SNF co-disposal waste package designs as embodied in the drawings of these components. The design outputs include 5-DHLW/DOE SNF short and long configuration drawings (References 2.2.16, 2.2.17, 2.2.18, 2.2.19, 2.2.20, and 2.2.21). This document also provides information to support the License Application.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

Unless otherwise specified in this section, assumptions requiring verification applicable to calculations are provided within the referenced calculations in Section 6.

3.1.1 The dimensions, masses, materials and load paths used in the development of this design report, corresponding to the 5-DHLW/DOE SNF co-disposal waste package configuration drawings (References 2.2.16, 2.2.17, 2.2.18, 2.2.19, 2.2.20, 2.2.21) are assumed to be the same as the final definitive design. The rationale for this assumption is that the designs of the 5-DHLW/DOE SNF co-disposal waste packages (References 2.2.16, 2.2.17, 2.2.18, 2.2.19, 2.2.20, 2.2.21) are created for the License Application (LA). This assumption is used in Section 6.1.3.

3.1.2 The *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25) is used for screening event sequences (e.g., based on design features for other systems) and to further define the credible event sequence scenarios. A QA: N/A source is used since the latest revision of the BOD (Reference 2.2.24) does not sufficiently describe the credible event sequences for the DOE waste packages. This assumption is used in Section 6.2.3.

3.1.3 Event sequences defined by the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25) which are satisfied by the addition of design features to preclude the event or considered to be not credible will not be addressed by this design report. The rationale for this is that the Preclosure Safety Analyses (PCSA) group will screen out the event sequences for inclusion into the Nuclear Safety Design Bases for License Application (NSDB-LA) at a later date (Appendix A, Reference 2.2.2), and satisfaction of design requirements resulting from these event sequences will be addressed by later revisions of the BOD (Reference 2.2.24). This assumption is used in Section 6.2.3.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

Assumptions not requiring verification applicable to calculations are provided within the referenced calculations in Section 6.

3.2.1 It is assumed that the event sequence where the waste package is caught on the Transport and Emplacement Vehicle (TEV) structure and dragged along the invert surface, resulting in the waste package falling off the emplacement pallet and against TEV structures (Reference 2.2.25, Section 4.3.8) is less severe than the event sequence where a loaded TEV is overdriven into an emplaced WP (Reference 2.2.25, Section 4.3.6). The rationale for this is that the momentum of the TEV in the dragging scenario is less due to the fact that it will be starting from rest and is unloaded, compared to the collision scenario where the TEV is moving at full speed and is loaded with the waste package. Furthermore, a waste package dragged along the invert surface will most likely impact one of the invert beams, resulting on a line contact across the lid or a point contact on the sleeve; this scenario is less challenging to the outer corrosion barrier (OCB) than the point contact on the lid initiated by an angled 2-MCO/2-DHLW WP that was analyzed in Reference 2.2.54. This assumption is used in Section 6.2.3.7.

3.2.2 It is assumed that the event sequence where a drip shield emplacement gantry collides with an emplaced waste package (Reference 2.2.25, Section 4.4.3) is less severe and bounded by the event sequence where a loaded TEV collides with an emplaced waste package. The rationale for this is that the loaded TEV (mass of 300 *tons* (272*MT*) max and top speed of 1.705 *mph* (0.762 *m/s*) per References 2.2.75 and 2.2.74 (Section 6.7.3), respectively) has a much larger momentum compared to the loaded drip shield emplacement gantry (mass of 100 *tons* (90.7 *MT*) max and top speed of 1.989 *mph* (0.889 *m/s*) per References 2.2.72 and 2.2.73 respectively). This assumption is used in Section 6.2.3.17.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This document was developed in accordance with EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Reference 2.1.1). The DOE waste packages are classified as important to safety (ITS) and important to waste isolation (ITWI) (Reference 2.2.24, Section 11.1.2). Therefore, the approved version is designated QA: QA.

The *Execution Plan for the Thermal-Structural Discipline Workflow for Design, Design Revisions, and Prototyping of Waste Packages and Related Components* (Reference 2.2.30) is QA: N/A. It is used to augment the *Waste Package Component Design Methodology Report* (Reference 2.2.40).

The *Value Study Report—Waste Package Reevaluation* (Reference 2.2.27) is QA: N/A. It is referenced for historical purposes only.

The *Yucca Mountain Science and Engineering Report* (Reference 2.2.52) is QA: N/A. It is referenced for historical purposes only.

The *BSC Position on the Use of the ASME Boiler and Pressure Vessel Code for the Yucca Mountain Waste Packages* (Reference 2.2.15) is QA: N/A. It is used to augment the *Yucca Mountain Review Plan, Final Report* (Reference 2.2.45).

The *Emplacement and Retrieval Drip Shield Emplacement Gantry Mechanical Equipment Envelope* (Reference 2.2.72) is QA: N/A. It is used to augment the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25).

The *Preliminary Preclosure Nuclear Safety Design Bases* (NSDB-LA) (Reference 2.2.2) is QA: N/A. It is used for controlling parameters and values related to the WP as dictated by the BOD (Reference 2.2.24). It has been incorporated by reference to the BOD (Reference 2.2.24).

The *Drip Shield Gantry Mechanical Equipment Envelope Calculation* (Reference 2.2.73) is QA: N/A. It is used to augment the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25).

The *TMRB Decision Proposal, Revise TDR-MGR-MD-000037, Postclosure Modeling and Analyses Design Parameters* (Reference 2.2.68) is QA: N/A. It is used to augment the *Postclosure Modeling and Analyses Design Parameters* (Reference 2.2.67).

The *Regulatory Guidance Agreement, Regulatory Guide 1.84, Rev. 33 - Design, Fabrication, and Materials Code Case Acceptability, ASME Section III* (Reference 2.2.78) is QA: N/A. It is used to provide guidance on the use of *Regulatory Guide 1.84* (Reference 2.2.79).

4.2 USE OF SOFTWARE

No computer software or models were used in the generation of this report. Contributory calculations provide descriptions of software used.

4.3 WASTE PACKAGE COMPONENT DESIGN METHODOLOGY

The design methodology for waste package components (including the emplacement pallet and drip shield) is described in the *Waste Package Component Design Methodology Report* (Reference 2.2.40). Common design work practices and design changes are controlled within the design group through the *Execution Plan for the Thermal-Structural Discipline Workflow for Design, Design Revision, and Prototyping of Waste Packages and Related Components* (Reference 2.2.30). Design methodology can be viewed simply as gathering all the design input information; making reasonable assumptions; selecting analyses methods and computational tools; and showing that design criteria are satisfied.

Inputs to the design come from project requirements, interfaces with other organizations, and specific technical information. Top level requirements originate from the U.S. Department of Energy (DOE) and include regulations such as *10 CFR Part 63* (Reference 2.2.1). These requirements flow to design through two documents, the BOD (Reference 2.2.24) and the PDC (Reference 2.2.39). Waste package component designs that interface with other parts of the YMP, include ties to fabrication and handling facilities, preclosure safety analysis, and performance assessment. Within Engineering and Repository Project Management (RPM), engineering drawings and reports provide the interfaces. The interfaces with science and performance assessment (Sandia National Laboratory (SNL) the YMP Lead Laboratory) are through Information Exchange Documents (IEDs) and Interface Definition Documents. Exchanged information includes physical dimensions and material properties for use in structural and thermal calculations.

Simplifying assumptions are used to bound design parameters. Assumptions are listed and justified in specific calculation reports. A few simple hand calculations are performed in this document, and the numeric results are used to show that design criteria are satisfied. Qualified computer programs were used in the feeding calculations and analyses.

5. LIST OF ATTACHMENTS

None

6. BODY OF CALCULATION

6.1 DESIGN DESCRIPTION

The waste isolation system is an important element of a repository. The primary component of the system is the waste package. As defined in *10 CFR 63* (Reference 2.2.1), a waste package includes the waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding it. The invert material, emplacement pallet, and drip shield do not immediately surround the waste package, so they are not considered part of the waste package. The designs of the DOE waste packages are described in Sections 6.1 and 6.2. The general configurations, justification of design features, material selections, and guidance for use of codes and standards are provided. Figure 1 shows an exploded view of the 5-DHLW/DOE SNF (long) co-disposal waste package. Figure 2 shows the waste package on an emplacement pallet.

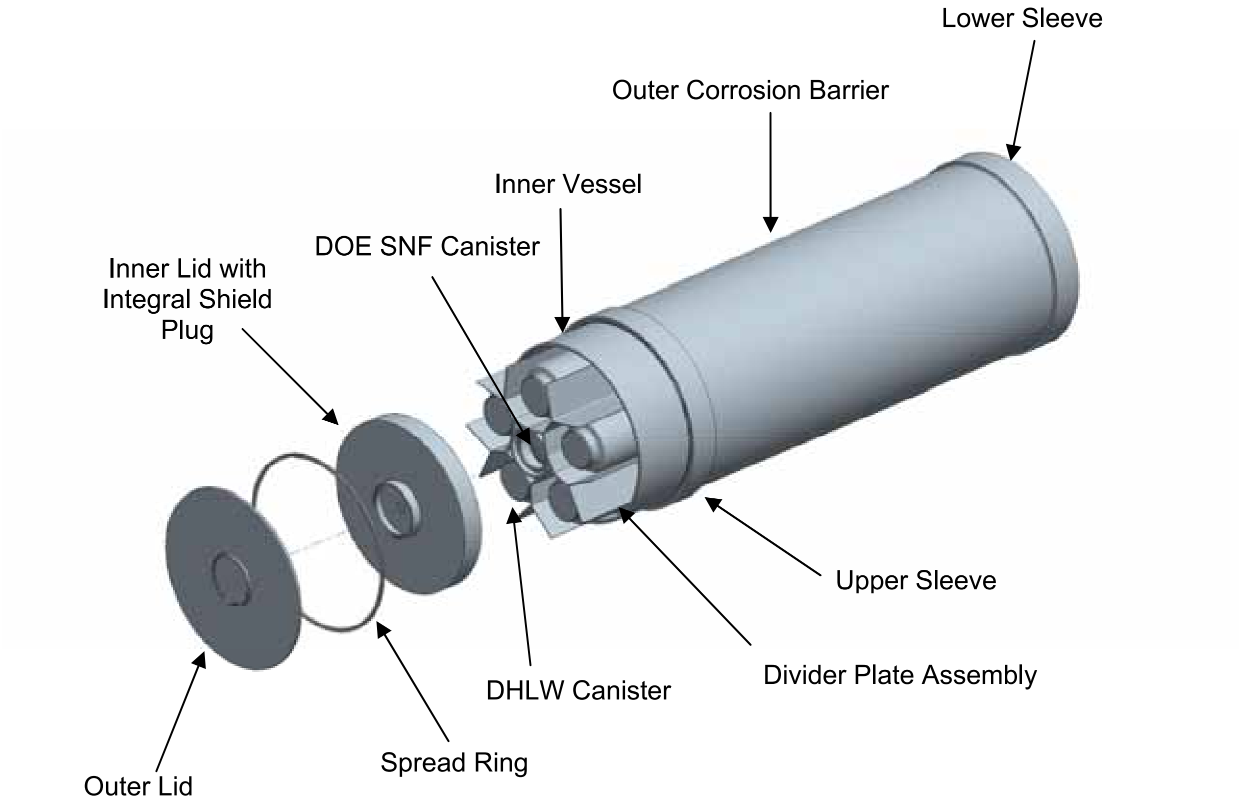


Figure 1. 5-DHLW/DOE SNF Co-Disposal Waste Package

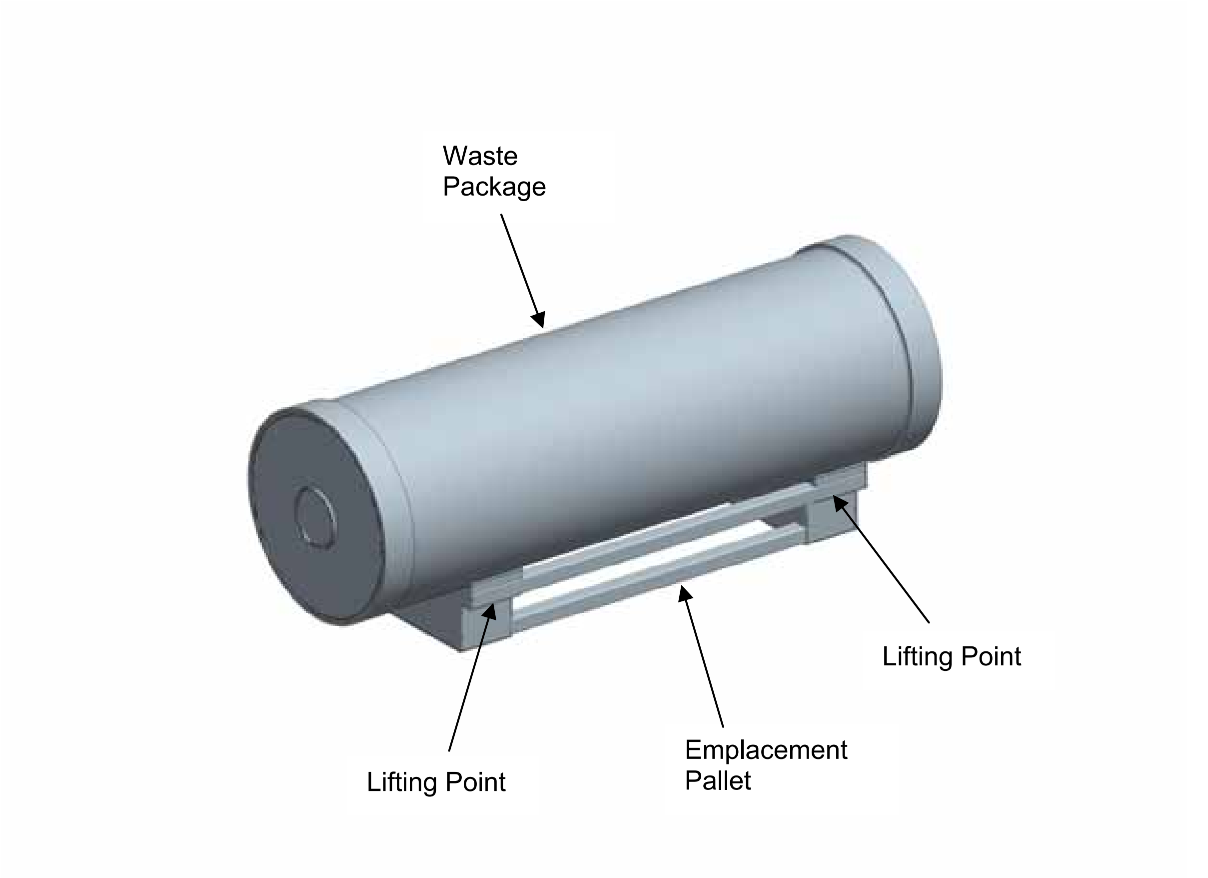


Figure 2. Waste Package on an Emplacement Pallet

6.1.1 DOE Waste Package Configurations

Three waste package design configurations have been developed for co-disposal of DOE SNF and HLW. They are: the 5-DHLW/DOE SNF co-disposal short, the 5-DHLW/DOE SNF co-disposal long, and the 2-MCO/2-DHLW co-disposal waste packages. Only the first two are discussed herein. The 2-MCO/2-DHLW co-disposal waste packages will be discussed further in a future report.

5 DHLW/DOE SNF Co-Disposal Short—This design configuration holds up to five vitrified waste canisters of 3.00 *m* (118 *in*) nominal length and 0.61 *m* (24 *in*) nominal diameter such as those from the Savannah River Site (SRS), and a 0.4742 *m* (18.68 *in*) maximum diameter canister of DOE-owned SNF in the center. Canister dimensions are given in the BOD (Reference 2.2.24, Sections 11.2.2.7 and 11.2.2.8). Alternatively, this design configuration can be loaded with up to four vitrified waste canisters and one 0.6299 *m* (24.80 *in*) maximum diameter DOE SNF canister in the peripheral locations with the center location empty. Both the 18 *in* and 24 *in* diameter "short" DOE SNF canisters have a nominal length of 118 *in* (3.00 *m*). This waste package design configuration can be seen in References 2.2.19, 2.2.20, and 2.2.21.

5 DHLW/DOE SNF Co-Disposal Long— This design configuration holds up to five vitrified waste canisters of 4.57 *m* (180 *in*) nominal length and 0.61 *m* (24 *in*) nominal diameter such as those from the Hanford Site, and a 0.4760 *m* (18.74 *in*) maximum diameter canister of DOE-owned SNF in the center. Canister dimensions are given in the BOD (Reference 2.2.24, Sections 11.2.2.7 and 11.2.2.8). Alternatively, this design configuration can be loaded with up to four vitrified waste canisters and one 0.6317 *m* (24.87 *in*) maximum diameter DOE SNF canister in the peripheral locations with the center location empty. Both the 18 *in* and 24 *in* diameter "long" DOE SNF canisters have a maximum length of 179.92 *in* (4.57 *m*). The 5-DHLW/DOE SNF co-disposal long waste package can also be loaded with any canisters designed for the 5-DHLW/DOE SNF co-disposal short waste package, though this is not economical. This waste package design configuration can be seen in References 2.2.16, 2.2.17, and 2.2.18.

There are a number of major components that comprise the waste package. A standard nomenclature has been established for referring to these components. This nomenclature is shown in Table 1.

Table 1. Standard Nomenclature for Waste Package Components

Preferred Terminology	Acceptable for Clarity or Brevity	Description
Upper Sleeve		The welded circular attachment that serves as additional structural support for the outer corrosion barrier.
Lower Sleeve		The welded circular attachment that serves as additional structural support for the outer corrosion barrier.
Outer Corrosion Barrier	Outer Barrier Alloy 22 Shell	The Alloy 22 (UNS N06022) shell (sides and the outer corrosion barrier bottom lid)
Outer Lid	Final Alloy 22 Lid	The outermost lid, Alloy 22 (UNS N06022)
Spread Ring		The ring that, when spread into position, mechanically holds the inner vessel lid in place
Inner Vessel Lid	Inner Lid	The stainless steel lid that seals the Inner Vessel
Inner Vessel	Stainless Steel Vessel	The inner vessel that is the ASME B&PV code-stamped pressure vessel
Shell Interface Ring	Interface Ring	The stainless steel ring that sits between the support ring and the inner vessel
Inner Vessel Support Ring	Support Ring	The Alloy 22 (UNS N06022) ring that keeps the inner vessel off of the bottom of the outer corrosion barrier
Divider Plate Assembly	Canister Guide Basket	The carbon steel (UNS K02700) structure exclusive to the DOE waste packages that provides mechanical separation of canisters, structural support, criticality control, and heat transfer as necessary.

The major internal differences between the 5 DHLW/DOE SNF Short, 5 DHLW/DOE SNF Long, and 2-MCO/2-DHLW waste packages and the fuels they accommodate are summarized in Table 2.

Table 2. HLW/DOE SNF Co-Disposal Waste Package Internal Components

Waste Form	Waste Package	Internal Placement	Notes
Vitrified High-Level Waste (SRS, INL, and West Valley)	5 DHLW/DOE SNF Short, 5 DHLW/DOE SNF Long, or	Five peripheral locations	The 5 DHLW/DOE SNF Long or 2-MCO/2-DHLW are acceptable, however not economical.
	2-MCO/2-DHLW	Two, diagonally across from each other	
Vitrified High-Level Waste (Hanford)	5 DHLW/DOE SNF Long, or	Five peripheral locations	
	2-MCO/2-DHLW	Two, diagonally across from each other	
18" DOE Long Standardized SNF Canister	5 DHLW/DOE SNF Long	Center location	
18" DOE Short Standardized SNF Canister	5 DHLW/DOE SNF Short or 5 DHLW/DOE SNF Long	Center location	The 5 DHLW/DOE SNF Long is acceptable, however not economical.
24" DOE Short Standardized SNF Canister	5 DHLW/DOE SNF-Short or 5 DHLW/DOE SNF-Long	One only in peripheral locations	Remaining peripheral locations must be loaded with HLW cylinders. Central location must be left empty. The 5 DHLW/DOE SNF Long is acceptable, however not economical.
24" DOE Long Standardized SNF Canister	5 DHLW/DOE SNF Long	One only in peripheral locations	Remaining peripheral locations must be loaded with HLW cylinders. Central location must be left empty.
Multi-canister Overpack (Hanford N-reactor Fuel)	2-MCO/2-DHLW	On MCO support plate assemblies; diagonally across from each other	Maximum of 2 per waste package.

6.1.2 Justification of Design Features

The waste package is comprised of two cylindrical layers (sometimes referred to as "shells"): a pressurized Type 316 Stainless Steel (SS) (UNS S31600) structural vessel (the inner vessel (IV)), and an Alloy 22 (UNS N06022) outer corrosion barrier (OCB). Each shell has its own lid. The inner lid is held in place by the spread ring. The inner lid of the DOE co-disposal waste packages is unique from those of the other waste packages in that it is designed with an integral shield plug (discussed further in Section 6.3).

The outer lid is designed with a flat top. This is a result of the value engineering study in *Value Study Report—Waste Package Reevaluation* (Reference 2.2.27, Attachment III). The outer lid weld is low-plasticity burnished to reduce residual stresses (Reference 2.2.24, Section 11.2.4.6). The bottom sleeve is extended past the outer corrosion barrier to form a skirt that acts as an energy absorber should the waste package be impacted on that surface. The part that extends has a tapered surface to allow for proper drainage when the waste package is horizontal.

To eliminate the possibility of induced stress corrosion cracking, the inner vessel and outer corrosion barrier have a gap in between, both radially and axially. The axial gap is at least 10 *mm* (0.394 *in*) (Reference 2.2.28, Section 7), and the radial gap will be at least 1 *mm* (0.0394 *in*) (Reference 2.2.14, Tables 4 and 5, p. 13). These distances account for differences in thermal expansion values for Alloy 22 (UNS N06022) and Type 316 SS (UNS S31600).

The shell interface ring is added as a measure to absorb energy. Its placement alleviates high stresses from occurring in the inner vessel bottom corner. The support ring is added to prevent the weight of the canister from creating a force in the middle of the bottom lid of the outer corrosion barrier when the waste package is in the vertical position. The support ring elevates the inner vessel and prevents it from contacting the outer corrosion barrier bottom lid.

For the 5 DHLW/DOE SNF waste packages a basket structure is designed to allow up to five HLW canisters placed radially with a single DOE standardized SNF canister in the center.

6.1.3 Dimensions

Dimensions of the two waste packages can be found in References 2.2.16, 2.2.17, 2.2.18, 2.2.19, 2.2.20, and 2.2.21 (Assumption 3.1.1). The cavity lengths for the 5-DHLW/DOE SNF long and short co-disposal waste packages are determined from the overall dimensions of the SNF canisters. Since there are two lengths of SNF canisters (3.00 *m* (118.11 *in*) and 4.57 *m* (179.92 *in*)) (Reference 2.2.37, Figures C-4, C-5, C-9, and C-10) there are two waste package configurations to accommodate them. The cavity lengths of the short and long waste packages are approximately 13 *mm* (0.5 *in*) and 49 *mm* (2.0 *in*) greater than the nominal lengths of the short and long DOE SNF canisters, respectively. For the 5-DHLW/DOE SNF short waste package the cavity length is 3.013 *m* (118.63 *in*), and for the 5-DHLW/DOE SNF long waste package the cavity length is 4.620 *m* (181.88 *in*). The waste package cavity diameter for both configurations is 1.883 *m* (74.13 *in*) and are designed such that, with the divider plate assembly, they will be able to accommodate five DHLW canisters. The inner vessel lids are designed with a thickness of 9 *in* (229 *mm*) for shielding purposes, as discussed in Section 6.2.4.5.

6.1.4 Material Selection

The following material selection analysis was excerpted from *Yucca Mountain Science and Engineering Report* (Reference 2.2.52, Section 3.4).

6.1.4.1 Material Selection Criteria

The selection of materials from which reliable waste packages could be fabricated followed a multistep analysis and design process. It began by analyzing the critical functions of a particular waste package and its various components. In selecting a material for a component, the designers considered both the material's availability and the critical functions the component will serve as part of the waste package. Major components and performance criteria were identified for selecting fabricating materials (Reference 2.2.43, Section 3). The major components are:

- Structural vessel (herein referred to as the Inner Vessel (IV))
- Corrosion-resistant barrier (herein referred to as the Outer Corrosion Barrier (OCB))
- Fill gas
- Canister guide for HLW and DOE SNF canisters

Not every waste package design configuration requires canister guides; it varies according to the waste form each will hold. In the case of DOE waste packages, all listed components apply.

The criteria that contribute to performance are:

- Mechanical performance (strength)
- Chemical performance (resistance to corrosion and microbial attack)
- Predictability of performance (understanding the behavior of materials)
- Compatibility with materials of the waste package and waste form
- Ease of fabrication using the material
- Previous experience (proven performance record)
- Thermal performance (heat distribution characteristics)
- Neutronic performance (criticality and shielding).

Reasonableness of cost was considered as a discriminator.

6.1.4.2 Corrosion-Resistant Materials

Corrosion performance has been determined to be the most important criterion for a long waste package lifetime. Essential performance qualities therefore include a material's resistance to general and localized corrosion, stress corrosion cracking, and hydrogen-assisted cracking and embrittlement. The effects of long-term thermal aging are also important. To address the performance requirements for the waste package, the DOE has initiated studies to gain a better understanding of the processes involved in predicting the rate of waste package material corrosion over the regulatory period.

Combinations and arrangements of materials as containment barriers were carefully considered from several perspectives. In the process, analysts considered such criteria as (1) material compatibility (e.g., galvanic/crevice corrosion effects); (2) the material's ability to contribute to defense in depth (e.g., because it has a different failure mode from other barriers); (3) the material's ease of fabrication; and (4) the potential impact of thin, corrosion-resistant materials used as containment barriers on a repository's essential operations, such as waste package loading, handling, and emplacement.

The major objectives centered on understanding the temperature and humidity conditions that exist at different times for a range of thermal operating modes in a particular unsaturated zone, then designing the waste packages accordingly. Since the properties of any material selected for a corrosion barrier will inevitably be influenced by the temperature and humidity conditions in a repository of a particular design at a particular site, selecting the right corrosion-resistant material became one of the most important priorities.

After assessing potential materials available for waste package corrosion barriers, analysts selected nickel- and titanium-based alloys as the most promising candidate materials for corrosion resistance in an oxidizing environment. Using a corrosion-resistant material as the outer corrosion barrier of the waste package significantly lowers the risk of waste package failure from corrosion. Alloy 22 (UNS N06022) was selected as the preferred material for the outer corrosion barrier because it has excellent resistance to corrosion in the environment expected at Yucca Mountain; it is easier to weld than titanium; and it has a better thermal expansion coefficient match to Type 316 SS (UNS S31600), the inner vessel material, than titanium. A structurally strong material Type 316 SS (UNS S31600) was chosen for the inner vessel of the waste package.

Alloy 22 (UNS N06022) also offers benefits in the areas of program and operating flexibility. It is extremely corrosion-resistant under conditions of high temperature and high humidity, such as those that will prevail for hundreds to thousands of years in a repository designed to allow a relatively high thermal output from the waste packages.

6.1.4.3 Structural Materials

The major functional requirement of the inner layer (inner vessel) of the waste package is to structurally support the corrosion-resistant outer material. Type 316 SS (UNS S31600 with additional controls on carbon and nitrogen) was selected for the structural layer. This material provides the required strength; has a better compatibility with Alloy 22 (UNS N06022) than carbon steel; and provides an economical solution to functional requirements.

6.1.4.4 Fill Gas

The fill gas can be a significant conductor of heat from the waste form to the inner vessel, so thermal performance was deemed one of the most important criteria in choosing a gas. The fill gas should not degrade other components of the waste package, so compatibility with other materials was another important criterion. Helium is inert and is routinely used as the fill gas for fuel rods, which indicates that helium will have an excellent compatibility with spent nuclear fuel. It is also neutrally buoyant, which reduces thermal stratification of the fill gas. Based on a review of data on thermal conductivity, it was chosen over other candidate gases, such as nitrogen, argon, and krypton.

6.1.5 Data and Parameters for Waste Package Materials

The sources of material properties are listed in the *Waste Package Component Design Methodology Report* (Reference 2.2.40, Tables 1 and 2). The main sources are listed as the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code (Reference 2.2.6), and the ASM Metals Handbook (Reference 2.2.5). However, Sections 6.1.1.11, 6.1.1.12 and 6.1.1.13 in the same reference also indicate that when the temperature-dependent material properties are not available from these sources, either normalized elevated temperature material properties based on vendor data or room temperature (20*℃* or 68*℉*) material properties are used in the calculations.

6.1.6 ASME Code Position

The basis for the selection and application of the ASME B&PV Code to the waste package is documented in the document entitled, *BSC Position on the Use of the ASME Boiler and Pressure Vessel Code for the Yucca Mountain Waste Packages* (Reference 2.2.15). This section summarizes the salient points of that document with regard to the design of the waste packages.

Yucca Mountain Review Plan, Final Report (Reference 2.2.45) provides specific guidance on the appropriateness of using the ASME B&PV Code (Reference 2.2.6) in the design of waste packages (e.g., Section 2.1.1.7.2.3 (1)); however, it does not prescribe the exact implementation of the ASME B&PV Code.

In any discussion of the ASME B&PV Code, it is important to first note that it is a pressure vessel safety code and that its primary mission is to assure structural adequacy for pressure loading. Any other use of the ASME B&PV Code, such as the use of the conservative material properties contained in it or failure limits for non-pressure loading, must be justified on insight into the structural phenomena that are postulated to occur. For the waste packages, component sizing and thickness are not determined by pressure loads but rather by dynamic events that the waste packages might experience. Therefore, the application of the ASME B&PV Code design rules for dynamic loading of the waste packages must be carefully scrutinized to ensure that the rules are properly applied.

For the code-compliant design and fabrication of the WPs, BSC has selected to apply Section III, Division I, Subsection NC of the ASME B&PV Code (Reference 2.2.6). It is important to differentiate the parts of the waste package to which the code apply. There are three major assembled components of the waste package. These are (1) the Type 316 SS inner vessel, (2) the Alloy 22 (UNS N06022) outer corrosion barrier, and (3) the divider plate assemblies (applicable to co-disposal waste packages only). With regard to the code design, the only one of these parts that is considered a pressure vessel is the Type 316 SS inner vessel.

With regard to the hermeticity of the inner vessel and integrity of the same against pressure loads, no currently postulated dynamic structural event involves simultaneous over-pressurization of the inner vessel. For over-pressurization, the capability of the spread ring and seal weld combination to retain the design pressure is assured by a helium leak check. While the seal welds are anticipated to be sound welds, no credit for resistance against dynamic events is taken for these welds. Therefore, for dynamic structural events where the inner vessel in the vicinity of the seal welds may be reasonably anticipated to experience significant loads, these welds are not credited to maintain the hermeticity of the inner vessel. In such cases, it must be shown that the outer corrosion barrier does not breach to maintain containment of the waste form.

For the other components of the waste package, the ASME B&PV code is only used as guidance, either through the use of conservative material properties or conservative stress limits. For credible preclosure event sequences and the assessment of those event sequences, the code and supporting code interpretations are used to formulate layered defensible material failure criteria.

It should be noted that if a waste package suffers a nontrivial dynamic event for which adequate long-term performance cannot be assured, the waste form would be repackaged in a new waste package and the original waste package permanently removed from service.

6.1.7 DOE Canister Surface Temperatures

Section 10.1.3 of the Integrated Interface Control Document (IICD) (Reference 2.2.37) states that during normal operations, DOE SNF canister wall temperatures shall not exceed 315.5 *C* in enclosed environments and 148.9 *C* in open (air) environments. This requirement is acknowledged, but Reference 2.2.42 clarifies that compliance with this requirement shall be shown to be achievable for any structure, system, or component that relies on the performance of the canister pressure vessel boundary. This includes activities from the loading of Environmental Management (EM) SNF into disposable canisters through final closure of the waste package. As this document primarily governs only sealed waste packages, this thermal requirement is not applicable for situations and scenarios discussed in this document.

6.1.8 Criticality

The preclosure safety analysis must include consideration of means to prevent and control criticality (Reference 2.2.1, 10 CFR 63.112(e)(6)). In addition to any criticality safety design features in the standardized DOE SNF canisters, and the inherent subcriticality of the vitrified high-level waste due to the low concentration of fissile material, criticality safety is ensured by a requirement in the PDC (Reference 2.2.39 Section 4.10.2.1.1) that SSCs shall be designed such that adequate controls and procedures can be effectively implemented to:

- prevent criticality and institute controls that are relied on to limit or prevent potential event sequences or mitigate their consequences during processing, handling, transfer, or transport of the waste form or waste package in the preclosure period and
- ensure compliance with the waste form and waste package performance objectives during the postclosure period.

In-depth discussion of criticality is beyond the scope of this document.

6.2 DESIGN REQUIREMENTS

Design requirements include those requirements that flow to design through the BOD (Reference 2.2.24) and PDC (Reference 2.2.39), as well as requirements derived by the nature of the engineered design solution or imposed by interfaces with postclosure performance assessment. Requirements imposed by the BOD (Reference 2.2.24), *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25), and PDC (Reference 2.2.39) are described in Sections 6.2.1 through 6.2.3 and are related to use of engineering codes and standards. They require the DOE waste packages to be designed in accordance with practices outlined in the ASME Pressure Vessel Code (Reference 2.2.6). The fabrication requirements are passed on to the vendor via the fabrication specification (Reference 2.2.23). Each design requirement is compared to design features, drawings, and/or calculations for the DOE waste packages and then a description of how the design satisfies the requirement is given.

6.2.1 DOE Waste Package Design Criteria

Requirement 6.2.1.1: Section 5.1.1 of the PDC (Reference 2.2.39) requires that structural design of the waste package be in accordance with ANSI N14.6-1993 (Reference 2.2.12), NUREG-0612 (Reference 2.2.22) and *2001 ASME Boiler and Pressure Vessel Code* (Reference 2.2.6), Section II and III, Division I. American Society of Mechanical Engineers (ASME) Section III Code Cases identified in Regulatory Guide 1.193 (Reference 2.2.76) shall not be used. RGA REG-CRW-RG-000071, *Agreement for Regulatory Guide 1.84, Rev. 33 - Design, Fabrication, and Materials Code Case Acceptability, ASME Section III* (Reference 2.2.78) has adopted Regulatory Guide 1.84 (Reference 2.2.79), to allow the option of using NRC approved ASME Section III code cases.

Satisfaction of Requirement 6.2.1.1: Key parameters (including material density, yield strength, tensile strength, and Modulus of Elasticity) that are used in the structural analyses (e.g. Reference 2.2.53) are taken from Reference 2.2.6. All structural analyses (e.g. Reference 2.2.35) follow the most appropriate method of classifying local primary membrane stress as defined by (Reference 2.2.6, Section III, Division 1, Appendix XIII, XIII-1123(j)). The requirement for ANSI N14.6-1993 (Reference 2.2.12) was intended for the trunnion collar, a component now deleted from the waste package configuration. NUREG-0612 (Reference 2.2.22) governs lifting procedures for heavy loads at nuclear power plants. There is nothing in the document that pertains to structural design requirements relating to components similar to waste packages. ASME Section III Code Cases identified in Regulatory Guide 1.193 (Reference 2.2.76) are not used. Therefore, Requirement 6.2.1.1 is satisfied.

Requirement 6.2.1.2: Section 5.1.2 of the PDC (Reference 2.2.39) requires that metallurgical design of the waste package be in accordance with *2001 ASME Boiler and Pressure Vessel Code* (Reference 2.2.6), Section III, Division I, Subsection NC. American Society of Mechanical Engineers (ASME) Section III Code Cases identified in Regulatory Guide 1.193 (Reference 2.2.76) shall not be used.

Satisfaction of Requirement 6.2.1.2: Material properties (tensile strength, yield strength, maximum allowable stress) that are used in structural analyses (e.g. Reference 2.2.35) are taken from Reference 2.2.6. ASME Section III Code Cases identified in Regulatory Guide 1.193 (Reference 2.2.76) are not used. Therefore, Requirement 6.2.1.2 is satisfied.

Requirement 6.2.1.3: Section 11.2.1.1 of the BOD (Reference 2.2.24) requires that the DOE and commercial waste package system shall be designed to be capable of isolating commercial SNF, DOE SNF, vitrified DHLW, vitrified commercial HLW, and IPWF at the following annual rates:

1. In the first full year of operation, the repository shall:
   a. Accept and receive 400 *MTHM* commercial SNF and HLW
   b. Accept and receive 66 DOE SNF canisters and 193 DHLW canisters.
2. During years two through four of operations, the repository shall:
   a. Accept and receive at least 3,800 *MTHM* commercial SNF and HLW
   b. Accept and receive at least 257 DOE SNF canisters and 1,143 DHLW canisters.
3. On year five, at the start of full-scale, steady-state operations, the repository shall:
   a. Accept and receive 3,000 *MTHM* commercial SNF and HLW annually
   b. Accept and receive 179 DOE SNF canisters and 763 DHLW canisters annually.

Satisfaction of Requirement 6.2.1.3: Tables 1 and 5 of Reference 2.2.32 use emplacement rates equal to or higher than those required above to represent nominal emplacement rates. This shows that it is possible to handle the amounts of nuclear material required. Therefore, Requirement 6.2.1.3 is satisfied.

Requirement 6.2.1.4: Section 11.2.1.3 of the BOD (Reference 2.2.24) requires that the DOE waste package shall be capable of operating over a range of thermal conditions and, in conjunction with the Subsurface Facility, shall be capable of allowing a maximum emplacement drift line load (over any seven waste package segment) (linear thermal power) of up to 2.0 *kW/m*.

The waste package emplacement shall be within an envelope such that the emplacement of waste packages does not exceed the other relevant thermal limits of mid-pillar temperature, drift wall temperature, waste package temperature, and cladding temperature. The calculated Thermal Energy Density of any seven adjacent as-emplaced waste packages shall not exceed 96°*C* at the mid-pillar calculated using mean host-rock thermal properties and representative saturation levels for wet and dry conditions.

<u>Satisfaction of Requirement 6.2.1.4</u>: Reference 2.2.32 demonstrates that the estimated limiting waste stream can be emplaced at a line load of 2.0 *kW/m* (Reference 2.2.32, Cases 3a, 3b, and 4). Operational requirements are expected to ensure that the 2.0 *kW/m* line load is not exceeded. Reference 2.2.46 demonstrates that 5-DHLW/DOE SNF short waste packages below 6.97 *kW* in 2.0 *kW/m* drifts satisfy waste form temperature limits (Reference 2.2.46, Figure 31, note: temperatures are slightly high initially but this is an anomaly of the assumed initial temperature). This result bounds all expected 5-DHLW/DOE SNF waste packages, which have a maximum thermal power 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6). Reference 2.2.83 (Table 22) gives a peak drift wall temperature of 195.3°*C* for a thermally misloaded drift segment that is expected to bound all other possible seven-package drift segments. This is compliant with the 200°*C* drift wall temperature limit given in Reference 2.2.24, Section 22.2.1.3. Reference 2.2.83 (Table 19) gives a peak mid-pillar temperature of 97.7°*C* for an "as-loaded" estimated limiting seven-package drift segment. Though this result exceeds the 96°*C* mid-pillar temperature limit given in Reference 2.2.67 (Table 1, item # 05-03), it uses only a small part of the 10°*C* margin provided by vaporization and movement of water in the rock indicated by Reference 2.2.80, Section 6.2. A model that fully accounts for hydrological effects is expected to give a mid-pillar temperature that is compliant with the 96°*C* limit. Therefore, Requirement 6.2.1.4 is satisfied.

Requirement 6.2.1.5: Section 11.2.2.2 of the BOD (Reference 2.2.24) requires that the DOE waste package design shall comply with the agreements established under the Integrated Interface Control Document (IICD) (Reference 2.2.37) to ensure compatibility of DOE owned SNF and HLW waste forms with repository surface facility interfaces, including canister interfaces.

<u>Satisfaction of Requirement 6.2.1.5</u>: The 5-DHLW/DOE SNF short and long co-disposal waste package configuration drawings (References 2.2.17 and 2.2.20) show cavity heights of 118.63 *in* (3013.1 *mm*) and 181.88 *in* (4619.6 mm) respectively. The divider plate tube inside diameter for both 5-DHLW/DOE SNF co-disposal waste packages is 19.74 *in* (501.4 *mm*) as shown in Reference 2.2.13. These dimensions are in compliance with those shown in Figures C-7, C-8, and C-9 of the IICD (Reference 2.2.37). Acknowledgement and discussion of temperature limits for the DOE SNF given in the IICD (Reference 2.2.37, Section 10.1.3) are discussed in Section 6.1.7. Therefore, Requirement 6.2.1.5 is satisfied.

Requirement 6.2.1.6: Section 11.2.2.5 of the BOD (Reference 2.2.24) requires that the commercial waste package shall be capable of allowing the disposing of the waste forms with a maximum thermal power of up to 18.0 *kW*.

The waste package emplacement shall be within an envelope such that the emplacement of waste packages does not exceed the other relevant thermal limits of mid-pillar temperature, drift wall temperature, waste package temperature, and cladding temperature. The calculated Thermal Energy Density of any seven adjacent as-emplaced waste packages shall not exceed 96°*C* at the mid-pillar calculated using mean host-rock thermal properties and representative saturation levels for wet and dry conditions.

Satisfaction of Requirement 6.2.1.6: With the release of CBCN 010 of the BOD (Reference 2.2.24), the first paragraph of the requirement (regarding waste package thermal power limits) no longer pertains to DOE waste packages. In theory, the maximum thermal power for a DOE waste package is limited to 9.47 *kW* (1,970 *W* DOE SNF + 5x 1,500 *W* HLW = 9,470 *W*) by the separate thermal power limits on DOE SNF and HLW set forth in Sections 11.2.2.12 and 11.2.2.19 of the BOD (Reference 2.2.24). However, loading to this maximum theoretical thermal power is precluded by the fact that actual HLW canisters have a maximum thermal power of 720 *watts* (Reference 2.2.84, Table 24). Therefore, in actuality, the 5-DHLW/DOE SNF waste packages have a maximum practical thermal limit of 5,570 *W* (1,970 *W* DOE SNF + 5x 720 *W* HLW = 5,570 *W*). The second paragraph of Requirement 6.2.1.6 is addressed in the Satisfaction of Requirement 6.2.1.4. Therefore, Requirement 6.2.1.6 is satisfied.

Requirement 6.2.1.7: Section 11.2.2.6 of the BOD (Reference 2.2.24) requires that the waste packages shall be designed to permit retrieval during the preclosure period until the completion of a performance confirmation program and commission review of the information obtained from such a program. The waste package shall be designed to permit retrieval during the preclosure period so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated.

Satisfaction of Requirement 6.2.1.7: The design of the waste package system includes an emplacement pallet that allows retrieval of the waste package during the preclosure period. The structural analysis of the emplacement pallet (Reference 2.2.29) showed acceptable stress levels under lifting with in-drift temperatures and reduced material thickness due to corrosion. Therefore, Requirement 6.2.1.7 is satisfied.

Requirement 6.2.1.8: Section 11.2.2.7 of the BOD (Reference 2.2.24) requires that the DOE waste packages shall be designed and procured to accommodate the following HLW canisters:

- SRS HLW canister, nominal outside diameter (OD) of 24 *in*. (61 *cm*), nominal overall height of 118 *in*. (3.00 *m*), maximum individual loaded canister weight of 5,512 *lb* (2,500 *kg*), canister material of Stainless Steel Type 304L –expected canisters 7,347,
- Hanford Site (Long) HLW, nominal OD of 24 *in*. (61 *cm*), nominal overall height of 180 *in*. (4.57 *m*), maximum individual loaded canister weight of 9,260 *lb* (4,200 *kg*), canister material of Stainless Steel Type 304L -expected canisters 14,500,
- INL, nominal OD of 24 *in*. (61 *cm*), nominal overall height of 118 *in*. (3.00 *m*), maximum individual loaded canister weight of 5,512 *lb* (2,500 *kg*), canister material of Stainless Steel Type 304L, expected canisters-not specified, and
- WVDP, nominal OD of 24 *in*. (61 *cm*), nominal overall height of 118 *in*. (3.00 *m*), maximum individual loaded canister weight of 5,512 *lb* (2,500 *kg*), canister material of Stainless Steel Type 304L -expected canisters 300.

Satisfaction of Requirement 6.2.1.8: HLW canisters of nominal length 118 *in* (3.00 *m*) shall be accommodated in one of the five peripheral locations of the 5-DHLW/DOE SNF short co-disposal waste package which has an inner vessel cavity length of 118.63 *in* (3.013 *m*) (Reference 2.2.20). HLW canisters of nominal length 180 *in* (3.00 *m*) will be accommodated in either the 2-MCO/2-DHLW waste package or in one of the five peripheral locations of the 5-DHLW/DOE SNF long co-disposal waste package. The 5-DHLW/DOE SNF long co-disposal waste package has an inner vessel cavity length of 181.88 *in* (4.62 *m*) (References 2.2.17). The given weights for the canisters are acknowledged in the predicted loaded waste package masses given in References 2.2.16, 2.2.19, and 2.2.59. These design requirements and the expected quantity of canisters are expected to be followed when procuring the waste packages. The canister materials are taken into consideration in supporting calculations (such as Reference 2.2.81). Therefore, Requirement 6.2.1.8 is satisfied.

Requirement 6.2.1.9: Section 11.2.2.8 of the BOD (Reference 2.2.24) requires that the DOE waste packages shall be designed and procured to accommodate the following DOE SNF canisters:

- NSNFP 18 *in*. × 10 *ft*, maximum diameter 18.68 *in*. (474.2 *mm*), maximum length 118.11 *in*. (3,000 *mm*), maximum weight 5,005 *lb* (2,271 *kg*), material Stainless Steel Type 316L
- NSNFP 18 *in*. × 15 *ft*, maximum diameter 18.74 *in*. (476.0 *mm*), maximum length 179.92 *in*. (4,570 *mm*), maximum weight 6,000 *lb* (2,721 *kg*), material Stainless Steel Type 316L
- NSNFP 24 *in*. × 10 *ft*, maximum diameter 24.80 *in*. (629.9 *mm*), maximum length 118.11 *in*. (3,000 *mm*), maximum weight 8,996 *lb* (4,080 *kg*), material Stainless Steel Type 316L
- NSNFP 24 *in*. × 15 *ft*, maximum diameter 24.87 *in*. (631.7 *mm*), maximum length 179.92 *in*. (4,569.9 *mm*), maximum weight 10,000 *lb* (4,535 *kg*), material Stainless Steel Type 316L
- MCO 25 *in*. × 14 *ft*, maximum diameter 25.51 *in*. (642.87 *mm*), maximum length 166.435 *in*. (4,227.5 *mm*), maximum weight 19,642 *lb* (8,909.6 *kg*), material Stainless Steel Type 304L.

Satisfaction of Requirement 6.2.1.9: The 5-DHLW/DOE SNF short and long divider plate tube drawing (Reference 2.2.13) shows an inner diameter of 19.74 *in* (501.4 *mm*) which is large enough to accommodate one SNF canister type of nominal diameter 18 *in* (457 *mm*) as shown in the IICD (Reference 2.2.37, Figures C-7 and C-8). The SNF canister types of nominal diameter 24 *in* (610 *mm*) shall be accommodated in one of the five peripheral locations of the 5-DHLW/DOE SNF co-disposal waste package separated by the divider plate assembly. The MCO canisters shall be accommodated within the 2-MCO/2-DHLW waste package as shown in the IICD (Reference 2.2.37, Figure C-16). The given weights for the canisters are acknowledged in the predicted loaded waste package masses given in References 2.2.16, 2.2.19, and 2.2.59. The design requirements are expected to be followed when procuring the waste packages. The canister materials are taken into consideration in supporting calculations (such as Reference 2.2.81). Therefore, Requirement 6.2.1.9 is satisfied.

Requirement 6.2.1.10: Section 11.2.2.9 of the BOD (Reference 2.2.24) requires that the waste package shall be fabricated in a controlled manner that results in minimal defects. The damage to the waste package corrosion barrier that displaces material (i.e. scratches) shall be limited to 1.6 *mm* (1/16 *in*) in depth. Modifications to the waste package corrosion barrier that deform the surface, but do not remove material (i.e. dents), shall be limited to having a width at least 5 times greater than the depth, but no dent that would result in the alloy 22 deforming into the stainless steel barrier is acceptable. The waste package will be inspected at the fabricator location to ensure that the as-fabricated waste package meets specified requirements.

The waste package outer corrosion barrier fabrication welds shall be nondestructively examined by radiographic examination, and ultrasonic testing, for flaws equal to or greater than 1/16 *inch* or as required by the applicable specification. Outer corrosion barrier fabrication welds shall be liquid penetrant examination by the applicable specification.

Welding flaws 1/16 *inch* and greater for the outer corrosion barrier shall be repaired, and criteria for acceptable marring shall be followed, in accordance with written procedures that have been accepted by the design organization prior to their usage.

The welding techniques for the fabrication welds shall be constrained to GMAW (gas metal arc welding) except for short-circuiting mode, and GTAW (gas tungsten arc welding) for Alloy 22 (UNS N06022) material, limited to <45 *kJ/in*.

Satisfaction of Requirement 6.2.1.10: The *Waste Package Fabrication Specification* (Reference 2.2.23, Section 3.5) specifies that the outer surfaces of the waste package shall have a surface roughness of 125 µ*inch* (3.2 *µm*) or better. There are no exceptions for scratches or any similar surface defects. The fabrication specification (Reference 2.2.23) covers weld examination in Section 6.1, weld flaw repair in Section 5.5.1.5, and welding techniques in Section 5.5.1.1. Therefore, Requirement 6.2.1.10 is satisfied.

Requirement 6.2.1.11: Section 11.2.2.10 of the BOD (Reference 2.2.24) requires that the waste package inner vessel shall have one lid and be made of Stainless Steel Type 316 (UNS S31600), and the outer corrosion barrier shall have one lid and be made of Alloy 22 (UNS N06022). The waste package outer barrier shall be comprised of Alloy 22 with a minimum thickness of 25 *mm* for co-disposal waste packages. For post closure mechanical calculations and analysis, a corrosion allowance of at least 2 *mm* per side shall be accounted for on exposed waste package surfaces. Calculations will be performed using material properties at 150 *°C* or greater. The waste package Alloy 22 will be manufactured to ASTM B 575-99a (Reference 2.2.55) with the additional more restrictive, elemental and chemical composition allowable specifications:

(a) Cr = 20.0 to 21.4%
(b) Mo = 12.5 to 13.5%
(c) W = 2.5 to 3.0%
(d) Fe = 2.0 to 4.5%

Satisfaction of Requirement 6.2.1.11: The co-disposal waste package configuration drawings (References 2.2.16, 2.2.17, 2.2.18, 2.2.19, 2.2.20, 2.2.21) show waste package components satisfying the material usage and thickness requirements. SNL, the YMP Lead Laboratory, has responsibility to provide postclosure mechanical calculations and analysis. The *Postclosure Modeling and Analyses Design Parameters* report (Reference 2.2.67) restricts the range of alloying constituents in Alloy 22 from that shown in the applicable material specification (Reference 2.2.55) as part of a larger group of restrictions on design as approved by the Technical Management Review Board (Reference 2.2.68). This restriction will be incorporated in the design as a part of the normal design change process as dictated by Engineering Procedure EG-PRO-3DP-G04B-00005, *Configuration Management* (Reference 2.1.3), supplemented by the guidance in the discipline-specific execution plan (Reference 2.2.30). It should be noted that the restrictions apply to the upper portion of the range of the alloying concentrations. Testing has shown that Alloy 22 produced at the higher end of the alloying concentrations of ASTM B 575-99a (Reference 2.2.55) often does not meet the minimum material properties required by the material specification (Reference 2.2.70, Section 5.7.1). Therefore, the alloying concentrations listed in a) through d) are unlikely to have any practical consequences to waste package design or fabrication. Therefore, Requirement 6.2.1.11 is expected to be satisfied.

Requirement 6.2.1.12: Section 11.2.2.11 of the BOD (Reference 2.2.24) requires that the waste packages shall be designed to accommodate canisters designed to support their own weight and that of their contents for multiple vertical lifts and horizontal translations while suspended from above via their lifting features.

<u>Satisfaction of Requirement 6.2.1.12</u>: The co-disposal waste packages are designed to hold HLW, SNF, and MCO canisters of DOE origin designed to support their own weight. The canisters are under production control of the DOE and this requirement will be addressed by the canister manufacturer at time of design. Therefore, Requirement 6.2.1.12 is expected to be satisfied by the final designs of the canisters.

Requirement 6.2.1.13: Section 11.2.2.12 of the BOD (Reference 2.2.24) requires that the DOE waste packages shall be designed to accommodate DOE SNF canisters that have thermal outputs at the time of acceptance into the repository less than 1,970 *W* (6,720 *BTU/hr*).

<u>Satisfaction of Requirement 6.2.1.13</u>: Reference 2.2.46 shows that the 5-DHLW/DOE SNF short waste package can accommodate a DOE SNF canister at 1,970 *W* for waste package thermal powers up to and beyond the maximum DOE waste package thermal power of 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6) while satisfying thermal limits on waste form temperatures (Reference 2.2.46, Tables 47 and 48). Therefore, Requirement 6.2.1.13 is satisfied.

Requirement 6.2.1.14: Section 11.2.2.18 of the BOD (Reference 2.2.24) requires that DOE waste packages shall be designed so that cladding temperature for DOE SNF of commercial origin placed in disposable multi-element canisters, over a 1,000 year period, shall not exceed:

1. 350°*C* for zircaloy-clad assemblies (to prevent damage from creep or hydride reorientation).
2. 400°*C* for stainless steel-clad assemblies.

Commercial waste packages shall be designed so that CSNF cladding shall not exceed a maximum temperature of 350°*C* upon emplacement (to prevent damage from creep or hydride reorientation). For off-normal and accident conditions, the maximum cladding temperature shall not exceed 570°*C*.

Satisfaction of Requirement 6.2.1.14: Though the requirement applies specifically to DOE SNF of commercial origin only, demonstration of compliance is applicable for all DOE SNF including that of non-commercial origin (which has no explicitly stated thermal limit). The thermal calculation (Reference 2.2.46, Tables 47 and 48) showed that the peak SNF fuel temperature for a waste package at 7.47 *kW* stayed below 350°*C* (662°*F*) in all cases of normal operation. This result bounds all expected 5-DHLW/DOE SNF waste packages, which have a maximum thermal power 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6). Though not explicitly stated, the off-normal cladding temperature limit for CSNF is interpreted to apply for all DOE SNF as well. Reference 2.2.46 (Tables 47 and 48) shows that the SNF fuel temperature never exceeds 570°*C*, even during an off-normal 30-day loss-of-ventilation. Therefore, Requirement 6.2.1.14 is satisfied.

Requirement 6.2.1.15: Section 11.2.2.19 of the BOD (Reference 2.2.24) requires that DOE waste packages shall be designed to accommodate the HLW form, which meets the following characteristics:

- Stands upright without support on a flat horizontal surface
- Fits without forcing into a right-circular, cylindrical cavity (64 *cm* diameter and 3.01 *m* length or alternatively 64 *cm* diameter and 4.57 *m* in length).
- Weight not to exceed 9,260 *lb* (4,200 *kg*).
- Total heat generation rates for canisters containing HLW not to exceed 1,500 *watts* per canister at the year of shipment.

Satisfaction of Requirement 6.2.1.15: The DOE waste packages and accompanying divider plate assemblies are designed with dimensions and tolerance intended to accommodate HLW with said qualities (see Satisfaction of Requirement 6.2.1.8). That the HLW canisters meet the listed criteria is the responsibility of the canister manufacturers. The given weights for the canisters are acknowledged in the predicted loaded waste package masses given in References 2.2.16, 2.2.19, and 2.2.59. The heat generation rate of 1,500 *watts* is utilized as a maximum in thermal calculations (such as Reference 2.2.46). In practice, however, HLW canisters have a maximum thermal power of 720 *watts* (Reference 2.2.84, Table 24). Therefore, Requirement 6.2.1.15 is expected to be satisfied.

Requirement 6.2.1.16: Section 11.2.2.22 of the BOD (Reference 2.2.24) requires that each waste package configuration shall be loaded with one of the following combinations (short loading is allowed):

(a) 2 HLW glass canisters and 2 N Reactor MCOs,
(b) 5 HLW glass canisters and 1 DSNF canister. A canister containing LaBS glass may replace 1 HLW canister,
(c) 1 24-*in*. DSNF canister and 4 HLW canisters (center location empty)
(d) Or a single CSNF TAD canister

Satisfaction of Requirement 6.2.1.16: The DOE waste packages are designed to hold waste in configurations (a), (b), and (c). Configuration (d) does not apply to DOE waste packages (Note - this design report is limited to the DOE WP designs). The 2-MCO/2-DHLW waste package is designed to hold waste in configuration (a) and is depicted in configuration drawings (References 2.2.59, 2.2.60, and 2.2.61) that show cavity dimensions and design commensurate with this requirement. The 5-DHLW/DOE SNF co-disposal waste packages are designed to hold waste in configurations (b) and (c) and are depicted in configuration drawings (References 2.2.16, 2.2.17, 2.2.18, 2.2.19, 2.2.20, and 2.2.21) that show cavity dimensions and design commensurate with this requirement. Therefore, Requirement 6.2.1.16 is satisfied.

Requirement 6.2.1.17: Section 11.2.2.23 of the BOD (Reference 2.2.24) requires that the waste package shall be designed to maintain the maximum HLW glass temperature to less than 400 *°C*.

Satisfaction of Requirement 6.2.1.17: The thermal calculation (Reference 2.2.46, Tables 47 and 48) showed that the peak HLW glass temperature stayed well below 400*°C* (752*°F*) in all cases analyzed, including during a 30-day loss of ventilation during preclosure. Therefore, Requirement 6.2.1.17 is satisfied.

Requirement 6.2.1.18: Section 11.2.2.24 of the BOD (Reference 2.2.24) requires that the waste package surface temperature shall be kept below 300 *°C* for the first 500 years and below 200*°C* for the next 9,500 years to eliminate postclosure issues (i.e. phase stability).

Satisfaction of Requirement 6.2.1.18: The thermal calculation (Reference 2.2.46, Section 7.12.3) showed that the waste package surface temperature stayed well below 300 *°C* (572*°F*) for the first 500 years and below 200*°C* (392*°F*) for the next 9,500 years in all cases analyzed. Therefore, Requirement 6.2.1.18 is satisfied. However, the fundamental responsibility for demonstrating postclosure thermal performance is the responsibility of the Lead Laboratory.

Requirement 6.2.1.19: Section 11.2.3.1.1 of the BOD (Reference 2.2.24) and Section A.7.1 of the NSDB-LA (Reference 2.2.2) require that the waste package in each waste handling building shall have a mean frequency of breach involving a non-seismic event impact or drop of less than 1E-03 over the preclosure period.

Satisfaction of Requirement 6.2.1.19: Satisfaction of all the DOE waste package design requirements based on credible preclosure event sequences as defined in the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25) are addressed in Section 6.2.3. The Preclosure Safety Analyses (PCSA) group is responsible for determining the DOE waste package mean frequency of failure for all credible event sequences. Requirement 6.2.1.19 is expected to be satisfied upon completion of the final design.

Requirement 6.2.1.20: Section 11.2.3.1.4 of the BOD (Reference 2.2.24) and Section A.7.2 of the NSDB-LA (Reference 2.2.2) require that an emplaced waste package shall have a mean frequency of breach of less than 1E-04 over the preclosure period from seismic events covering the spectrum of seismic events less severe than that of a frequency of 1E-07/*yr*, including the relative motion of the waste package with its surroundings and rockfall.

Satisfaction of Requirement 6.2.1.20: Satisfaction of all the DOE waste package design requirements based on credible preclosure event sequences as defined in the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25) are addressed in Section 6.2.3. The PCSA group is responsible for determining the DOE waste package mean frequency of failure for all credible event sequences. Requirement 6.2.1.20 is expected to be satisfied upon PCSA's review and the completion of the final design.

Requirement 6.2.1.21: Section 11.2.3.1.6 of the BOD (Reference 2.2.24) and Section A.7.3 of the NSDB-LA (Reference 2.2.2) require that a waste package in a TEV shall have a mean frequency of failure of less than 1E-04 over the preclosure period from seismic events covering the spectrum of seismic events less severe than that of a frequency of 1E- 07*/yr*.

Satisfaction of Requirement 6.2.1.21: Satisfaction of all the DOE waste package design requirements based on credible preclosure event sequences as defined in the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25) are addressed in Section 6.2.3. The PCSA group is responsible for determining the DOE waste package mean frequency of failure for all credible event sequences. Requirement 6.2.1.21 is expected to be satisfied upon PCSA's review and the completion of the final design.

Requirement 6.2.1.22: Section 11.2.3.1.11 of the BOD (Reference 2.2.24) requires that the engineered barrier system shall be designed so that, working in combination with natural barriers, there is reasonable expectation that, for 10,000 years following disposal, the reasonably maximally exposed individual receives no more than an annual dose of 15 *mrem* (0.15 *mSv*) from releases from the undisturbed Yucca Mountain disposal system.

For the protection of ground water, working in combination with natural barriers and other engineered barriers, the DOE and commercial waste package shall be designed so that there is reasonable expectation that, for 10,000 years of undisturbed performance after disposal, releases of radionuclides from waste in the Yucca Mountain disposal system into the accessible environment will not cause the level of radioactivity in the representative volume of ground water to exceed the following limits:

- Combined radium-226 and radium-228 are less than 5 *picocuries per liter* (including natural background)
- Gross alpha activity (including radium-226 but excluding radon and uranium) is less than 15 *picocuries per liter* (including natural background)
- Combined beta and photon emitting radionuclides are less than 4 *mrem* (0.04 *mSv*) per year to the whole body or any organ, based on drinking 2 *liters* of water per day from the representative volume (excluding natural background).

Satisfaction of Requirement 6.2.1.22: SNL the YMP Lead Laboratory has responsibility to provide postclosure analysis of the engineered barrier system (which includes the waste package) with respect to annual dose rates. Requirement 6.2.1.22 is expected to be satisfied upon the Lead Lab's review and the completion of the final design.

Requirement 6.2.1.23: Section 11.2.3.1.12 of the BOD (Reference 2.2.24) requires that all waste package cavities shall be verified to be dry and backfilled with helium to achieve < 0.43 *gram-mole* of H_2O in a 7 m^3 volume after drying. This drying process shall limit oxidizing gases to below 1 *gram-mole* to prevent cladding degradation.

Satisfaction of Requirement 6.2.1.23: This requirement is part of the Waste Package Closure System which falls under the responsibility of the Mechanical Handling Closure and Loadout Group as defined in the BOD (Reference 2.2.24, Section 29.2.1.3). Requirement 6.2.1.23 is expected to be satisfied upon Mechanical Handling's review and the completion of the final design.

Requirement 6.2.1.24: Section 11.2.3.2.2 of the BOD (Reference 2.2.24) and Section A.7.4 of the NSDB-LA (Reference 2.2.2) require that mean frequency of a waste package breach outside of a facility nuclear confinement Heating, Ventilation, and Air-Conditioning (HVAC) area shall be less than 1E-04 over the preclosure period.

Satisfaction of Requirement 6.2.1.24: Satisfaction of all the DOE waste package design requirements based on credible preclosure event sequences as defined in the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25) are addressed in Section 6.2.3. The PCSA group is responsible for determining the DOE waste package mean frequency of failure for all credible event sequences. Requirement 6.2.1.24 is expected to be satisfied upon PCSA's review and the completion of the final design.

Requirement 6.2.1.25: Section 11.2.4.3 of the BOD (Reference 2.2.24) requires the Characteristics and interfaces of the commercial waste packages shall be maintained in the following IEDs:

- *IED Waste Package Configuration*, 800-IED-WIS0-02101-000 (Reference 2.2.36)
- *IED Waste Package Characteristics - 1999 Design Basis Waste Stream [Sheet 1 of 1]*, 800-IED-WIS0-01401-000 (Reference 2.2.62)
- *IED Waste Package Decay Heat Generation-Basis Reference Case*, 800-IED-WIS0-00701-000 (Reference 2.2.49)
- *IED Waste Package Decay Heat Generation Design Basis and Thermal Information*, 800-IED-WIS0-00801-000 (Reference 2.2.50)
- *IED Seismic and Consequence Data*, 800-IED-MGR0-00701-000 (Reference 2.2.48)
- *IED Waste Package Radiation Characteristics [Sheet 1 of 1]*, 800-IED-WIS0-01301-000 (Reference 2.2.51)
- *IED Waste Package Weld Characteristics [Sheet 1 of 1]*, 800-IED-WIS0-01001-000 (Reference 2.2.63)
- *IED Emplacement Drift Configuration and Environment,* 800-IED-MGR0-00501-000 (Reference 2.2.64)
- *IED Emplacement Drift Invert,* 800-IED-MGR0-00601-000 (Reference 2.2.65)
- *IED Interlocking Drip Shield,* 800-IED-SSE0-00101-000 (Reference 2.2.66).

The interface for the emplaced waste packages shall be controlled through the Emplacement Drift Configuration and Environment IED. Also, the interface for the waste package component masses and weld volumes shall be controlled through the Waste Package Configuration IED**.**

The interface for the waste packages in the LA-design inventory shall have the quantities, dimensions, materials, and characteristics controlled through the Waste Package Configuration IED(s). Materials that have not been previously analyzed and included in the Waste Package Configuration IEDs shall not be placed in the TAD waste package.

Interfaces for the design basis bounding dose rate calculations for waste packages and representative neutron flux shall be controlled through the Waste Package Radiation Characteristics IED. Interfaces for the design waste package decay heat shall be controlled through the Waste Package Decay Heat Generation IEDs.

Satisfaction of Requirement 6.2.1.25: Though not explicitly called for by the requirement, characteristics and interfaces of the DOE waste packages are also maintained on the listed IEDs. All characteristics and interfaces of the waste packages are maintained in all the above mentioned IEDs (References 2.2.36, 2.2.62, 2.2.49, 2.2.50, 2.2.48, 2.2.51, 2.2.63, 2.2.64, 2.2.65, 2.2.66). The Emplacement Drift Configuration and Environment IED (Reference 2.2.64) contains the subsurface temperature and humidity data as provided by the Lead Laboratory. The Waste Package Configuration IED (Reference 2.2.36) contains the waste package component masses, quantities, dimensions, materials and weld volumes as provided by BSC Engineering. The Waste Package Radiation Characteristics IED (Reference 2.2.51) contains the design basis bounding dose rate calculations for waste packages and representative neutron flux data as provided by the Lead Laboratory. The Waste Package Decay Heat Generation IEDs (References 2.2.49 and 2.2.50) contain the design waste package decay heat data as provided by the Lead Laboratory. Therefore, Requirement 6.2.1.25 is satisfied.

Requirement 6.2.1.26: Section 11.2.4.4 of the BOD (Reference 2.2.24) requires that the waste package barrier radial gap between the inner vessel and outer corrosion barrier shall be at least 1 *mm* and a maximum of 5 *mm* for the as fabricated package. The waste package barrier longitudinal gap shall be at least 30 *mm* (between stainless steel lid and Alloy 22 lid).

Satisfaction of Requirement 6.2.1.26: The DOE waste package configuration drawings (References 2.2.16, 2.2.17, 2.2.18, 2.2.19, 2.2.20, 2.2.21) show a nominal radial gap of 4.7 *mm* (0.185 *in*) and a nominal axial gap (between the bottom of the outer lid and the top of the inner lid lifting feature) of 44.5 *mm* (1.752 *in*). These gaps minimize internal pressurization and tangential stress of the WP OCB due to thermal expansion. Therefore, Requirement 6.2.1.26 is satisfied.

Requirement 6.2.1.27: Section 11.2.4.5 of the BOD (Reference 2.2.24) requires that the waste package shall be designed to accommodate internal pressurization of the waste package including effects of high temperature and fuel rod gas release.

Satisfaction of Requirement 6.2.1.27: If the waste packages all have the same initial fill pressure at room temperature, and no leakages or changes in internal volume occur, the ideal gas law (pV = nRT) shows that the waste packages will have the same pressurization at elevated temperatures as well. Therefore, internal pressurization results calculated for the 21-PWR AP are valid for the DOE waste packages as well. The maximum calculated 21-PWR WP internal pressure (assuming 10% fuel rod rupture) is 0.672 *MPa* (97.5 *psi*) at an elevated temperature of 600*°C* (1112*°F*) (Reference 2.2.58, Table 1). This value is less than the maximum allowable internal pressure of 0.84 *MPa* (121.8 *psi*) at 600°*C* (1112°*F*) for the 5-DHLW/DOE SNF WP (Reference 2.2.57, Table 6-1). Therefore, Requirement 6.2.1.27 is expected to be satisfied.

Requirement 6.2.1.28: Section 11.2.4.6 of the BOD (Reference 2.2.24) requires that all waste package welding materials shall be verified immediately prior to usage to prevent incorrect material usage.

a) The Alloy 22 outer lid will be sealed utilizing the gas tungsten arc weld (GTAW) process, limited to <45 *kJ/in*. The weld mass shall be less than 0.104 *lb/in* (18.5 *g/cm*) of weld.

b) The Alloy 22 outer lid weld will be nondestructively examined using VT, ET, and UT. Flaws greater than 1/16" shall be repaired.

c) The Alloy 22 outer lid weld will be stress mitigated using low-plasticity burnishing to a compressive depth of at least 3 *mm*.

d) Process control to ensure there has been adequate stress mitigation on the welds will be performed. Following the stress mitigation, the final closure weld will be reexamined using VT, ET, and UT.

<u>Satisfaction of Requirement 6.2.1.28</u>: The waste package closure welding and inspection requirements are part of the Waste Package Closure System which falls under the responsibility of the Mechanical Handling Closure and Loadout Group. Requirement 6.2.1.28 is expected to be satisfied upon Mechanical Handling's review and the completion of the final design.

Requirement 6.2.1.29: Section 11.2.4.7 of the BOD (Reference 2.2.24) requires that after fabrication and before inserting the inner vessel, the waste package outer corrosion barrier shall be solution annealed and quenched.

a) The minimum time for solution annealing will be 20 minutes at 2,050 °*F* (1,121 °*C*) +50 °*F* (28 °*C*) / -0 °*F* (0 °*C*).
b) The waste package shall be quenched at a rate greater than 275 °*F* (153 °*C*) per minute to below 700 °*F* (371 °*C*).
c) After solution annealing and quenching, the waste package surface temperature will be kept below 300 °*C* to eliminate postclosure issues (i.e., phase stability), except for short-term exposure (closure-weld, etc.).

<u>Satisfaction of Requirement 6.2.1.29</u>: Requirements "a" and "b" are controlled via the *Waste Package Fabrication Specification* (Reference 2.2.23, Section 5.6). The specified quench initiation temperature (Reference 2.2.23, Section 5.6) will be adjusted to match the annealing temperature during the final design process. The thermal calculation (Reference 2.2.46, Section 7.12.3) showed that the waste package surface temperature stayed well below 300°*C* (572°*F*) for the first 500 years and below 200°*C* (392°*F*) for the next 9,500 years in all cases analyzed, which satisfies requirement "c". (Note- postclosure performance is the responsibility of the Lead Laboratory). Requirement 6.2.1.29 is expected to be satisfied upon the Mechanical Handling review and the completion of the final design.

Requirement 6.2.1.30: Section 11.2.4.8 of the BOD (Reference 2.2.24) requires that the waste package shall be certified as suitable for emplacement by process control and/or inspection to ensure surface marring is acceptable per derived constraint. The surface marring constraints are: The damage to the waste package corrosion barrier that displaces material (i.e. scratches) shall be limited to 1.6 *mm* (1/16 *in*) in depth. Modifications to the waste package corrosion barrier that deform the surface, but do not remove material (i.e. dents), shall not leave residual tensile stresses greater than 257 *MPa*.

Satisfaction of Requirement 6.2.1.30: Mechanical Handling is responsible for this requirement as defined in the BOD (Reference 2.2.24, Section 13.2.3.1.37). Requirement 6.2.1.30 is expected to be satisfied upon Mechanical Handling's review and the completion of the final design.

Requirement 6.2.1.31: Section 11.2.4.9 of the BOD (Reference 2.2.24) requires that the waste package surface finish shall be specified to be at least 125 *microinches* roughness as defined in ASME B46.1-2002 (Reference 2.2.7).

Satisfaction of Requirement 6.2.1.31: The *Waste Package Fabrication Specification* (Reference 2.2.23, Section 3.5) specifies that the outer surfaces of the waste package shall have a surface roughness of 125 *µinch* (3.2 *µm*) or better. There are no exceptions for scratches or any similar surface defects. Therefore, Requirement 6.2.1.31 is satisfied.

Requirement 6.2.1.32: Section 11.2.4.10 of the BOD (Reference 2.2.24) requires that the median probability of defects for the manufacture, handling, and emplacement of the waste packages shall be less than 4.14×10^{-5} per waste package. For TSPA purposes this distribution is the probability that a waste package will be early-failed.

Satisfaction of Requirement 6.2.1.32: The pertinent fabrication requirements are controlled via the *Waste Package Fabrication Specification* (Reference 2.2.23, Sections 3 and 5). The Science document (Reference 2.2.33, Section 6.2.15) concludes that the implementation of those fabrication requirements achieve this reliability. Performance of the waste package in the post-closure will be demonstrated by the Lead Laboratory. Requirement 6.2.1.32 is expected to be satisfied upon Lead Lab's review and the completion of the final design.

Requirement 6.2.1.33: Section 11.2.4.11 of the BOD (Reference 2.2.24) requires that the waste package shall be handled in a controlled manner to minimize defects; surface contamination; exposure to adverse substances; impacts; and tension loads during fabrication, handling, transport, storage, emplacement, installation, operation, and closure activities.

Satisfaction of Requirement 6.2.1.33: All fabrication, handling and transport related requirements are controlled by the fabrication specification (Reference 2.2.23). Mechanical Handling is responsible for compliance to the remainder of this requirement which is defined in the BOD (Reference 2.2.24, Section 13.2.3.1.35). Requirement 6.2.1.33 is expected to be satisfied upon Mechanical Handling's review and the completion of the final design.

Requirement 6.2.1.34: Section 11.2.4.12 of the BOD (Reference 2.2.24) requires that the waste package closure systems operations shall be controlled. The waste package sealing process shall be remotely controlled in a manner that ensures safe waste package closure.

Satisfaction of Requirement 6.2.1.34: The waste package closure welding and inspection requirements are part of the Waste Package Closure System which falls under the responsibility of the Mechanical Handling Closure and Loadout Group. Requirement 6.2.1.34 is expected to be satisfied upon Mechanical Handling's review and the completion of the final design.

Requirement 6.2.1.35: Section 11.2.4.13 of the BOD (Reference 2.2.24) requires that the waste package lids and inerting caps shall be welded. The welding process shall be conducted in a manner to meet weld requirements.

Satisfaction of Requirement 6.2.1.35: The waste package closure welding and inspection requirements are part of the Waste Package Closure System which falls under the responsibility of the Mechanical Handling Closure and Loadout Group. Requirement 6.2.1.35 is expected to be satisfied upon Mechanical Handling's review and the completion of the final design.

Requirement 6.2.1.36: Section 11.2.4.14 of the BOD (Reference 2.2.24) requires that the waste package containing the TAD canister with 21-PWR fuel assemblies shall represent the worst-case dose rate (80 *GWd/MTU* burnup, 5% U-235 enrichment and 5 years decay).

Satisfaction of Requirement 6.2.1.36: This is a requirement that will be addressed by operational requirements for the loading of the DOE waste packages to ensure dose rates fall below these limits. Hence, Requirement 6.2.1.36 is expected to be satisfied.

Requirement 6.2.1.37: Section 8.2.1.23 of the BOD (Reference 2.2.24) requires that the tensile stresses imposed on the Alloy 22 components of both the waste package and the emplacement pallet in the nominal emplacement configuration shall be less than 257 *MPa*.

Satisfaction of Requirement 6.2.1.37: Table 7-2 of Reference 2.2.77 shows that the maximum tensile stresses for 21*℃* (70*℉*) and 250*℃* (482*℉*) are located in the OCB of the WP with values of 56.8 *MPa* (8,238 *psi*), which are significantly less than the 257 *MPa* (37,275 *psi*) limit. Results from Reference 2.2.77 were computed for the TAD waste package, which is the heaviest of all WPs, and are considered bounding for the remaining waste packages. Therefore, Requirement 6.2.1.37 is satisfied.

6.2.2 Waste Package Fabrication Criteria

Requirement 6.2.2.1: Sections 5.2 and 5.2.1 of the PDC (Reference 2.2.39) state that waste packages shall be fabricated in accordance with the following:

> ANSI/AWS A2.4-98 (Reference 2.2.4) provides the standard symbols for the welding, brazing, and nondestructive examination of nuclear components.
>
> ANSI/AWS A5.32/A5.32M-97 (Reference 2.2.3) provides the specifications of welding shielding gases used in the welding processes of nuclear components.
>
> ANSI N14.6-1993 (Reference 2.2.12) provides definitions for special lifting devices for shipping containers weighing 10,000 pounds or more.

ASME 2001 (Reference 2.2.6), Section II, provides the properties for the materials used in the design and fabrication of Class NF nuclear components.

ASME 2001 (Reference 2.2.6), Section III, Subsection NCA, provides the general requirements for the design and fabrication of nuclear power plant components.

ASME 2001 (Reference 2.2.6), Section III, Division 1, Subsection NB, NC, and NF.

ASME 2001 (Reference 2.2.6), Section V, provides the requirements for the nondestructive examination of nuclear components.

ASME 2001 (Reference 2.2.6), Section IX, provides welding and brazing qualifications for the welding of nuclear components.

ASME B46.1-2002 (Reference 2.2.7) provides surface texture (surface roughness, waviness, and lay) requirements for fabrication of nuclear components.

ASME Y14.36M-1996 (Reference 2.2.10) provides the requirements for surface texture symbols used in the designing of nuclear components.

ASME Y14.38-1999 (Reference 2.2.11) provides the requirements for abbreviations and acronyms used in the designing of nuclear components.

ASME Y14.5M-1994 (Reference 2.2.9) provides the requirements for dimensioning and tolerancing of drawing.

ASME Section III Code Cases that shall not be used are those listed in Regulatory Guide 1.193 (Reference 2.2.76).

Cleaning, packaging, shipping, receiving, storage, and handling of waste packages shall be in accordance with ASME NQA-1-2000 (Reference 2.2.8), Subparts 2.1 and 2.2. There are now additional quality assurance requirements applicable to the fabrication and construction activities identified in Table A-1 of the *Quality Management Directive* (Reference 2.1.2).

Satisfaction of Requirement 6.2.2.1: The specific applicable requirements from codes and standards are implemented by specification. Sections 2 through 9 of Reference 2.2.23 impose the specific, applicable sections from codes and standards for the Waste Package Design, Materials, Fabrication, and Examination and Testing. ASME Y14.38-1999 (Abbreviations and Acronyms) is not listed in the current version of the waste package fabrication specification (Reference 2.2.23) but updates are expected as the specification is a living document and the standards refer to common definitions. All structural analyses (e.g. Reference 2.2.35) follow the most appropriate method of classifying local primary membrane stress as defined by (Reference 2.2.6, Section III, Division 1, Appendix XIII, XIII-1123(j)), and code cases listed in Regulatory Guide 1.193 (Reference 2.2.76) are not used. The requirement for ANSI N14.6-1993 (Reference 2.2.12) was intended for the trunnion collar, a component now deleted from the waste package configuration. Updates to the PDC (Reference 2.2.39) will include removal of this requirement. Therefore, Requirement 6.2.2.1 is expected to be satisfied as final design is completed.

6.2.3 Requirements as defined by the Hypothetical Event Sequences

The waste package shall not breach during normal operation or during credible preclosure event sequences as defined in the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25). The requirements in this study are used as a supplement since the latest revision of the BOD (Reference 2.2.24) does not sufficiently describe the credible event sequences for the DOE waste package (Assumption 3.1.2). Event sequences defined by the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25) which are satisfied by the addition of design features to preclude the event or considered to be not credible will not be addressed by this design report (Assumption 3.1.3).

Requirement 6.2.3.1: Section 4.1.2 of Reference 2.2.25 requires that the waste package shall not breach in an event where the waste package while inside the waste package transfer trolley is subjected to the dynamics imposed by vibratory ground motion.

Satisfaction of Requirement 6.2.3.1: Mechanical Handling is responsible for compliance to this requirement as defined in the BOD (Reference 2.2.24, Section 13.2.3.1.21). Requirement 6.2.3.1 is expected to be satisfied upon Mechanical Handling's review and the completion of the final design.

Requirement 6.2.3.2: Section 4.1.6 of Reference 2.2.25 requires that the waste package shall not breach in an event where there is protracted loss of forced ventilation in the surface facility while the WP transfer trolley is laden with a waste package. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is within durations allowed by Licensing specifications.

Satisfaction of Requirement 6.2.3.2: A thermal analysis (Reference 2.2.81) of the 5-DHLW/DOE SNF short waste package in a transfer trolley in a surface facility during a 30-day loss of ventilation scenario showed that the waste package surface temperature reached a maximum of 259.9°*C* (499.8°*F*) (Reference 2.2.81, Tables 97 and 98). During a loss of ventilation scenario, for a waste package with a 9.47 *kW* heat load, the SNF cladding and DHLW glass temperatures reach 406.3°*C* (763.3°*F*) and 340.1°*C* (644.1°*F*) respectively for a sealed waste package inside the transfer trolley (Reference 2.2.81, Tables 103 and 104). These temperatures for the waste package surface, SNF cladding, and DHLW glass fall below their respective 300°C (572°*F*) , 570°*C* (1058°*F*), and 400°*C* (752°*F*) temperature limits (Reference 2.2.24, Sections 11.2.2.24, 11.2.2.18, and 11.2.2.23) with significant margin. This result bounds all expected 5-DHLW/DOE SNF waste packages, which have a maximum thermal power 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6). Therefore, Requirement 6.2.3.2 is satisfied.

Requirement 6.2.3.3: Section 4.1.7 of Reference 2.2.25 requires that the waste package shall not breach in the event of a fire in any of the rooms in which the waste package transfer trolley may be present when laden with a sealed waste package. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is prevented.

Satisfaction of Requirement 6.2.3.3: Credible fires are expected to be only a few minutes with only a small part of the waste package exposed to flame. Results for a 5-DHLW/DOE SNF waste package exposed to a fully engulfing, 800°*C* (1472°*F*) fire show that SNF temperatures increase about 10°*C* (18°*F*) and DHLW glass temperature increase about 30°*C* (54°*F*) at most in 30 minutes (Reference 2.2.38), for a rate of temperature increase of up to about 1°*C*/*minute* (1.8°*F*/*minute*). During normal operating conditions, for a waste package with a 6.97 *kW* heat load, the SNF and DHLW glass temperatures reach 345.9°*C* (654.7°*F*) and 265.8°*C* (510.4°*F*) respectively for a sealed waste package inside the transfer trolley in a surface facility (Reference 2.2.81, Tables 55 and 56). A credible fire is unlikely to raise the SNF cladding or DHLW glass temperatures above their respective 570°*C* (1058°*F*) and 400°*C* (752°*F*) limits (Reference 2.2.24, Sections 11.2.2.18 and 11.2.2.23). The maximum thermal power for 5-DHLW/DOE SNF waste packages is 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6), so the actual SNF and DHLW glass temperatures will be significantly lower and all temperature limits will be achieved. Therefore, Requirement 6.2.3.3 is expected to be satisfied.

Requirement 6.2.3.4: Section 4.3.1 of Reference 2.2.25 requires that the waste package shall not breach in an event where one or more of the handling hooks in the TEV breaks resulting in an approximately horizontal drop of the waste package and emplacement pallet.

Satisfaction of Requirement 6.2.3.4: Analysis of this event sequence (Reference 2.2.53, Section 6.3) showed that the maximum element wall-averaged (EWA) stress intensity (SI) ratio stayed below the project tiered first condition acceptance criterion of 0.7 (Reference 2.2.40, Section 7.1.4) for all runs analyzed. Therefore, Requirement 6.2.3.4 is satisfied.

Requirement 6.2.3.5: Section 4.3.5 of Reference 2.2.25 requires that the waste package shall not breach in an event where the waste package while inside the TEV is subjected to the dynamics imposed by vibratory ground motion.

Satisfaction of Requirement 6.2.3.5: The analysis (Reference 2.2.35, Section 6.3) gives the ratios of EWA SI to true tensile strength for various impact velocities and, through interpolation, predicts a maximum allowable impact velocity of 9.67 *m/s* (31.7 *ft/s*) before the EWA SI ratio reaches the project tiered second condition acceptance criterion of 0.77 (Reference 2.2.40, Section 7.1.4). The PCSA group is responsible for determining the probability of a credible seismic event resulting in the waste package moving at velocities reaching 9.67 *m/s* (31.7 *ft/s*). Requirement 6.2.3.5 is expected to be satisfied upon PCSA's review and the completion of the final design.

Requirement 6.2.3.6: Section 4.3.6 of Reference 2.2.25 requires that the waste package shall not breach in an event where an over-driven TEV collides with a line of emplaced waste packages.

Satisfaction of Requirement 6.2.3.6: Analysis of this event sequence (Reference 2.2.54, Table 7-2) showed that the maximum EWA SI ratio stayed below the project tiered first condition acceptance criterion of 0.7 (Reference 2.2.40, Section 7.1.4) for both cases analyzed, meaning that the effects of the maximum stresses in the OCB due to a TEV collision do not cause failure. Therefore, Requirement 6.2.3.6 is satisfied.

Requirement 6.2.3.7: Section 4.3.8 of Reference 2.2.25 requires that the waste package shall not breach in an event where the waste package is caught on the TEV structure and dragged along the invert surface, resulting in the waste package falling off the emplacement pallet and against TEV structures.

Satisfaction of Requirement 6.2.3.7: The TEV collision with an emplaced WP analysis (Reference 2.2.54, Table 7-2) showed that the maximum EWA SI ratio stayed below the project tiered first condition acceptance criterion of 0.7 (Reference 2.2.40, Section 7.1.4) for both cases analyzed, meaning that the effects of the maximum stresses in the OCB due to TEV collision does not cause failure. Since the dragging of the emplaced waste package is bounded by the TEV collision (Assumption 3.2.1), we can conservatively assume that the stress intensity ratio for the waste package would be less while being dragged. Therefore, Requirement 6.2.3.7 is satisfied.

Requirement 6.2.3.8: Section 4.3.11 of Reference 2.2.25 requires that the waste package shall not breach in an event where there is protracted loss of ventilation in the surface facility while the TEV is laden with the waste package. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is within durations allowed by licensing specifications.

Satisfaction of Requirement 6.2.3.8: The steady-state analysis (Reference 2.2.34, Table 34) showed that the 5-DHLW/DOE SNF Short waste package surface temperature inside the TEV remained around 178°*C* (352°*F*) without ventilation, using a heat load of 9.47 *kW* and 50°*C* (122°*F*) ambient temperature. During a loss of ventilation scenario, the SNF and DHLW glass temperatures reach 404°*C* (759°*F*) and 339°*C* (642°*F*) respectively for a maximum heat sealed waste package inside the TEV (Reference 2.2.34, Table 34). These temperatures for the waste package surface, SNF cladding, and DHLW glass fall below their respective 300°C (572°*F*) , 570°*C* (1058°*F*), and 400°*C* (752°*F*) temperature limits (Reference 2.2.24, Sections 11.2.2.24, 11.2.2.18, and 11.2.2.23) with significant margin. This result bounds all expected 5-DHLW/DOE SNF waste packages, which have a maximum thermal power 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6). Therefore, Requirement 6.2.3.8 is expected to be satisfied.

Requirement 6.2.3.9: Section 4.3.12 of Reference 2.2.25 requires that the waste package shall not breach in an event of a fire in any of the rooms in which the TEV may be present when laden with a waste package. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is prevented.

Satisfaction of Requirement 6.2.3.9: Credible fires are expected to be only a few minutes with only a small part of the waste package exposed to flame. Results for a 5-DHLW/DOE SNF waste package exposed to a fully engulfing, 800°*C* (1472°*F*) fire show that SNF temperatures increase about 10°*C* (18°*F*) and DHLW glass temperature increase about 30°*C* (54°*F*) at most in 30 minutes (Reference 2.2.38), for a rate of temperature increase of up to about 1°*C*/*minute* (1.8°*F*/*minute*). The steady-state analysis (Reference 2.2.34, Table 34) showed that the 5-DHLW/DOE SNF Short waste package temperature inside the TEV remained around 178°*C* (352°*F*) without ventilation, using a heat load of 9.47 *kW* and 50°*C* (122°*F*) ambient temperature. Without accounting for ventilation, the SNF cladding and DHLW glass temperatures remain around 404°*C* (759°*F*) and 339°*C* (642°*F*) respectively for a maximum heat sealed waste package inside the TEV (Reference 2.2.34, Table 34). A credible fire is unlikely to raise the SNF cladding or DHLW glass temperatures above their respective 570°*C* (1058°*F*) and 400°*C* (752°*F*) limits (Reference 2.2.24, Sections 11.2.2.18 and 11.2.2.23). The maximum thermal power for 5-DHLW/DOE SNF waste packages is 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6), so the actual SNF and DHLW glass temperatures will be significantly lower and all temperature limits will be achieved. Therefore, Requirement 6.2.3.9 is expected to be satisfied.

Requirement 6.2.3.10: Section 4.3.13 of Reference 2.2.25 requires that the waste package shall not breach in an event where there is protracted stoppage of the TEV during transit from the surface facilities to the subsurface entry portal while the TEV is laden with the waste package. Analysis of this event sequence will include the rate of delivery of all direct solar energy per unit of horizontal TEV surface. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is prevented. Licensing specifications for the durations of the off-normal cladding temperatures must be determined.

Satisfaction of Requirement 6.2.3.10: The steady-state analysis (Reference 2.2.34, Table 39) showed that the 5-DHLW/DOE SNF Short waste package temperature inside the TEV remained around 176°*C* (349°*F*) without ventilation, using a heat load of 9.47 *kW* and 46.7°*C* (116°*F*) maximum ambient outdoor temperature (with solar insolation). The SNF cladding and DHLW glass temperatures reach 403°*C* (757°*F*) and 338°*C* (640°*F*) respectively for a maximum heat sealed waste package inside the TEV under protracted outdoor stoppage (Reference 2.2.34, Table 39). These temperatures for the waste package surface, SNF cladding, and DHLW glass fall below their respective 300°C (572°*F*) , 570°*C* (1058°*F*), and 400°*C* (752°*F*) temperature limits (Reference 2.2.24, Sections 11.2.2.24, 11.2.2.18, and 11.2.2.23) with significant margin. This result bounds all expected 5-DHLW/DOE SNF waste packages, which have a maximum thermal power 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6). Therefore, Requirement 6.2.3.10 is expected to be satisfied.

Requirement 6.2.3.11: Section 4.3.14 of Reference 2.2.25 requires that the waste package shall not breach in an event of a fire involving the TEV when laden with a waste package that occurs outside the surface facilities and before passing into the subsurface entrance portal. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is prevented.

Satisfaction of Requirement 6.2.3.11: Credible fires are expected to be only a few minutes with only a small part of the waste package exposed to flame. Results for a 5-DHLW/DOE SNF waste package exposed to a fully engulfing, 800°*C* (1472°*F*) fire show that SNF temperatures increase about 10°*C* (18°*F*) and DHLW glass temperature increase about 30°*C* (54°*F*) at most in 30 minutes (Reference 2.2.38), for a rate of temperature increase of up to about 1°*C*/*minute* (1.8°*F*/*minute*). The steady-state analysis (Reference 2.2.34, Table 39) showed that the 5-DHLW/DOE SNF Short waste package temperature inside the TEV remained around 176°*C* (349°*F*) without ventilation, using a heat load of 9.47 *kW* and 46.7°*C* (116°*F*) ambient temperature (with solar insolation). Without accounting for ventilation, the SNF cladding and

DHLW glass temperatures remain around 403°*C* (757°*F*) and 338°*C* (640°*F*) respectively for a maximum heat sealed waste package inside the TEV (Reference 2.2.34, Table 39). A credible fire is unlikely to raise the SNF cladding or DHLW glass temperatures above their respective 570°*C* (1058°*F*) and 400°*C* (752°*F*) limits (Reference 2.2.24, Sections 11.2.2.18 and 11.2.2.23). The maximum thermal power for 5-DHLW/DOE SNF waste packages is 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6), so the actual SNF and DHLW glass temperatures will be significantly lower and all temperature limits will be achieved. Therefore, Requirement 6.2.3.11 is expected to be satisfied.

Requirement 6.2.3.12: Section 4.3.15 of Reference 2.2.25 requires that the waste package shall not breach in an event where there is a protracted stoppage of the TEV traversing the subsurface mains while the TEV is laden with the waste package. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is prevented. Licensing specifications for the durations of the off-normal cladding temperatures must be determined.

Satisfaction of Requirement 6.2.3.12: The steady-state analysis of this event sequence (Reference 2.2.34, Table 42) showed that the 5-DHLW/DOE SNF Short waste package temperature inside the TEV remained around 150°*C* (302°*F*) without ventilation, using a heat load of 9.47 *kW* and 22°*C* (72°*F*) cold drift wall temperature. The SNF cladding and DHLW glass temperatures reach 391°*C* (736°*F*) and 324°*C* (615°*F*) respectively for a maximum heat sealed waste package inside the TEV under protracted stoppage in the subsurface (Reference 2.2.34, Table 42). These temperatures for the waste package surface, SNF cladding, and DHLW glass fall below their respective 300°C (572°*F*) , 570°*C* (1058°*F*), and 400°*C* (752°*F*) temperature limits (Reference 2.2.24, Sections 11.2.2.24, 11.2.2.18, and 11.2.2.23) with significant margin. This result bounds all expected 5-DHLW/DOE SNF waste packages, which have a maximum thermal power 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6). Therefore, Requirement 6.2.3.12 is expected to be satisfied.

Requirement 6.2.3.13: Section 4.3.16 of Reference 2.2.25 requires that the waste package shall not breach in an event of a fire involving the TEV laden with the waste package while it is traversing the subsurface mains. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is prevented.

Satisfaction of Requirement 6.2.3.13: Credible fires are expected to be only a few minutes with only a small part of the waste package exposed to flame. Results for a 5-DHLW/DOE SNF waste package exposed to a fully engulfing, 800°*C* (1472°*F*) fire show that SNF temperatures increase about 10°*C* (18°*F*) and DHLW glass temperature increase about 30°*C* (54°*F*) at most in 30 minutes (Reference 2.2.38), for a rate of temperature increase of up to about 1°*C*/*minute* (1.8°*F*/*minute*). The steady-state analysis (Reference 2.2.34, Table 42) showed that the 5-DHLW/DOE SNF Short waste package temperature inside the TEV remained around 150°*C* (302°*F*) without ventilation, using a heat load of 9.47 *kW* and 22°*C* (72°*F*) cold drift wall temperature. The SNF cladding and DHLW glass temperatures remain around 391°*C* (736°*F*) and 324°*C* (615°*F*) respectively for a maximum heat sealed waste package inside the TEV in the subsurface (Reference 2.2.34, Table 42). A credible fire is unlikely to raise the SNF cladding or

DHLW glass temperatures above their respective 570°*C* (1058°*F*) and 400°*C* (752°*F*) limits (Reference 2.2.24, Sections 11.2.2.18 and 11.2.2.23). The maximum thermal power for 5-DHLW/DOE SNF waste packages is 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6), so the actual SNF and DHLW glass temperatures will be significantly lower and all temperature limits will be achieved. Therefore, Requirement 6.2.3.13 is expected to be satisfied.

Requirement 6.2.3.14: Section 4.3.17 of Reference 2.2.25 requires that the waste package shall not breach in an event where there is a protracted stoppage of the TEV traversing the emplacement drifts while the TEV is laden with the waste package. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is prevented. Licensing specifications for the duration of the off-normal cladding temperatures must be determined.

Satisfaction of Requirement 6.2.3.14: The steady-state analysis (Reference 2.2.34, Table 42) showed that the 5-DHLW/DOE SNF Short waste package temperature inside the TEV remained around 150°*C* (302°*F*) without ventilation, using a heat load of 9.47 *kW* and 22°*C* (72°*F*) cold drift wall temperature. The SNF cladding and DHLW glass temperatures reach 391°*C* (736°*F*) and 324°*C* (615°*F*) respectively for a maximum heat sealed waste package inside the TEV under protracted stoppage in the subsurface (Reference 2.2.34, Table 42). These temperatures for the waste package surface, SNF cladding, and DHLW glass fall below their respective 300℃ (572°*F*) , 570°*C* (1058°*F*), and 400°*C* (752°*F*) temperature limits (Reference 2.2.24, Sections 11.2.2.24, 11.2.2.18, and 11.2.2.23) with significant margin. This result bounds all expected 5-DHLW/DOE SNF waste packages, which have a maximum thermal power 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6). Therefore, Requirement 6.2.3.14 is expected to be satisfied.

Requirement 6.2.3.15: Section 4.3.18 of Reference 2.2.25 requires that the waste package shall not breach in an event of a fire involving the TEV when laden with a waste package that occurs while it is traversing the emplacement drifts. It must be shown that the ability of the waste package to confine the waste form is maintained and that the loss of margin to the off-normal cladding temperature limit is prevented.

Satisfaction of Requirement 6.2.3.15: Credible fires are expected to be only a few minutes with only a small part of the waste package exposed to flame. Results for a 5-DHLW/DOE SNF waste package exposed to a fully engulfing, 800°*C* (1472°*F*) fire show that SNF temperatures increase about 10°*C* (18°*F*) and DHLW glass temperature increase about 30°*C* (54°*F*) at most in 30 minutes (Reference 2.2.38), for a rate of temperature increase of up to about 1°*C*/*minute* (1.8°*F*/*minute*). The steady-state analysis (Reference 2.2.34, Table 42) showed that the 5-DHLW/DOE SNF Short waste package temperature inside the TEV remained around 150°*C* (302°*F*) without ventilation, using a heat load of 9.47 *kW* and 22°*C* (72°*F*) cold drift wall temperature. The SNF cladding and DHLW glass temperatures remain around 391°*C* (736°*F*) and 324°*C* (615°*F*) respectively for a maximum heat sealed waste package inside the TEV in the subsurface (Reference 2.2.34, Table 42). A credible fire is unlikely to raise the SNF cladding or DHLW glass temperatures above their respective 570°*C* (1058°*F*) and 400°*C* (752°*F*) limits (Reference 2.2.24, Sections 11.2.2.18 and 11.2.2.23). The maximum thermal power for 5-

DHLW/DOE SNF waste packages is 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6), so the actual SNF and DHLW glass temperatures will be significantly lower and all temperature limits will be achieved. Therefore, Requirement 6.2.3.15 is expected to be satisfied.

Requirement 6.2.3.16: Section 4.4.2 of Reference 2.2.25 requires that the waste package shall not breach in an event where the waste package while horizontal inside the waste package transfer trolley on the waste package transfer carriage is subjected to the dynamics imposed by vibratory ground motion. The waste package is then ejected from the emplacement pallet and falls into the shielded enclosure of either the waste package transfer trolley or the TEV.

Satisfaction of Requirement 6.2.3.16: The analysis (Reference 2.2.35, Section 6.3) gives a maximum allowable impact velocity of 9.67 *m/s* (31.7 *ft/s*) before the EWA SI ratio reaches the project tiered second condition acceptance criterion of 0.77 (Reference 2.2.40, Section 7.1.4). Using Newton's equation of motion (Reference 2.2.69, Equation 15, p. 20) we can determine the drop height needed for the WP to reach this velocity:

$$V^2 = V_o^2 + 2gh$$

where,

V_o = initial velocity
V = final velocity
g = acceleration due to gravity
h = vertical drop height

For this calculation:

V = 9.67 *m/s* (31.7 *ft/sec*) (WP final velocity)
V_o = 0.0 *m/s* (WP initially at rest)
g = 9.81 m/s^2 (32.2 ft/s^2) (acceleration due to gravity)

Solving for h:

$$h = (V^2 - V_o^2) / 2g = 4.766\ m\ (187.6\ in)$$

A drop height of 4.766 *m* (187.6 *in*) is more than twice any possible drop that the WP might experience whether within the transfer trolley or TEV. Therefore, Requirement 6.2.3.16 is satisfied.

Requirement 6.2.3.17: Section 4.4.3 of Reference 2.2.25 requires that the waste package shall not breach in an event where the drip shield emplacement gantry collides with an emplaced waste package.

Satisfaction of Requirement 6.2.3.17: The analysis (Reference 2.2.54, Table 7-2) showed that the EWA SI ratio stayed below the project tiered first condition acceptance criterion of 0.7 (Reference 2.2.40, Section 7.1.4) for both cases analyzed, meaning that the effects of the maximum stresses in the OCB due to a TEV collision do not cause failure. Since the drip shield emplacement gantry collision is bounded by the TEV collision (Assumption 3.2.2), we can conservatively assume that the stress intensity ratio for the waste package would remain below failure criteria levels (Reference 2.2.40, Section 7.1.4). Therefore, Requirement 6.2.3.17 is satisfied.

Requirement 6.2.3.18: Section 4.4.4 of Reference 2.2.25 requires that the waste package shall not breach in an event where the drip shield gantry drops a drip shield onto an emplaced waste package.

Satisfaction of Requirement 6.2.3.18: An event where a drip shield (weighing 5*MT* (5.5 ton) per Reference 2.2.56) dropped onto a waste package is a lot less severe than the largest credible rockfall with a weight of 20*MT* (22 ton) (Reference 2.2.26, Section 6.4.5.2.5) onto the waste package, which we can conservatively conclude is a bounding case. The calculation *Nonlithophysal Rock Fall on Waste Packages* (Reference 2.2.41, Table 4, Cases 15 and 16) indicated that the EWA SI ratio of the OCB in both rockfall cases did not exceed the project tiered first condition acceptance criterion of 0.7 (Reference 2.2.40, Section 7.1.4), indicating that the rockfall scenarios did not result in failure of the waste package. Therefore, Requirement 6.2.3.18 is satisfied.

Requirement 6.2.3.19: Section 4.4.5.1 of Reference 2.2.25 requires that the waste package shall not breach in an event of a very large block rock fall in the non-lithophysal portions of the repository.

Satisfaction of Requirement 6.2.3.19: The largest credible rockfall in the non-lithophysal portions of the repository is a 20 *MT* (22 ton) block (Reference 2.2.26, Section 6.4.5.2.5). The calculation (Reference 2.2.41, Table 4, Cases 15 and 16) indicated that EWA SI ratio at any point in the OCB did not exceed the project tiered first condition acceptance criterion of 0.7 (Reference 2.2.40, Section 7.1.4), indicating that none of the rockfall scenarios resulted in failure of the waste package. Therefore, Requirement 6.2.3.19 is satisfied.

Requirement 6.2.3.20: Section 4.4.5.2 of Reference 2.2.25 requires that the waste package shall not breach in an event of general drift collapse in the lithophysal portions of the repository caused by vibratory ground motion.

Satisfaction of Requirement 6.2.3.20: The analysis (Reference 2.2.44, Table 7-1) showed that the EWA SI ratio stayed below the project tiered first condition acceptance criterion of 0.7 (Reference 2.2.40, Section 7.1.4), meaning that the effects of the maximum stresses in the OCB due to drift collapse do not cause failure. Therefore, Requirement 6.2.3.20 is satisfied.

Requirement 6.2.3.21: Section 4.4.5.3 of Reference 2.2.25 requires that the waste package shall not breach in an event where the waste package is under a load of fallen rock and then subject to vibratory ground motion, including a scenario where "posts" of invert beams rotating up into the drift strike the waste package due to the failure of the structural steel in the invert.

Satisfaction of Requirement 6.2.3.21: In an event where vibratory ground motion during a load on the WP due to drift collapse, the rubble surrounding the WP is expected to act as a dampener during "fluidization" of the rock due to shaking. The situation of the structural steel in the invert rotating up into the drift and striking the waste package is similar to the oblique impact scenario evaluated in Reference 2.2.35, in which a 5-DHLW/DOE SNF short co-disposal waste package strikes the lifting bar (angled at 21º from the vertical) inside the TEV at a pitch of 1° during an accident condition. The analysis (Reference 2.2.35, Section 6.3) gives a maximum allowable impact velocity of 9.67 *m/s* (31.7 *ft/s*) before the EWA SI ratio reaches the project tiered second condition acceptance criterion of 0.77. The PCSA group is responsible for determining the probability of a credible seismic event resulting in the WP moving at velocities reaching 9.67 *m/s* (31.7 *ft/s*) as well as the probability of a seismic event occurring after a drift collapse. Therefore, Requirement 6.2.3.21 is expected to be satisfied.

6.3 MISCELLANEOUS SUPPORTING CALCULATIONS AND ANALYSES

Shielding and dose limitations do not result in design requirements for waste packages. However, waste package design affects shielding and dose calculations as discussed in the following subsections. Note particularly that the recommended waste package inner lid thickness (9 *inches* (0.2286 *m*)) has been taken into consideration as shown in References 2.2.18 and 2.2.21.

6.3.1 Shielding

Shielding analyses evaluate the effects of ionizing radiation on personnel, equipment, and materials. The primary sources for waste package radiation are gamma rays and neutrons emitted from SNF and HLW. Loading, handling, and transporting of waste packages would be carried out remotely to keep personnel exposure as low as reasonably achievable (e.g., having the human operators behind radiation shield walls, using remote manipulators, viewing operations with video cameras). The general shielding requirements are stated in Section 4.10 of the PDC (Reference 2.2.39).

The dose rate calculation details and results in Sections 6.3.2 through 6.3.4 are from *Dose Rate Calculation for the 5-DHLW/DOE SNF Short Waste Package* (Reference 2.2.31).

The shield plug thickness conclusions in Section 6.3.5 are from *Shielding Evaluation of the Plug/Insert Thickness for the 5-DHLW/DOE SNF and 2-MCO/2-DHLW Co-Disposal Waste Packages* (Reference 2.2.47).

6.3.2 Source Specification

The TRIGA-SS (Training, Research, Isotope, General Atomics - stainless steel) FLIP (Fuel Life Improvement Program) fuel design for which DOE (Reference 2.2.82, Table B-3) provides neutron source terms and physical characteristics was used. Based upon the specified loading scheme and the spectrum data, the TRIGA waste form was found to be the limiting waste form from a shielding perspective with respect to the short DOE SNF standardized canister (Reference 2.2.31, Section 5.1.3). The isotopic concentrations (Reference 2.2.71, p. A-176) on a per element basis coupled with the curie to photon emission rate conversion factors (Reference 2.2.71, p. 31) were used to calculate the TRIGA-SS FLIP fuel gamma spectrum, shown in Table 3. The neutron sources, on a per fuel element basis, are provided in Table 4. The neutron intensity is comprised of two components: (α,n) and spontaneous fission terms. These values reflect the highest burnup and isotopic inventory associated with a TRIGA-SS FLIP fuel.

SRS HLW glass possesses the largest total gamma source intensity (Reference 2.2.31, Section 5.1.5) therefore from a shielding perspective it is the limiting waste stream of the potential (short) DHLW forms. Table 5 and Table 6 contain the gamma and neutron spectrum and total intensity for the DHLW glass, on a per canister basis.

Table 3. Gamma Sources for TRIGA FLIP SNF Element

Gamma Intensity (photons/s)		
Upper Energy Boundary [a] (MeV)	**Mean Energy [a] (MeV)**	**Fuel Region [b] (5 year cooled)**
0.02	0.015	1.073E+13
0.03	0.025	2.355E+12
0.05	0.0375	2.083E+12
0.07	0.0575	2.077E+12
0.10	0.085	1.294E+12
0.15	0.125	1.039E+12
0.30	0.225	1.100E+12
0.45	0.375	5.486E+11
0.70	0.575	9.080E+12
1.00	0.85	1.665E+12
1.50	1.25	6.399E+12
2.00	1.70	8.529E+09
2.50	2.25	6.709E+09
3.00	2.75	6.075E+07
4.00	3.50	7.161E+06
6.00	5.00	2.303E+03
8.00	7.00	2.652E+02
14.0	11.0	3.045E+01
Total		3.839E+13

Source: [a] Reference 2.2.71, p. 31
[b] Calculated in Reference 2.2.31 (spreadsheet *Attachment.xls*, spreadsheet *TRIGA*).

Table 4. Neutron Sources for TRIGA FLIP SNF Assembly

Isotope	**Activity [b] (Ci)**	**(α,n) 20 yr. Cooling [b] (n/s)**	**Spontaneous Fission (20 yr.) [b] (n/s)**	**Activity [a] (Ci)**	**(α,n) 5 yr. Cooling [c] (n/s)**	**Spontaneous Fission (5 yr.) [c] (n/s)**
Bi 211	3.78E-03	5.51E-03		1.041E-08	1.52E-08	
Po 212	1.72E-05	1.84E+01		1.340E-05	1.43E+01	
Po 215	3.78E-08	2.57E-01		1.041E-08	7.07E-02	
Rn 219	3.78E-08	9.24E-03		1.041E-08	2.54E-03	
U 235	1.19E-04	9.71E-03	1.82E-02	1.193E-04	9.71E-03	1.82E-02
U 238	1.83E-05	9.49E-04	6.43E-01	1.832E-05	9.49E-04	6.43E-01
Pu 238	3.24E+00	1.31E+03		3.647E+00	1.47E+03	
Pu 239	9.35E-02	4.66E+01	4.70E+00	9.350E-02	4.66E+01	4.70E+00
Pu 240	7.69E-02	2.70E+01		7.665E-02	2.69E+01	
Am 241	7.80E-01	4.57E+02		3.036E-01	1.78E+02	
Total		1.86E+03	5.36E+00		1.74E+03	5.36E+00

SOURCE: [a] Reference 2.2.82, p. B-4.
[b] Reference 2.2.82, Table B-3.
[c] Calculated in Reference 2.2.31 (spreadsheet *Attachment.xls*, spreadsheet *source_terms*).

Table 5. Gamma Sources for DHLW Glass Canisters

Gamma Intensity (photons/s)		
Upper Energy Boundary (MeV)	**Photons/s**	**Mev/s**
0.05	1.29E+15	3.87E+13
0.10	3.89E+14	2.91E+13
0.20	3.02E+14	4.53E+13
0.30	8.58E+13	2.15E+13
0.40	6.27E+13	2.19E+13
0.60	8.55E+13	4.27E+13
0.80	1.34E+15	9.38E+14
1.00	2.08E+13	1.87E+13
1.33	2.91E+13	3.39E+13
1.66	6.18E+12	9.24E+12
2.00	4.86E+11	8.89E+11
2.50	2.70E+12	6.07E+12
3.00	1.91E+10	5.27E+10
4.00	2.15E+09	7.51E+09
5.00	5.20E+05	2.34E+06
6.50	2.09E+05	1.20E+06
8.00	4.09E+04	2.96E+05
10.0	8.67E+03	7.81E+04
Total	3.61E+15	1.25E+15

SOURCE: Reference 2.2.31, Table 18.

Table 6. Neutron Sources for DHLW Glass Canisters

Neutron Intensity	
Upper Energy Boundary (MeV)	**Neutrons/s**
0.10	1.54E+05
0.40	1.60E+06
0.90	5.58E+06
1.40	5.98E+06
1.85	5.21E+06
3.00	2.12E+07
6.43	2.74E+07
20.0	2.99E+05
Total	6. 74E+07

SOURCE: Reference 2.2.31, Table 19.

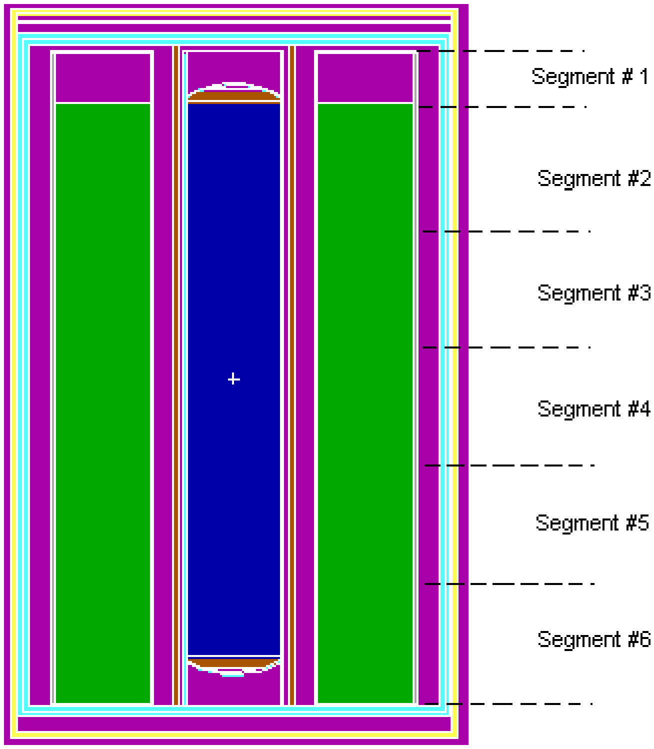
6.3.3 Waste Package Dose Rate Calculation

Monte Carlo N-Particle (MCNP) is used to estimate particle crossings over the surfaces of interest to determine the particle flux. Therefore, the external radial and axial surfaces of the waste package are divided into surface segments. The average dose rate over each segment area is tabulated to examine the spatial distribution of the dose rate. Figure 3, Figure 4, and Figure 5 illustrate the radial, axial, and angular segments, respectively, used in this dose rate calculation.

The 18-*inch* (0.457 *m*) outer diameter (OD) DOE Standardized SNF Canister lies at the center location, surrounded by five DHLW glass canisters near the WP perimeter. In this configuration, the DHLW glass canisters shield the center location. As a result, there will be an angular dose distribution across the WP perimeter between the shadowed and unshadowed solid angles. Therefore, the radial waste package surface is divided into 10 equivalent angular segments as shown in Figure 5. Due to the symmetrical nature of the WP, as well as the source region geometry, the shadowed and unshadowed slices will vary only within the statistical limits of the Monte Carlo process. Therefore the dose rates at segment a, and segment b were only tabulated.

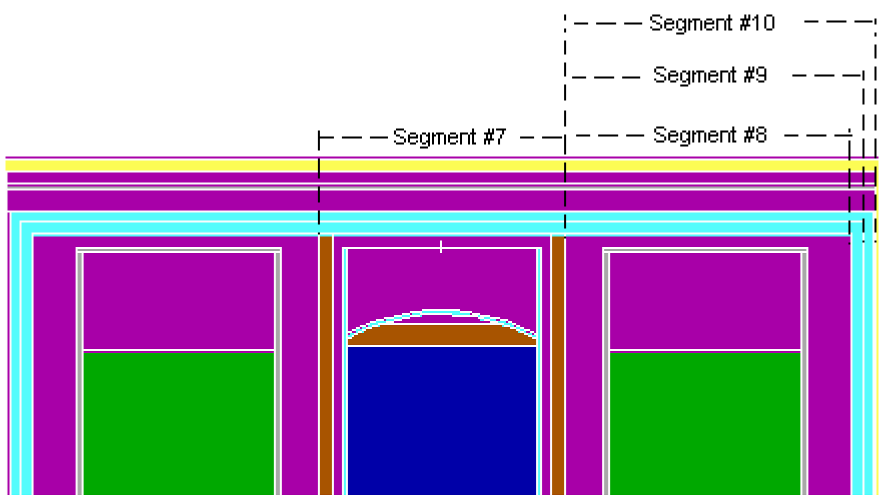
Segment # 1 corresponds to the air cavity bound by the upper surface of the DHLW glass, and the canister interior top surface. Segments # 2 through 6 are five equivalent radial segments bound by the DHLW glass top surface and bottom surface. Due to the difference in lengths with regards to the 18-*inch* OD DOE Standardized SNF Canister, and the DHLW glass canisters we will also observe a spatial particle flux distribution across the radial surfaces. Segments # 7 through 10 were created to examine the radial profile. Segment # 7 corresponds to the radial surface area above the 18-*inch* OD DOE Standardized SNF Canister. Segment # 8 corresponds to the radial surface area above the DHLW glass within the inner barrier inner radius, excluding the area above the 18-*inch* OD DOE Standardized SNF Canister. Segment # 9 corresponds to the radial surface area above the DHLW glass within the outer barrier inner radius, excluding the area above the 18-*inch* OD DOE Standardized SNF Canister. Segment # 10 corresponds to the radial surface area above the DHLW glass within the outer barrier outer radius, excluding the area above the 18-*inch* OD DOE Standardized SNF Canister.

The photon and coupled neutron-photon calculations are performed in two separate simulations. The total dose rate is then the sum of the gamma and neutron dose components.



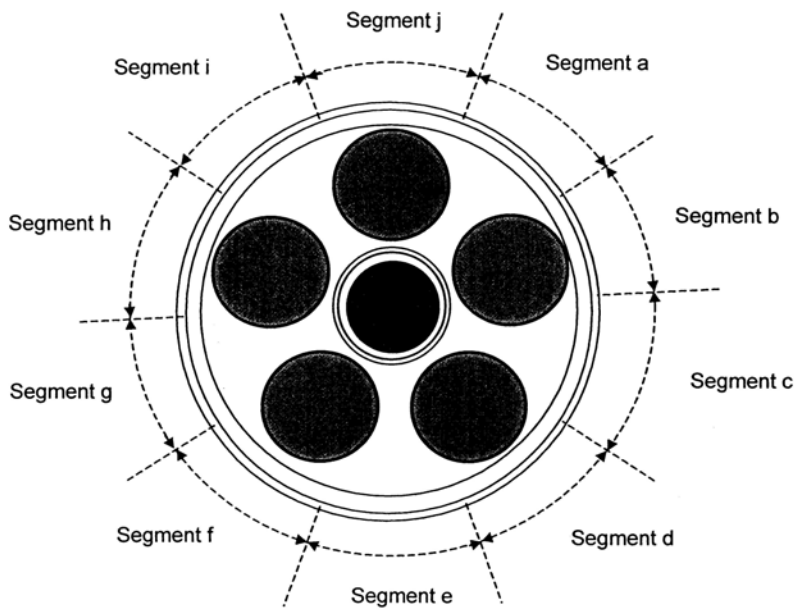
NOTE: Figure not to scale.
Source: Reference 2.2.31, Figure 4

Figure 3. Waste Package Radial Surfaces Segments used in Dose Rate Calculation



NOTE: Figure not to scale.
Source: Reference 2.2.31, Figure 5.

Figure 4. Waste Package Axial Surfaces Segments used in Dose Rate Calculation



Source: Reference 2.2.31, Figure 6.

Figure 5. Angular Segments of Waste Package Outer Radial Surface used in Dose Rate Calculations

6.3.4 Dose Rate Results and Conclusions

6.3.4.1 Radial Dose Rates

The data presented in this section is for the radial surfaces of the 5-DHLW/DOE SNF short co-disposal WP. Table 7 through Table 12 present the total dose rates on the inner and outer surface of the IV, the inner and outer surfaces of the OCB, and at distances of one and two *meters* from the WP surface. Table 13 and Table 14 present the dose rates over the shadowed and unshadowed segments (Segments a and b as shown in Figure 5).

Table 7. Dose Rates on the Waste Package Inner Vessel Inner Surface

Axial Location	Gamma		Neutron		Total	
	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error
Segment 1	2964.48	0.0031	0.160	0.023	2964.64	0.0031
Segment 2	6572.63	0.0015	0.253	0.0143	6572.88	0.0015
Segment 3	7435.69	0.0014	0.301	0.0129	7435.99	0.0014
Segment 4	7521.66	0.0014	0.309	0.0126	7521.97	0.0014
Segment 5	7443.30	0.0014	0.306	0.0131	7443.61	0.0014
Segment 6	6451.38	0.0015	0.256	0.0143	6451.64	0.0015

Source: Reference 2.2.31, Table 21.

Table 8. Dose Rates on the Waste Package Inner Vessel Outer Surface

Axial Location	Gamma		Neutron		Total	
	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error
Segment 1	141.201	0.006	0.079	0.0205	141.280	0.0060
Segment 2	354.551	0.0027	0.131	0.0133	354.682	0.0027
Segment 3	393.845	0.0025	0.157	0.0121	394.002	0.0025
Segment 4	394.811	0.0025	0.159	0.0118	394.970	0.0025
Segment 5	394.581	0.0025	0.157	0.012	394.738	0.0025
Segment 6	343.236	0.0027	0.133	0.0134	343.369	0.0027

Source: Reference 2.2.31, Table 22.

Table 9. Dose Rates on the Waste Package Outer Barrier Outer Surface

Axial Location	Gamma		Neutron		Total [a]	
	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error
Segment 1	26.829	0.0076	0.036	0.0184	26.866	0.0076
Segment 2	66.815	0.0035	0.059	0.0125	66.874	0.0035
Segment 3	74.566	0.0033	0.070	0.0114	74.636	0.0033
Segment 4	74.847	0.0033	0.070	0.0111	74.918	0.0033
Segment 5	74.471	0.0033	0.070	0.0113	74.541	0.0033
Segment 6	64.113	0.0035	0.059	0.0125	64.172	0.0035

NOTE: [a] The gamma dose rates in Table 9, and Table 10 vary only within statistical limits.
Source: Reference 2.2.31, Table 23.

Table 10. Dose Rates on the Waste Package Outer Barrier Outer Surface by Source

Axial Location	DHLW Glass Primary Gamma		TRIGA Primary Gamma		Total [a]	
	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error
Segment 1	23.693	0.0078	4.458	0.009	28.151	0.0067
Segment 2	59.890	0.0034	6.983	0.0048	66.873	0.0031
Segment 3	65.903	0.0032	8.726	0.0043	74.629	0.0029
Segment 4	66.230	0.0032	8.883	0.0042	75.114	0.0029
Segment 5	65.919	0.0032	8.470	0.0044	74.389	0.0029
Segment 6	59.305	0.0034	5.029	0.0055	64.334	0.0032

NOTE: [a] The gamma dose rates in Table 9, and Table 10 vary only within statistical limits.
Source: Reference 2.2.31, Table 24.

Table 11. Dose Rates 1m from the Waste Package Outer Barrier Outer Surface

Axial Location	Gamma		Neutron		Total	
	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error
Segment 1	15.727	0.004	0.017	0.0078	15.744	0.0040
Segment 2	22.916	0.0027	0.021	0.0068	22.937	0.0027
Segment 3	29.132	0.0025	0.025	0.0064	29.157	0.0025
Segment 4	30.679	0.0024	0.026	0.0062	30.705	0.0024
Segment 5	28.731	0.0025	0.025	0.0064	28.756	0.0025
Segment 6	21.798	0.0028	0.020	0.0069	21.818	0.0028

Source: Reference 2.2.31, Table 25.

Table 12. Dose Rates 2m from the Waste Package Outer Barrier Outer Surface

Axial Location	Gamma		Neutron		Total	
	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error
Segment 1	11.020	0.0035	0.013	0.0067	11.033	0.0035
Segment 2	13.751	0.0026	0.014	0.006	13.765	0.0026
Segment 3	16.482	0.0024	0.016	0.0059	16.497	0.0024
Segment 4	17.361	0.0024	0.016	0.0058	17.377	0.0024
Segment 5	16.188	0.0024	0.016	0.0059	16.203	0.0024
Segment 6	13.277	0.0026	0.014	0.0060	13.290	0.0026

Source: Reference 2.2.31, Table 26.

Table 13. Dose Rates Averaged over the Angular Segment a (Unshadowed)

	Gamma		Neutron		Total	
Axial Location	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error
Angular Segment a						
1	26.75	0.0245	0.036	0.0565	26.79	0.0245
2	68.79	0.0109	0.058	0.038	68.84	0.0109
3	73.29	0.0104	0.069	0.0364	73.36	0.0104
4	74.02	0.0104	0.069	0.0339	74.09	0.0104
5	73.25	0.0104	0.071	0.0354	73.32	0.0104
6	68.87	0.0108	0.057	0.0376	68.92	0.0108

Source: Reference 2.2.31, Table 28.

Table 14. Dose Rates Averaged over the Angular Segment b (Shadowed)

	Gamma		Neutron		Total	
Axial Location	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error
Angular Segment b						
1	30.10	0.0251	0.038	0.0511	30.14	0.0251
2	65.36	0.0114	0.059	0.0335	65.42	0.0114
3	77.03	0.0104	0.072	0.0306	77.10	0.0104
4	76.32	0.0104	0.074	0.0301	76.39	0.0104
5	75.13	0.0101	0.071	0.0307	75.20	0.0101
6	61.52	0.0112	0.061	0.0328	61.58	0.0112

Source: Reference 2.2.31, Table 29.

6.3.4.2 Axial Dose Rates

The data presented in this section are for the axial surfaces of the 5-DHLW/DOE SNF short co-disposal WP. Table 15 presents the total dose rates on various top and bottom surfaces of the WP as well as at distances of one and two meters from the WP ends. The segments used in Table 15 are described and diagramed in Section 6.3.3 and Figure 4.

Table 15. Dose Rates at the Waste Package Surface

		Gamma		Neutron		Total	
Axial Location	Segment	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error	Dose (rem/hr)	Relative Error
Lower Inner Vessel top surface	Segment 7	6161.90	0.0039	0.675	0.0234	6162.58	0.004
	Segment 8	5453.96	0.002	0.199	0.018	5454.16	0.002
Lower Inner Vessel bottom surface	Segment 7	165.66	0.0138	0.106	0.034	165.77	0.014
	Segment 9	248.02	0.0035	0.110	0.016	248.13	0.003
Outer Barrier Bottom Surface	Segment 7	41.92	0.0174	0.050	0.0327	41.97	0.017
	Segment 10	43.81	0.0046	0.048	0.0153	43.86	0.005
1m from Outer Barrier Bottom	WP bottom	22.14	0.005	0.019	0.013	22.16	0.005
2m from Outer Barrier Bottom	WP bottom	12.38	0.0057	0.012	0.0117	12.39	0.006
Top of Waste Package Cavity	Segment 7	1358.74	0.0094	0.129	0.0517	1358.87	0.009
	Segment 8	3066.65	0.0024	0.164	0.0199	3066.81	0.002
Outer Lid Bottom Surface	Segment 7	91.08	0.0155	0.069	0.0375	91.15	0.015
	Segment 9	88.50	0.0048	0.069	0.0182	88.57	0.005
Outer Lid Top Surface	Segment 7	22.90	0.0212	0.030	0.0375	22.93	0.021
	Segment 10	17.12	0.0066	0.031	0.0175	17.15	0.007
1m from Outer Lid Top Surface	WP top	9.57	0.0068	0.014	0.0141	9.59	0.007
2m from Outer Lid Top Surface	WP top	5.76	0.0074	0.009	0.0121	5.77	0.007

Source: Reference 2.2.31, Table 27.

6.3.4.3 Dose Rate Conclusions

Dose rates, including gamma and neutron contributions, were calculated inside the waste package, on the external surface of the waste package, and at various distances away from the waste package.

A maximum of 74.91 *rem/hr* (Table 9) at the external radial surface of the waste package occurs at the shadowed axial segment # 4. The dose rates on the waste package bottom and top surfaces, seen in Table 15, are 43.86 *rem/hr* (Segment 10) and 22.93 *rem/hr* (Segment 7), respectively.

The waste package radial surface dose rates features a slight angular variation, with a value of 77.10 *rem/hr* (Table 14) on segments next to the DHLW canisters and a value of 74.09 *rem/hr* (Table 13) on segments next to the gaps between canisters. The waste package radial dose rates are also characterized by a small variation along the axial direction. Thus, the average waste package exterior surface dose rates vary from a maximum of 74.91 *rem/hr* (Segment 4) to a minimum of 64.17 *rem/hr* (Segment 6) across the height of the DHLW glass canisters, as seen in Table 9. At the location of the maximum and minimum surface dose rate, the DHLW glass canisters fractional dose is 66.23 *rem/hr* and 59.30 *rem/hr*, respectively (Table 10).

The waste package radial shells reduce the maximum dose rate values from 7521.97 to 74.91 *rem/hr*, the top shells reduce the dose rate values from 1358.87 to 22.93 *rem/hr*, and the bottom shells reduce the dose rate values from 6162.58 to 41.97 *rem/hr*.

The neutron component is negligible as compared with the photon component of the total dose rates.

6.3.5 Inner Vessel Lid/Shield Plug Thickness

The calculation *Shielding Evaluation of the Plug/Insert Thickness for the 5-DHLW/DOE SNF and 2-MCO/2-DHLW Co-Disposal Waste Packages* (Reference 2.2.47) was performed to provide a parametric shielding evaluation for the inner vessel stainless steel shield lid/plug/insert. The results of that calculation (Reference 2.2.47, Section 7.2.1) concluded:

1. For inner vessel lid thickness over 9 *in* (0.229 *m*), the primary gamma is not the main contributor to dose rate (Reference 2.2.47, Tables 20 to 23 and 26 to 29). Therefore, further increase in lid thickness is not recommended due to decrease in shield effectiveness.

2. The homogenized model overestimates the dose rate above the inner vessel lid with 10 to 30 percent depending on location and shield thickness (Reference 2.2.47, Table 24). For a lid thickness of 9 *in* (0.229 *m*) the overestimate ranges from 20 to 25 percent. This difference (equivalent with reduction in dose rate due to approximately 0.2 *in* (0.005 *m*) of stainless steel) can not justify a reduced requirement for the inner vessel lid thickness.

3. The radiation streaming dose rate between inner vessel and outer barrier is approximately 200 *mrem/hr* (Reference 2.2.47, Section 7.1.3). The streaming dose rate starts to be

significant when compared with the lid dose rate for inner vessel lid thicknesses over 7 *in* (0.178 *m*). For a lid thickness of 9 *in* (0.229 *m*) the radiation streaming dose rate is approximately four times the dose rate over the lid, because the streaming is very localized, but the averaged dose rate over the lid and gap together is only three percent higher than the lid dose rate (Reference 2.2.47, Table 25).

The calculation *Shielding Evaluation of the Plug/Insert Thickness for the 5-DHLW/DOE SNF and 2-MCO/2-DHLW Co-Disposal Waste Packages* (Reference 2.2.47, Section 7.2.2) also recommended:

1. To reduce the dose rate above the 5-DHLW/DOE SNF co-disposal WP with no outer lid below the intermittent access in restricted areas limit of 100 *mrem/hr*, the minimum inner vessel lid thickness should be approximately 9 *in*. (0.229 *m*) (Reference 2.2.47, Figures 1 and 2).

2. To reduce the dose rate above the 2-MCO/2-DHLW co-disposal WP with no outer lid below the intermittent access in restricted areas limit of 100 *mrem/hr*, the minimum inner vessel lid thickness should be approximately 8 *in*. (0.203 *m*) (Reference 2.2.47, Figure 3).

3. In order to reduce the contribution of the radiation streaming to a manageable value, the difference between the outer barrier ID and the inner vessel OD (Reference 2.2.47, Tables 15 and 16) should not exceed the values used in this calculation (0.95 *cm* (0.37 *in*)).

The recommended lid thickness of 9 *in* has been taken into consideration as shown in References 2.2.18 and 2.2.21.

7. RESULTS AND CONCLUSIONS

This report demonstrates that the design methodology can be applied successfully to the 5-DHLW/DOE SNF co-disposal waste package configurations and supports the License Application for construction of the repository. General design features were given including design configurations, materials, and guidance for use of codes and standards.

Design features and structural analysis of the 5-DHLW/DOE SNF co-disposal waste packages were compared to design requirements from the *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.24), the *Project Design Criteria Document* (Reference 2.2.39), and the *Provisional Event Sequence Definitions for Waste Packages* (Reference 2.2.25). In addition, requirements were derived by the nature of the engineered design solution or imposed by interfaces with postclosure performance assessment. The comparison of 5-DHLW/DOE SNF co-disposal waste package design features against thermal and structural analyses demonstrates requirements are satisfied, or (in a few cases) will be satisfied as final design is completed.

BSC

Calculation/Analysis Change Notice

Complete only applicable items.

1. QA: QA
2. Page 1 of 1

3. Document Identifier:	4. Rev.:	5. CACN:
000-00C-DS00-00600-000	00F	001

6. Title:
HLW/DOE SNF Co-Disposal Waste Package Design Report

7. Reason for Change:
Clarification that normal temperatures for HLW and DOE SNF in the TEV and transfer trolley are below normal limits.

8. Supersedes Change Notice: ☐ Yes If, Yes, CACN No.: ______ ☒ No

9. Change Impact:

Inputs Changed:	☐ Yes	☒ No	Results Impacted:	☐ Yes	☒ No
Assumptions Changed:	☐ Yes	☒ No	Design Impacted:	☐ Yes	☒ No

10. Description of Change:

On page 46, add the following note after Satisfaction of Requirement 6.2.3.8:

NOTE: The peak HLW and DOE SNF cladding temperatures for a 7.1 kW 5-DHLW/DOE SNF waste package in the TEV were calculated to be 288°C and 339°C (Reference 2.2.34, Attachment V, file: results_summary.xls, tab: k for NS-4-FR = 6.5). This thermal power (7.1 kW) bounds all expected 5-DHLW/DOE SNF waste packages which have a maximum thermal power of 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6). These temperatures are valid for both normal and off-normal events and are well below their corresponding normal temperature limits of 400°C for HLW (see Requirement 6.2.1.17) and 350°C for DOE SNF (see Requirement 6.2.1.14).

On page 44, add the following note after Satisfaction of Requirement 6.2.3.2:

NOTE: The peak HLW and DOE SNF cladding temperatures for a 6.97 kW 5-DHLW/DOE SNF waste package in a transfer trolley in a surface facility were calculated to be 265.8°C and 345.9°C (Reference 2.2.81, Table 55). This thermal power (6.97 kW) bounds all expected 5-DHLW/DOE SNF waste packages which have a maximum thermal power of 5,570 *watts* (see Satisfaction of Requirement 6.2.1.6). These temperatures under normal operating conditions are well below their corresponding normal temperature limits of 400°C for HLW (see Requirement 6.2.1.17) and 350°C for DOE SNF (see Requirement 6.2.1.14).

11. REVIEWS AND APPROVAL

Printed Name	Signature	Date
11a. Originator: Del Mecham	[signature]	2/21/08
11b. Checker: Daniel Wang	[signature]	2/28/08
11c. EGS: FOR Del Mecham	[signature]	2/28/08
11d. DEM: Michael Anderson	[signature]	2/28/08
11e. Design Authority: Barbara Rusinko	[signature]	2/29/08