Safety Analysis Report for the West Valley Melter Package

SARWVMP-01

Revision 0

USNRC Docket Number 71-9797

Submitted by the:
U.S. Department of Energy
West Valley Demonstration Project
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[Under IEWO M14-WV-0001]
&
CH2M Hill-B&W West Valley, LLC
[Under Contract DE-EM0001259]

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EXECUTIVE SUMMARY

The purpose of this report is to analyze the West Valley Melter Package, a Type B(U) radioactive material transportation package Model Number 9797 containing the vitrification melter from the West Valley Demonstration Project, to support a request for special package authorization by the U.S. Nuclear Regulatory Commission. This report demonstrates the West Valley Melter Package meets the Commission's regulation at Title 10, Part 71 of the Code of Federal Regulations (10 CFR 71), *Packaging and Transportation of Radioactive Material*, by compliance with or equivalency to those requirements.

The West Valley Melter Package, shown in Figure ES-1, consists of the Grouted Melter Package and an Impact Limiter.

The Grouted Melter Package consists of the container with the melter encased in Low Density Cellular Concrete. The container was constructed in 2004 of welded steel plate with one side being a door secured with bolts and a neoprene gasket. Each corner contains a shock absorber. The Low Density Cellular Concrete, poured in 2013, completely encases the melter.

The Impact Limiter will be constructed of steel plate and foam filled steel tubing. It will be welded to the shock absorbers on door side of the Grouted Melter Package.

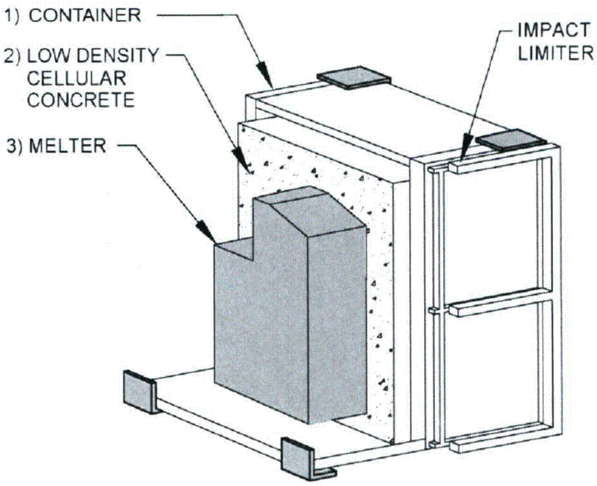


Figure ES-1. West Valley Melter Package Components

The residual radioactivity in the melter amounts to approximately 3,554 curies, with over 99.8 percent of this amount from cesium 137 and strontium 90 and their daughter products. There are approximately 82 grams of fissile material within the melter.

The melter consists of a stainless steel box structure approximately 10 feet on each side lined with refractory material. The melter contains radioactive material immobilized in borosilicate glass, which accounts for over 99 percent of the residual radioactivity. The melter weighs approximately 107,500 pounds (49,000 kilograms).

The melter was used from 1996 through 2002 to produce a homogenized mixture of high-level waste and borosilicate glass. During use, the primary pour spout became plugged with hardened glass and the secondary pour spout was used to complete the waste vitrification. After completion of waste vitrification, the melter was used to process low-activity flush solutions to reduce the radioactivity concentration in the molten material in the melter cavity. When processing was completed as much of the molten material was removed as practical. The melter now contains approximately 1,030 pounds (467 kilograms) of hardened glass, with approximately 218 pounds (99 kilograms) in the plugged primary pour spout.

Table ES-1 summarizes how the West Valley Melter Package meets the requirements of 10 CFR 71. This table is organized using NRC Regulatory Guide 7.9, *Standard Format and Content of Part 71*

Applications for Approval of Packages for Radioactive Material, which was closely followed in preparing this report.

Table ES-1. 10 CFR 71 Compliance Summary

Chapter	Subject	Compliance	Discussion
2	Structural Evaluation	Complies	Analyses of the West Valley Melter Package show it meets Normal Conditions of Transport and Hypothetical Accident Conditions. The analysis shows only localized damage to the Low Density Cellular Concrete and minor face seal displacement under Hypothetical Accident Conditions.
3	Thermal Evaluation	Complies	The thermal evaluation demonstrates requirements are met using conservative analyses that did not consider the insulating values of the Impact Limiter.
4	Containment	Equivalent Safety	Equivalent safety is demonstrated by package performance in accordance with requirements with release rates below regulatory limits under Normal Conditions of Transport and Hypothetical Accident Conditions.
5	Shielding Evaluation	Complies	The evaluation demonstrates compliance with the applicable requirements.
6	Criticality Evaluation	Complies	The package is fissile exempt.
7	Package Operations	Complies	Operations are performed in accordance with approved procedures.
8	Acceptance Tests and Maintenance Program	Complies	The required acceptance tests are completed as required.

1.0 GENERAL INFORMATION

This chapter provides an introduction to the Safety Analysis Report (SAR) and a general description of the West Valley Melter Package (WVMP) and its contents.

1.1 Introduction

1.1.1 Purpose

The purpose of this SAR is to analyze the safety aspects of the WVMP, Model Number 9797, a Type B(U) radioactive material transportation package containing the vitrification melter from the West Valley Demonstration Project (WVDP). The WVMP is a fissile exempt package.

Key Terms and Acronyms in this Chapter	
CHBWV	CH2M Hill-B&W West Valley, LLC
GMP	Grouted Melter Package (consisting of the melter, LDCC inside the container, and the container)
IL	Impact Limiter
LDCC	Low Density Cellular Concrete
PBS	Polymeric Barrier System
WVDP	West Valley Demonstration Project
WVMP	West Valley Melter Package (consisting of the GMP with the IL installed)

This SAR was prepared for a Special Package Authorization (SPA) from the U.S. Nuclear Regulatory Commission (US NRC) for use of the WVMP. Such special package authorization is required by the Commission's regulation per Title 10, Part 71 of the Code of Federal Regulations (10 CFR 71), *Packaging and Transportation of Radioactive Material*, §71.41(d) (reference 1-1) for a one-time shipment of radioactive material transportation packages.

1.1.2 Scope

This SAR demonstrates the WVMP complies with 10 CFR 71 or provides safety measures equivalent to those in the applicable regulations. The WVMP design includes an impact limiting component attached to an existing Grouted Melter Package (GMP) component. This SAR was prepared following the guidance provided in Regulatory Guide 7.9, *Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material* (reference 1-2), to facilitate US NRC staff review.

1.1.3 Background

The WVDP vitrification melter contains residual radioactivity associated with spent nuclear fuel reprocessing at the West Valley site. At the heart of the vitrification plant was the slurry-fed vitrification melter. The melter consisted of an electrically heated box structure approximately 10 feet on each side containing refractory material, with an outer shell of stainless steel. The vitrification melter was used from 1996 through 2002 to heat high-level waste slurry and glass forming chemicals to produce a molten homogeneous mixture that was poured into stainless steel canisters, where it hardened to produce a highly stable glass waste form.

In 2004, West Valley procured a specially designed container for the melter. This approximately 208,000 lb container consists of 6" thick sidewalls and 4" thick top and bottom. The package was designed so that once the melter was loaded, and prior to shipment, the interstitial spacing within the melter and the spacing between the melter and the container would be filled with Low Density

Cellular Concrete (LDCC). This provides securement of the melter within the container and impact limiting resistance in the event of an accident. In 2004 the melter was transferred into the container and placed into storage until 2013 when the LDCC was added.

In 2014, it was determined that the melter was required to be shipped in either a Type B certified package or under SPA granted by the US NRC. Since the melter was already in the GMP and encased in LDCC, it is necessary to submit an application to the US NRC for a SPA.

West Valley plans to ship the WVMP to the Waste Control Specialists (WCS) low-level waste facility in Texas for disposal.

1.2 Package Description

1.2.1 Packaging

The WVMP is a rectangular shaped packaging 15'9" long by 12'7" wide by 12'6.5" high containing eight shock absorbers and an Impact Limiter (IL). The maximum fully loaded weight is approximately 390,800 lbs as discussed in Chapter 2 and the minimum empty weight is approximately 208,000 lbs (reference 1-3).

The containment feature is the WVMP's container. The container is fabricated with SA516, Grade 70 carbon steel. It has a bolted side door recessed into the container secured with 32 ASTM A193-B7 1½-inch diameter bolts. This bolted side door has a neoprene gasket. The container was designed, constructed, and procured under the WVDP's Nuclear Quality Assurance (NQA)-1 program. A copy of the engineering drawing describing the container details (reference 1-3) appears in Appendix 1.3.2.

Figure 1-1 shows a cutaway view depicting the melter encased in LDCC within the container. The GMP is comprised of the container, the melter, and the LDCC.[1]

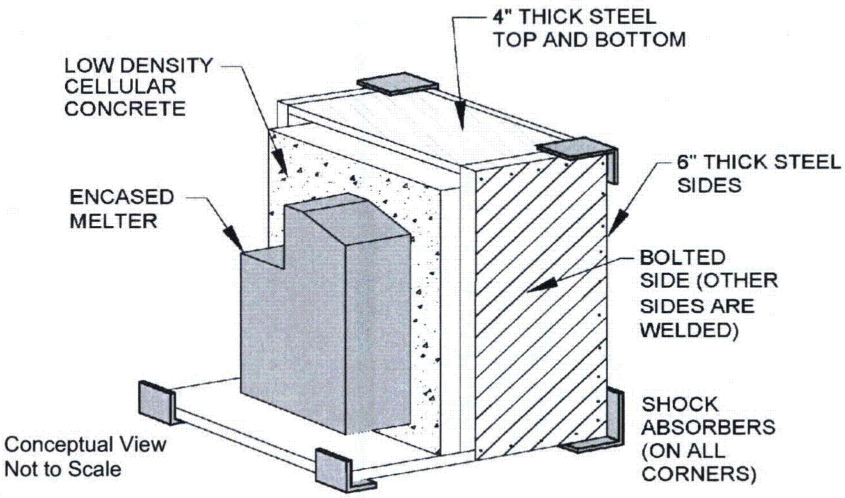


Figure 1-1. GMP Configuration (Cutaway)

[1]The three figures included in this chapter are conceptual sketches. Refer to the engineering drawings in the appendix for details.

To meet 10 CFR 71 performance criteria for both structural and containment, an IL is attached to the bolted side door of the GMP as shown on Figure 1-2. This IL is comprised of 2" by 9" steel plates and foam-filled 6" by 10" tube steel. The GMP with the IL component in place forms the WVMP. A copy of the engineering drawing describing the IL (reference 1-4) appears in Appendix 1.3.3.

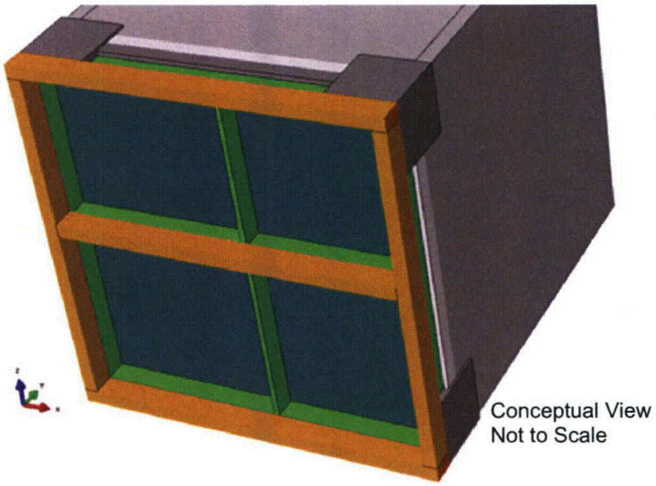


Figure 1-2. WVMP Showing the Impact Limiter

Figure 1-3 shows a cutaway view of the WVMP (the GMP with the IL in place).

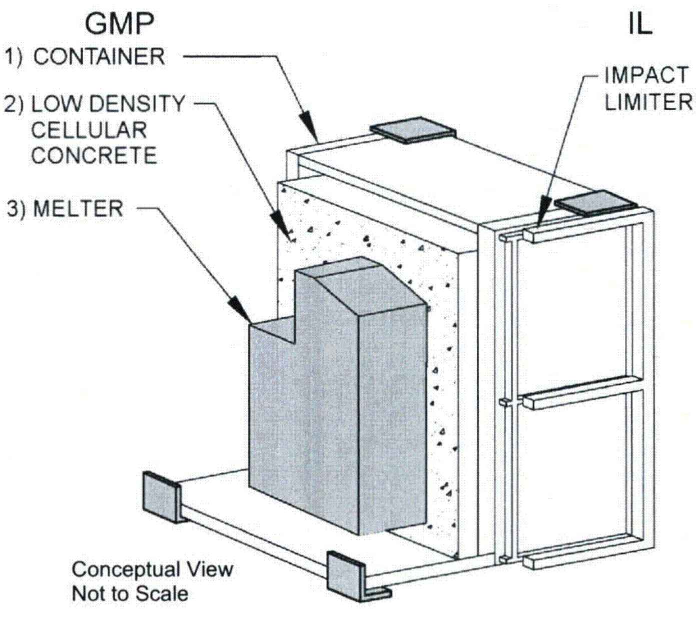


Figure 1-3. Components of the WVMP

Appendix 1.3.4 shows how the WVDP contractor's Quality Assurance Program (QAP) followed in construction of the packaging is comparable with the applicable regulatory requirements. Appendix 1.3.5 shows that American Welding Society (AWS) welding requirements used in construction of

the packaging are comparable with those of NUREG/CR-3019, *Recommended Welding Criteria For Use in the Fabrication of Shipping Containers for Radioactive Materials* (reference 1-5) and the ASME Boiler and Pressure Vessel Code, Subsection ND (reference 1-6).

The gamma shielding features of the WVMP include the 6" thick side walls of the container and the 4" thick top and bottom, made of SA516 carbon steel. The next gamma shielding feature is the LDCC, filling the annular space in the container. The innermost gamma shielding feature is the melter. The melter contains refractory brick, Inconel, and Type 304L stainless steel. The neutron dose is negligible.

The WVMP is fissile exempt. There are no criticality control features.

The WVMP design has no active heat transfer features.

The WVMP will be marked per 10 CFR 71.85(c), which states *"The licensee shall conspicuously and durably mark the packaging with its model number, serial number, gross weight, and a package identification number assigned by the NRC."*

1.2.2 Contents

Radionuclide Content

The melter contains four primary source terms consisting of (1) the heel contained within the melter cavity, (2) residual glass contained within the cracks, crevices and interstitial spacing associated to the refractory brick, (3) the plugged discharge port (pour spout), and (4) the surface contamination on the melter exterior. Each of these source terms was characterized independently utilizing available historical information, analytical results, and swipe sample results. The total activity associated with the melter is 3,554 curies. Total fissile (gram) content of the melter is 81.56 grams. Total number of A_2's associated to the melter is 214.9. Thermal decay heat associated to the melter is 9.2 watts. (reference 1-7)

Primary isotopes of concern consist of Cs-137 (Ba-137m) and Sr-90 (Y-90), which contribute greater than 99.8 percent of the total activity associated with the melter. Other nuclides present include actinides, other fission products, activation products, and other associated daughter products, with a combined contribution to total activity of less than 0.2 percent.

In characterizing the melter, a conservative approach was taken to ensure that the isotopic distribution and associated activity was bounded. Decay correction was incorporated in the final content.

The melter was characterized utilizing analytical data associated with the waste materials that were processed through it, swipe sample results within the vitrification cell, and swipe samples of the melter. When available, shard sample data were used which increase accuracy and reduce uncertainty.

The melter contains fissile radionuclides in the form of Pu-239, Pu-241, U-233, and U-235 with a bounding fissile content of 81.56 grams. Of the 81.56 grams of fissile material, 80.90 grams is contained within 467 kg of vitrified glass contained within the melter. The remaining 0.66 gram of

fissile material is fixed to the outer surface of the melter body. Table 1-1, based on reference 1-7, gives a breakdown of the total activity by source term, quantify of fissile material by source term, activity of primary isotopes by source terms, and quantity of vitrified glass by source term.

Table 1-1. Source Term Totals

Activity Breakdown by Source Term						
Source Term	Total Activity (Ci)	Fissile Mass (g)	A2's	Decay Heat (W)	% of Total Activity	Mass of Vitrified Glass (kg)
Exterior Contamination (decay corrected)	1.436E+01	6.569E-01	2.136E+00	4.054E-02	0.404%	
Melter Spout (decay corrected)	1.793E+03	1.899E+01	8.244E+01	4.551E+00	50.445%	9.90E+01
Refractory (decay corrected)	6.300E+02	3.268E+01	6.713E+01	1.768E+00	17.725%	6.82E+01
Melter Heel (decay corrected)	1.117E+03	2.923E+01	6.315E+01	2.834E+00	31.426%	3.00E+02
Totals	**3.554E+03**	**8.156E+01**	**2.149E+02**	**9.194E+00**		4.67E+02

Activity Associated to Primary Isotopes						
	Exterior Surface	Spout	Refractory	Heel	Totals	
	Act (Ci)	Act (Ci)	Act (Ci)	Act (Ci)	Act (Ci)	% of Total Act
Cs-137	5.062E+00	8.566E+02	2.132E+02	5.419E+02	1.617E+03	45.487%
Ba-137m	4.778E+00	8.086E+02	2.012E+02	5.116E+02	1.526E+03	42.938%
Sr-90	2.213E+00	6.332E+01	1.068E+02	3.120E+01	2.035E+02	5.726%
Y-90	2.213E+00	6.333E+01	1.068E+02	3.121E+01	2.036E+02	5.727%
Total Activity of Primary Isotopes	1.427E+01	1.792E+03	6.280E+02	1.116E+03	3.550E+03	99.878%
Total Activity of Remaining Activity	9.400E-02	1.150E+00	2.000E+00	1.090E+00	4.334E+00	0.122%

Conservatism and Uncertainty

The source term estimate is a bounding estimate that is conservative in several respects, for example:

- The estimated mass of hardened glass in the bottom of melter cavity of 300 kg was conservatively based on an eight-inch depth of glass, where the best estimate of glass depth is 6.5 inches, which corresponds to approximately 192 kg at a glass density of 2.6 g/cm^3.
- The estimated mass of 99 kg in the plugged pour spout and pour chamber was conservatively based on assuming that the spout and pour chamber are completely full of hardened glass, which may not be the case.
- The calculated mass of residual glass associated with the refractory material of 68.2 kg was estimated using a conservative volume of material based on one percent of the actual

volume of refractory brick considering the results of visual inspection of the refractory condition after completion of vitrification.

- The amount of removable activity on the melter exterior was conservatively estimated using the maximum result from swipe samples taken from the exterior surfaces, which was approximately twice the average value (reference 1-7) and applying a conservative wiping efficiency of 10 percent.

Uncertainties associated with the inventory estimate are not discussed in the characterization report. The two primary sources of uncertainties are the residual glass mass estimates and the sample analytical data used in the calculations. The residual glass estimates are conservative as just discussed and the total residual glass mass of 467 kg is considered to be bounding. That is, the positive uncertainty in this value is essentially zero and the negative uncertainty is of the order of 25 percent (+0%,-25%)

The sample data uncertainties are reflected in analytical reports (reference 1-7). However, uncertainties in these data were not used in calculating the activity scaling factors since multiple results were available and they were consistent. Geometric averaging of scaling factors is a common practice throughout the commercial nuclear power industry in cases where more than one representative sample is available. This practice is incorporated into the Radman™ software used in the characterization, which has been reviewed and accepted by the US NRC (reference 1-8).

This practice is also consistent with NUREG/CR-6567/PNNL-11659, *Low-Level Waste Classification, Characterization, and Assessment: Waste Streams and Neutron-Activated Metals* (reference 1-9), which states that it "is important that waste generators utilize the most accurate scaling factors possible, so that reliable estimates of these nuclides [ones for which activity scaling factors are used] can be made."

In summary, the use of average values without regard for uncertainty in the analytical data to develop activity scaling factors is consistent with accepted practice and the conservatism in the glass mass estimating process bounds the uncertainty in the analytical data.

Considering the forgoing discussion, rounding down the total inventory estimate of 3,554 curies, including all daughter products, to 3,500 curies appropriately reflects the accuracy of the estimate. However, the 3,554 curie value is used in the analyses in the interest of conservatism.

Physical Description

The physical form of the contents is solid. The chemical form of the contents is oxide and non-reactive.

The melter content is comprised of a stainless steel outer housing and an exterior structural steel frame with the interior lined with refractory materials. See figure 1-4. The maximum envelope dimensions of the melter are 11'10" long by 10'9¾" wide by 10'5 ½" high. All external surfaces of the melter are coated with three layers of Bartlett's Polymeric Barrier System (PBS) contamination fixative. The interior of the melter contains refractory material, vitrified glass, and LDCC.

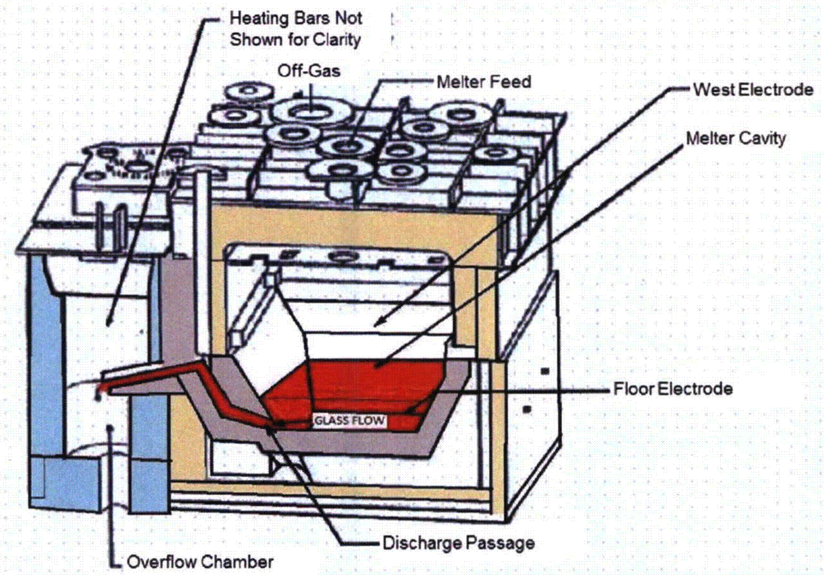


Figure 1-4. Melter

The content weight of the WVMP consisting of the melter, its refractory, and the residual vitrified glass is approximately 107,500 lbs. The WVMP's Maximum Normal Operating Pressure is 12 psi.

1.2.3 Special Requirements for Plutonium

The WVMP contains less than 20 curies of plutonium (reference 1-7). Consequently, there are no special requirements for plutonium related to this package.

1.2.4 Operational Features

All activities related to the WVMPs' final assembly, handling, loading, and transport will be performed in accordance with approved plans, procedures, and work planning instructions.

Prior to the WVMP leaving the WVDP site, an impact limiter will be installed to the bolted door side of the GMP which will render the door inoperable. The IL component will be procured, receipt inspected, and installed by the WVDP site. A copy of the engineering drawing showing the details of the IL is included in Appendix 1.3.3.

The WVMP will be marked per 10 CFR 71.85 (c), which states *"The licensee shall conspicuously and durably mark the packaging with its model number, serial number, gross weight, and a package identification number assigned by the NRC."* Tamper-indicating devices will be applied to the five gasketed ports, four on the top and one on the side of the package.

Radiation surveys of the package (on contact and at one meter from the surface) and non-fixed (removable) contamination surveys will be performed within 60 days of loading and prior to transport. The package exterior surface is expected to be free of removable contamination, and package exterior radiation levels will not exceed the limits specified in 10 CFR 71.47 at any time during transportation.

1.3 Appendix

This appendix contains the following information:

1.3.1 List of references

1.3.2 Engineering drawing for the container

1.3.3 Engineering drawing for the Impact Limiter

1.3.4 CHBWV Quality Assurance Program and Regulatory Requirements Matrix

1.3.5 Code Requirements Comparison Tables

APPENDIX 1.3.1 – REFERENCES

1-1 10 CFR Part 71, *Packaging and Transportation of Radioactive Material.*

1-2 *Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material*, Regulatory Guide 7.9, Revision 2, U.S. Nuclear Regulatory Commission, Washington, D.C., March 2005.

1-3 *West Valley Melter Container*, Drawing 4005-DW-001, Revision 7, WMG, Inc., Peekskill, New York, June, 2013. (PROPRIETARY – see Appendix 1.3.2)

1-4 *WVMP Impact Limiter*, Drawing R-R3-A-00063, Revision 0, Savannah River National Laboratory, Aiken, South Carolina, October 2014. (See Appendix 1.3.3)

1-5 *Recommended Welding Criteria For Use in the Fabrication of Shipping Containers for Radioactive Materials*, NUREG/CR-3019, Monroe, R.E., H.H. Woo, and R.G. Sears, Lawrence Livermore National Laboratory, Livermore, California, March 1984.

1-6 *ASME Boiler and Pressure Vessel Code, Subsection ND*, American Society of Mechanical Engineers, New York, New York, 2004.

1-7 *West Valley Demonstration Project Waste Characterization of Vitrification Melter*, WVDP-577, Brandjes, C., CH2M Hill-B&W West Valley, LLC, West Valley, New York, September 2014. (provided)

1-8 *Acceptance for Referencing, RADMAN Topical Report (WMG-102, as Revised from WMG-101P)*, HPPOS-288 PDR-9306180293, U.S. Nuclear Regulatory Commission, Washington, D.C., http://www.nrc.gov/about-nrc/radiation/protects-you/hppos/hppos288.html (site visited September 12, 2014).

1-9 *Low-Level Waste Classification, Characterization, and Assessment: Waste Streams and Neutron-Activated Metals*, NUREG/CR-6567/PNNL-11659, U.S. Nuclear Regulatory Commission, Washington, D.C., August 2000.

APPENDIX 1.3.2 – ENGINEERING DRAWING FOR THE CONTAINER

Drawing withheld under 10 CFR 2.390, *Public Inspections, Exemptions, Requests for Withholding*

WMG Inc.

West Valley
Melter Container

Dwn. By	Date	SIZE	FSCM NO.	DWG NO.	REV
[illegible]		B		4005-DW-001	7
Proprietary Information		SCALE NTS		SHEET 1 of 8	

Drawing withheld under 10 CFR 2.390,
Public Inspections, Exemptions, Requests for Withholding

All dimensions apply to reference temp. of 68° F. Tolerances on: Fractions ±1/4" Decimals .X ±0.1" .XX ±0.03" Angles ± 1° unless noted	WMG Inc. West Valley Melter Container			
Dwn. By / Date	SIZE B	FSCM NO.	DWG NO. 4005-DW-001	REV 7
Proprietary Information	SCALE NTS		SHEET 2 of 8	

Drawing withheld under 10 CFR 2.390,
Public Inspections, Exemptions, Requests for Withholding

All dimensions apply to reference temp. of 68° F. Tolerances on: Fractions ±1/4" Decimals .X ±0.1" .XX ±0.03" Angles ± 1° unless noted	WMG Inc. West Valley Melter Container			
Dwn. By Date 6/30/13	SIZE B	FSCM NO.	DWG NO. 4005-DW-001	REV 7
Proprietary Information	SCALE NTS		SHEET 3 of 8	

Drawing withheld under 10 CFR 2.390,
Public Inspections, Exemptions,
Requests for Withholding

All dimensions apply to reference temp. of 68° F. Tolerances on: Fractions ±1/4" Decimals .X ±0.1" .XX ±0.03" Angles ± 1° unless noted	WMG Inc. West Valley Melter Container				
Dwn. By Date	SIZE B	FSCM NO.	DWG NO. 4005-DW-001		REV 7
Proprietary Information	SCALE NTS			SHEET 4 of 8	

Drawing withheld under 10 CFR 2.390,
Public Inspections, Exemptions,
Requests for Withholding

All dimensions apply to reference temp. of 66° F. Tolerances on: Fractions ±1/4" Decimals .X ±0.1" .XX ±0.03" Angles ± 1° unless noted	WMG Inc. West Valley Melter Container				
Dwn. By Date	SIZE B	FSCM NO.	DWG NO. 4005-DW-001		REV 7
Proprietary Information	SCALE NTS		SHEET 5 of 8		

Drawing withheld under 10 CFR 2.390,
Public Inspections, Exemptions,
Requests for Withholding

All dimensions apply to reference temp. of 68° F. Tolerances on: Fractions ±1/4" Decimals .X ±0.1" .XX ±0.03" Angles ± 1° unless noted	WMG Inc. West Valley Melter Container			
Dwn. By [signature] Date [illegible]	SIZE B	FSCM NO.	DWG NO. 4005-DW-001	REV 7
Proprietary Information	SCALE NTS		SHEET 6 of 8	

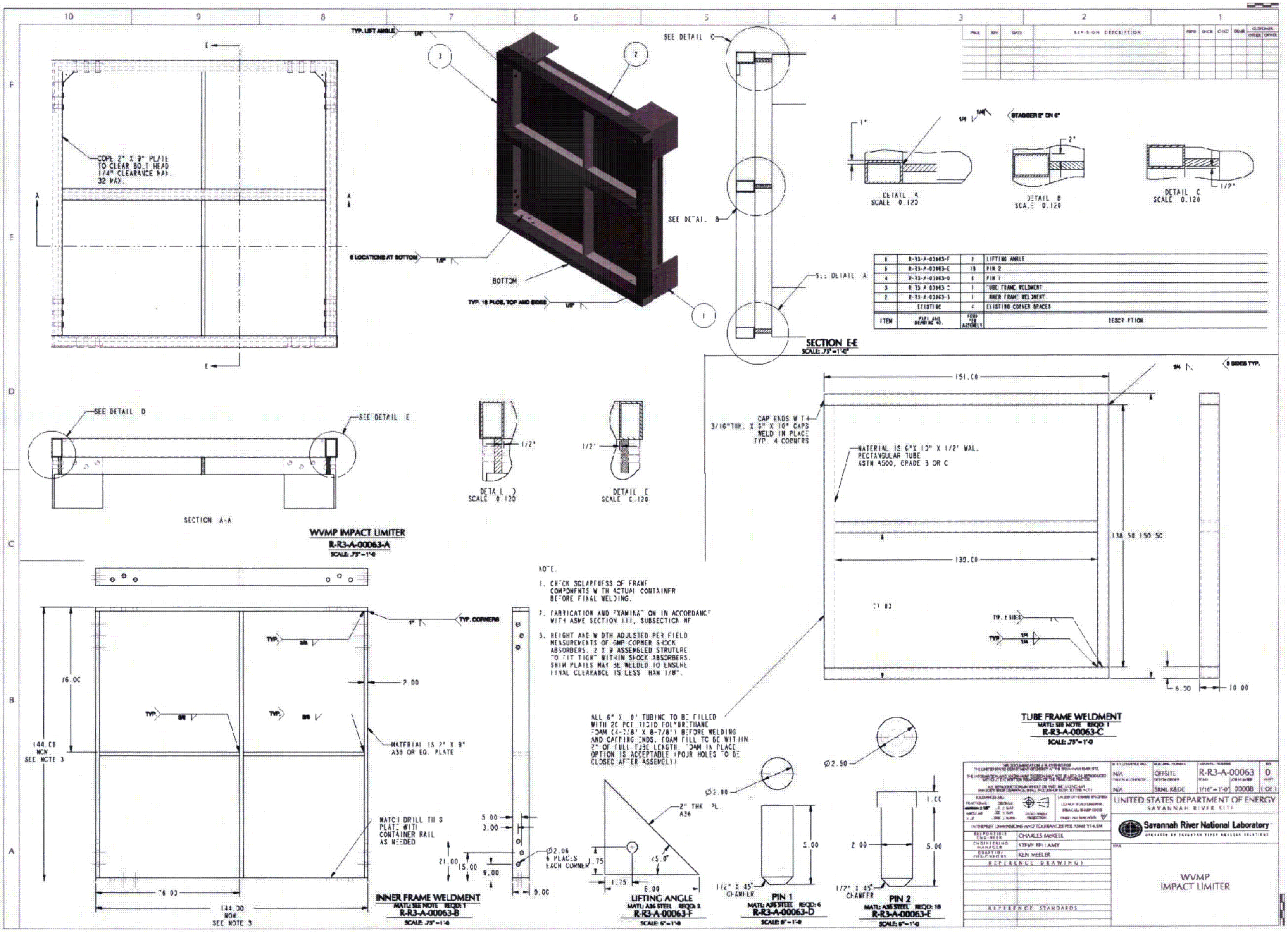
Drawing withheld under 10 CFR 2.390, *Public Inspections, Exemptions, Requests for Withholding*

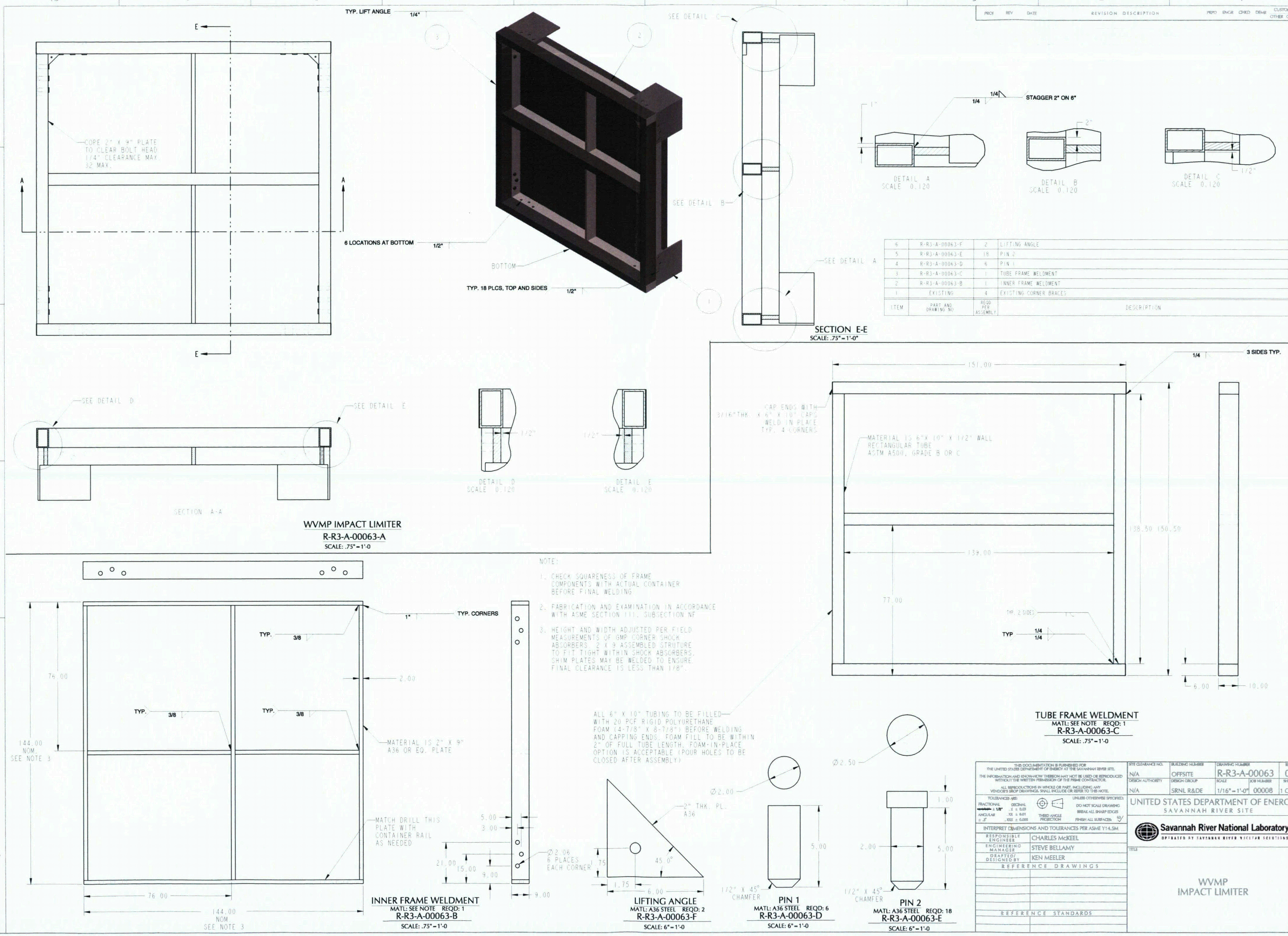
All dimensions apply to reference temp. of 68° F. Tolerances on: Fractions ±1/16" Decimals .X ±0.1" .XX ±0.03" Angles ± 1° unless noted	WMG Inc. West Valley Melter Container			
Dwn. By [illegible] Date 6/26/13	SIZE B	FSCM NO.	DWG NO. 4005-DW-001	REV 7
Proprietary Information	SCALE NTS		SHEET 7 of 8	

Drawing withheld under 10 CFR 2.390, *Public Inspections, Exemptions, Requests for Withholding*

All dimensions apply to reference temp. of 68° F. Tolerances on: Fractions ±1/4" Decimals .X ±0.1" .XX ±0.03" Angles ± 1° unless noted	WMG Inc. West Valley Melter Container				
Dwn. By Date 6/26/15	SIZE B	FSCM NO.	DWG NO. 4005-DW-001		REV 7
Proprietary Information	SCALE NTS			SHEET 8 of 8	

APPENDIX 1.3.3 – ENGINEERING DRAWING FOR THE IMPACT LIMITER





ITEM	PART AND DRAWING NO	REQD PER ASSEMBLY	DESCRIPTION
6	R-R3-A-00063-F	2	LIFTING ANGLE
5	R-R3-A-00063-E	18	PIN 2
4	R-R3-A-00063-D	6	PIN 1
3	R-R3-A-00063-C	1	TUBE FRAME WELDMENT
2	R-R3-A-00063-B	1	INNER FRAME WELDMENT
1	EXISTING	4	EXISTING CORNER BRACES

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TOLERANCES ARE: FRACTIONAL ± 1/8"; DECIMAL .X ± 0.03, .XX ± 0.01, .XXX ± 0.005; ANGULAR ± .5°
THIRD ANGLE PROJECTION
UNLESS OTHERWISE SPECIFIED: DO NOT SCALE DRAWING; BREAK ALL SHARP EDGES; FINISH ALL SURFACES: 63
INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M

SITE CLEARANCE NO.	BUILDING NUMBER	DRAWING NUMBER		REV
N/A	OFFSITE	R-R3-A-00063		0
DESIGN AUTHORITY	DESIGN GROUP	SCALE	JOB NUMBER	SHEET
N/A	SRNL R&DE	1/16" = 1'-0"	00008	1 OF 1

RESPONSIBLE ENGINEER	CHARLES McKEEL
ENGINEERING MANAGER	STEVE BELLAMY
DRAFTED/ DESIGNED BY	KEN MEELER

REFERENCE DRAWINGS

REFERENCE STANDARDS

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TITLE
WVMP IMPACT LIMITER

The 1 drawing specifically referenced in the table of contents have been processed into ADAMS.

These drawings can be accessed within the ADAMS package or by performing a search on the Document/Report Number.

D01

APPENDIX 1.3.4 – CHBWV QUALITY ASSURANCE PROGRAM AND REGULATORY REQUIREMENTS MATRIX

10 CFR 71 Subpart H	CHBWV QA Program WVDP-111	Description
1 (71.103) Quality Assurance Organization	Part A: Management §1.0 and Part C: Assessment §9.0	Defines the responsibilities for the establishment and implementation of the CH2M Hill-B&W West Valley, LLC (CHBWV) Quality Assurance Program (QAP). The organizational structure and the assignment of responsibility shall be such that quality is achieved and maintained by those who are assigned responsibility for performing the work, and the quality achievement is verified by persons not directly responsible for performing the work.
2 (71.105) QA Program	Part A: Management §1.0 – 3.0	The CHBWV QAP is comprised of WVDP-111, "CHBWV Quality Assurance Program", company-wide implementing documents, work control procedures, training procedures and other CHBWV documents. The company-wide and functional area or project-specific procedures, and other policies, plans and documents that are directly credited as being the implementing procedures for the QAP requirements are listed within this table.
3 (71.107) Package Design Control	Part B: Performance §6.0 Part E: Control of Software	It is CHBWV policy to design items and systems using sound engineering/scientific principles and appropriate standards. Design work, including changes, is incorporated with applicable requirements and design basis. Design interfaces are identified and controlled. Procedures describe the requirements and responsibilities established to plan, control, and verify design activities, including design input, design output, configuration and design changes, documentation, and technical interfaces consistent with the graded approach. The software quality control procedures also define the requirements governing the development, acquisition, maintenance and use of computer software.
4 (71.109) Procurement Document Control	Part A: Management §4.0 and Part B: Performance §7.0	Establishes the process by which procurement documents and their changes contain technical, quality, and safety requirements relative to the scope, nature, importance, complexity and desired reliability of the procured items or services, and that those requirements are independently reviewed prior to issuing the documents.
5 (71.111) Instructions, Procedures and Drawings	Part A: Management §3.0 Part B: Performance §5.0	Activities that can affect the quality, safety, or the environment of CHBWV products and services are prescribed by and performed in accordance with documented, management-approved procedures, instructions, checklists, and design documents.
6 (71.113) Document Control	Part A: Management §4.0	A program is established and implemented to control the preparation, review, approval, issuance, use, and revision of documents that prescribe activities, specify requirements, or establish design. Examples of document to be controlled include drawings, data files, calculations, specifications, computer codes, purchase orders and related documents, vendor-supplied documents, procedures, work instructions and data sheets.
7 (71.115) Control of	Part A: Management §3.0 Part B: Performance §7.0-8.0	Describes the process that CHBWV has developed to ensure that potential suppliers are evaluated prior to contract award and at intervals during the course of the

APPENDIX 1.3.4 – CHBWV QUALITY ASSURANCE PROGRAM AND REGULATORY REQUIREMENTS MATRIX

10 CFR 71 *Subpart H*	CHBWV QA Program WVDP-111	Description
Purchased Items and Services Commercial Grade Item Dedication	Part F: Commercial Grade Item or Service Dedication	contract. Procedures provide for the inspection of items either during manufacture or when received onsite. The scope of work which accompanies the purchase requisition provides all the required specifications, documentation and criteria for acceptance.
8 (71.117) Identification and Control of Items	Part B: Performance §5.4 Implementation §5.4.2 – Identification and Control of Items §7.0, Procurement §7.3.3 – QA Responsibility §8.0, Inspection & Acceptance Testing §8.1 – Introduction	CHBWV has defined a process for the control and maintenance of M&TE, calibrated instruments and the required documentation. It is CHBWV policy to perform work under suitable conditions using approved instructions, procedures, or other appropriate means. Items are identified and controlled to ensure their proper use, and are maintained to prevent their damage, loss or deterioration. When specified, items shall be identified from the initial receipt and fabrication of items up to and including installation and use. When codes, standards, or specifications include specific identification or traceability requirements (such as identification or traceability of the item to applicable specification and grade of material; heat, batch, lot, part, or serial number; or specified inspection, test, or other records), implementing departmental procedures shall provide such identification and traceability control methods. Quality Assurance is responsible for verifying proper identification and traceability of received items and documentation. It is the policy of CHBWV that the status of inspection and test activities shall be identified on the items or in documents traceable to the item to ensure that required inspections and tests have been performed, and to assure that items which have not passed the required inspections and tests are not inadvertently installed, used, or operated.
9 (71.119) Control of Processes	Part A: Management §2.0 Part B: Performance §5.0	CHBWV identified those activities that must be controlled as special processes and shall be performed by qualified personnel using approved procedures, drawings, checklists, travelers, or other appropriate means to specify requirements (i.e. welding, brazing, soldering, nondestructive assay, etc.).
10 (71.121) Inspection	Part A: Management §2.0 Part B: Performance §8.0	Establishes the requirements and responsibilities for specifying, planning, performing, and documenting receipt inspection, independent assessments, surveillances and peer verification.

APPENDIX 1.3.4 – CHBWV QUALITY ASSURANCE PROGRAM AND REGULATORY REQUIREMENTS MATRIX

10 CFR 71 Subpart H	CHBWV QA Program WVDP-111	Description
11 (71.123) Test Control	Part B: Performance §5.0	CHBWV has established and implemented procedures to perform inspections and acceptance testing of engineered systems, components, or parts according to the intended use of the items as specified in approved design specifications.
12 (71.125) Control of Measuring & Test Equipment	Part B: Performance §5.0 and 8.0	Describes the program which is established and implemented to control the calibration, maintenance, and use of equipment used for data collection and process monitoring of work including environmental data collection activities.
13 (71.127) Packaging, Handling, Shipping and Storage	Part B: Performance §5.0	Defines the requirements and states the responsibilities for the handling, shipping, packaging, and storage of items to prevent damage, deterioration, or loss. Controlled storage requirements are identified for those items needing an added level of protection from environmental environments (i.e. moisture, heat, etc.)
14 (71.129) Inspection, Test and Operating Status	Part B: Performance §5.0 and 8.0	Establishes the measures used to mark, label or tag items to indicate the status of inspections and tests performed. Procedures provide for the identification of items to preclude use of items that are in need of inspection or calibration, etc.
15 (71.131) Control of non-conforming Items	Part A: Maintenance §3.0 Part B: Performance §8.0	It is the policy of CHBWV on items that do not conform to specified requirements be controlled to prevent inadvertent installation or use. Controls provide for identification, documentation, evaluation, segregation when practical, disposition of nonconforming items, and for notification to affected organizations. The implementation of these requirements is through written procedures.
16 (71.133) Corrective Action	Part A: Maintenance §3.0	Establishes significance, assigns responsibilities and authorities, defines requirements, and provides for proper identification, documentation, control, evaluation, and resolution of identified issues through the development and tracking of deficiencies or improvements.
17 (71.135) Quality Assurance Records	Part A: Maintenance §2.0, 4.0 Part B: Performance §5.0	CHBWV integrates the requirements of documents and records processes into implementing procedures for the timely preparation, issuance, control and revision of documents that specify requirements of prescribed processes or quality-affecting activities.
18 (71.137) Audits	Part A: Maintenance §2.0 Part C: Assessment §10.0	Establishes the method for scheduling, planning, performing, reporting, and closing Quality Assurance (QA) and other program or activity audits.

Assigning CHBWV Quality Levels

The CHBWV quality level system provides graded quality assurance application. This system assigns quality levels based upon increasing levels of quality as the severity of incidents of safety, health, and environmental impact increase. With activities clearly identified by quality level, existing CHBWV procedures and practices provide a mechanism and process for the graded application of quality assurance. The quality level system is used to assure that each system is designed, procured, fabricated, installed, and operated in accordance with the appropriate design and operational codes and standards.

The quality level system evolved over the years from the initial Safety Classification System which was evaluated to determine if the Quality Level program met the graded approach to quality assurance. It resulted in combining Service Classes into the Quality Level definitions, leaving a dual classification system: Safety Class and Quality Level. The new system emphasized up-front planning, involving engineers in key process steps; timely decision-making; and consideration of resources, priorities, and risk bases. Moreover, it allowed for a graded approach to implementation.

This "graded approach" allows the level of effort needed for the WVDP to satisfy the multitude of directives. It ensures that the highest level of effort will be provided for work that has the greatest impact on safety, health, and the environment.

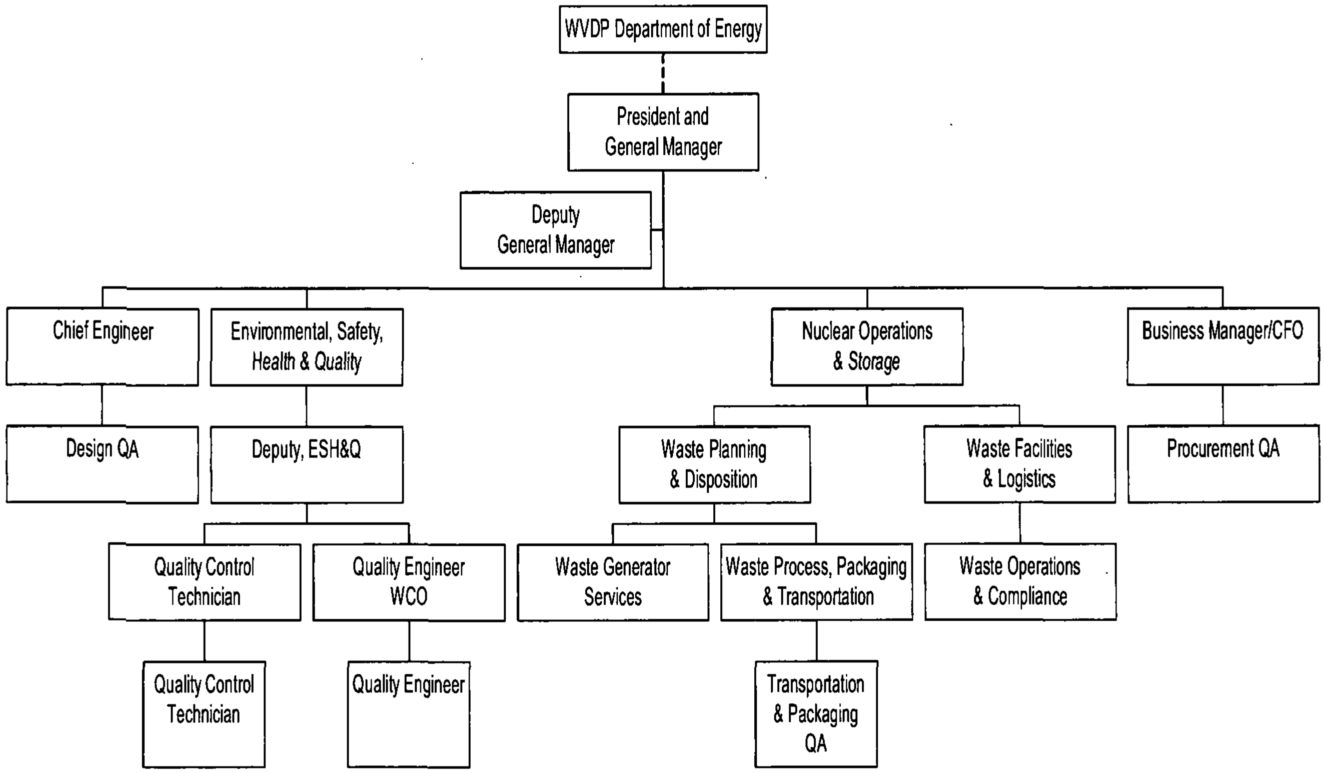
Comparison of NUREG/CR-6407 and CHBWV Classification Categories

NUREG/CR-6407 Safety Designation	Importance to Safety	CHBWV Safety Designation
A	Critical to safe operation	B
B	Major impact on safety	C
C	Minor impact on safety	N

Safety Assessment of Packaging Features

Package Components	Quality Level - NREG Type B (Normal Form)	NQA-1
Melter	B	B
LDCC	A	C
Side door	A	C
Bolts	A	C
Impact limiter	A	B
Container	A	C
Lifting lugs	B	B

CHBWV Organization Chart



The QA organization monitors the activities by performing QA surveillances on packaging and shipping activities, receipt inspections and shipping documentation review and approval. In addition, QA is responsible for reviewing and approving procedures and procurement documents.

The CHBWV Deputy ESH&Q/Quality Assurance Manager is responsible for ensuring the maintenance of the Quality Assurance Manual as well as for providing training and certification of QA personnel at CHBWV. Supplier evaluations, surveillances and audits are performed in accordance with approved procedures.

APPENDIX 1.3.5 – CODE REQUIREMENTS COMPARISON TABLES

Table 1. Material Requirements ASME/WVMP Compliance

ASME Sect. III, Div. 1, Subsection ND		WVMP Compliance
Section	**Requirements**	**Compliance Method**
ND-2121	Materials shall be restricted to those listed in Tables 1A, 1B and 3.	The WVMP is compliant. SA516-70 and SA-36 are listed in Table 1A and within the permitted thickness.
ND-2221	Coupon and specimen location shall be as required by the material specification. Note that the ASME/ASTM material specification (Sect. II Part A Specification SA 20/A 20M-89, Section 11.2 states; the longitudinal axis of the tension test specimens shall be transverse to the final rolling direction of the plate).	The WVMP is compliant. Per the Certified Material Test Reports (CMTRs), coupons were taken in accordance with ASTM A516.
ND-2128	Bolting material to be listed in Table 3.	The WVMP is compliant. ASTM 193-B7 is in Table 3.
ND-2130	Material CMTRs to be supplied.	The WVMP is compliant. CMTRs for SA-516, SA-36, and Bolts were supplied.
ND-2311	Pressure retaining material shall be impact tested, unless LST is set above Table ND-2311-1 values.	The WVMP is compliant. Table ND-2311-1 exempts impact testing for LST > -10 °F for SA-516-70 up to 2½ inches. Appendix 2.12.2 analysis justifies LST = 3°F for 6 inch thick.
ND-2410	All welding material used in construction and repair of components shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX.	The WVMP demonstrates equivalent safety. Lowest Service Temperature of 3°F and NQA-1 program for purchase QA of weld rods.

Table 2. Design Requirements ASME/WVMP Compliance

ASME Sect. III, Div. 1, Subsection ND		WVMP Compliance
Section	**Requirements**	**Compliance Method**
ND-3100	Loading and Design Criteria are specified.	The WVMP is compliant. The loads are per the CFR and consistent with ND-3100. Design Criteria are per ND-3100.
ND-3300	Design Requirements are specified.	The WVMP is compliant. Stress Limits used in Chapter 2 structural analysis are in compliance with RG 7.6 and consistent with ND-3300.
ND-3350	Weld Joint requirements: The walls of the rectangular GMP are fabricated of single slabs. The only structural welds are on the corner joints. ND-3350 is targeted to circular vessels constructed of pieced plates. The best match to the corner joint is ND-3350, Category D.	The WVMP is compliant. The corner joints feature partial groove welds on both inside and outside edges with reinforcing fillets on the inside. ND-3350 permits partial groove welds.

Table 3. Fabrication Requirements ASME/WWMP Compliance

ASME Sect. III, Div. 1, Subsection ND		WVMP Compliance
Section	**Requirements**	**Compliance Method**
ND-4100	Material control requirements are specified.	The WVMP is compliant. CMTRs were supplied and maintained on record for the structural components of the GMP.
ND-4200	Forming, fitting, and aligning requirements are specified.	The WVMP is compliant. These requirements are focused on circular vessels. There are no features of the GMP sensitive to tolerance or fit-up beyond those already controlled by material specifications and construction drawings. Weld joint requirements are already discussed in ND-3350.
ND-4300 and ND-4400	Welding Qualifications are specified.	The WVMP is compliant. AWS D1.1 welding was used and is consistent with ND-4300.
ND-4600	Preheat, interpass and post-weld heat treatment are specified.	The WVMP demonstrates Equivalent Safety. AWS D1.1 pre-qualified weld procedures were used and provide equivalent safety.

Table 4. Examination Requirements ASME/WVMP Compliance

ASME Sect. III, Div. 1, Subsection ND-5200		WVMP Compliance
Section	**Requirements**	**Compliance Method**
ND-5230	Radiography is not required when the weld joint is not a butt-weld.	The WVMP is compliant. All welded joints are liquid penetration and magnetic particle tested, per AWS D1.1 requirements,
ND-5280	Based on Storage Tanks to WVMP similarity. Bottom-to Sidewall, Roof to sidewall joints shall be examined visually. Alternatively, MT and PT may be substituted.	The WVMP is compliant. All welded joints are liquid penetration and magnetic particle tested, per AWS D1.1 requirements.
ND-5340 and ND-5350	Acceptance standards for MT and PT are specified.	The WVMP is compliant. Both ND and AWS D1.1 disallow any crack indications. AWS D1.1 Table 6.1 limit weld undersize, undercut and porosity to levels compliant with ND-5000

Table 5. Welding Requirements NUREG & AWS/West Valley Compliance

NUREG/CR-3019 – Containment Related Welds, Category II; ASME Section III, Sub. ND	Fabrication Code – AWS D1.1, 2004 Edition	WVMP Compliance Method
Base Materials – *ND-2000 (except ND-2300 and ND-4100)*	Base Materials – A36, A572 grade 50/60 (sub. A633 E/C), A516 grade 70 – Thickness (1/8" 1/2", 1", 2", 4" 6")	The WVMP demonstrates equivalent safety. Base materials approved by ASME and AWS, same SA (ASME specification designation) and ASTM specifications as applicable. Base materials prior to welding receive a visual examination based on AWS and an NDE (UT) in accordance with ASME Section III, Subsection NB. LST set to 3°F to exempt fracture toughness testing.
Welding Materials – *ND-2400* NUREG/CR-3019 and ASME Subsection ND require addressing fracture toughness. ASME Section III, Subsection ND requires filler material testing for tensile and chemistry.	Welding Materials Used – E71T-1 (spec. A5.20), ER70S-3 (spec. A5.18), E81T1-A1M (spec. A5.29), E7018 (spec. A5.1), and EA1 (spec. A5.23)	The WVMP demonstrates equivalent safety. Welding filler materials meet ASME SFA5.X specifications and AWS A5.X specifications. Storage and handling of welding materials are met.
Joint Preparation – *ND-4200* ASME Section III, Subsection ND specifies weld requirements based on weld type.	Weld Joint/Welds - Complete/partial joint penetration v-groove, fillet and plug welds.	The WVMP demonstrates equivalent safety. Weld joint preparation, groove type, weld type, and welding profiles used in the fabrication. The corner joints feature partial groove welds on both inside and outside edges with reinforcing fillets on the inside. ND-3350 permits partial groove welds.
Welding – *ND-4400*	Welding Processes – FCAW, GTAW, SMAW, and SAW	The WVMP is compliant.
Heat Treatment – *ND-4600*	AWS only requires heat treatment when specified contractually.	The WVMP demonstrates equivalent safety. Weld procedures and specifications used are prequalified for heat treatment if required.
Qualification Procedure/Personnel – *ND-4300*	Welding Procedure Specifications – Prequalified and qualified Welder Performance Qualifications – Performed in accordance with ASME Section IX	The WVMP is compliant.

2.0 STRUCTURAL EVALUATION

This chapter describes the structural evaluation of the West Valley Melter Package (WVMP) and how this exclusive use Type B package complies with the performance requirements of 10 CFR 71 (reference 2-1).

2.1 Description of Structural Design

2.1.1 Discussion

The WVMP consists of two components the Grouted Melter Package (GMP) and the Impact Limiter (IL), shown in Figure 2-1. The GMP consists of a 13'5" long by 12'4" wide by 12'4" high container which contains the vitrification melter with the volume between the two filled with Low Density Cellular Concrete (LDCC). The second component to the WVMP is the externally mounted IL. With the IL, the WVMP is 15'9" long 12'7" wide by 12'6.5" high, with a total weight of 390,800 lbs.

Key Terms and Acronyms in this Chapter	
FEA	Finite Element Analysis
GMP	Grouted Melter Package (consisting of the melter and LDCC inside the container)
HAC	Hypothetical Accident Conditions
IL	Impact Limiter
LDCC	Low Density Cellular Concrete
MNOP	Maximum Normal Operating Pressure
NCT	Normal Conditions of Transport
PBS	Polymeric Barrier System
RTV	Room Temperature Vulcanizing
WVMP	West Valley Melter Package (consisting of the GMP with the IL installed)

The Melter

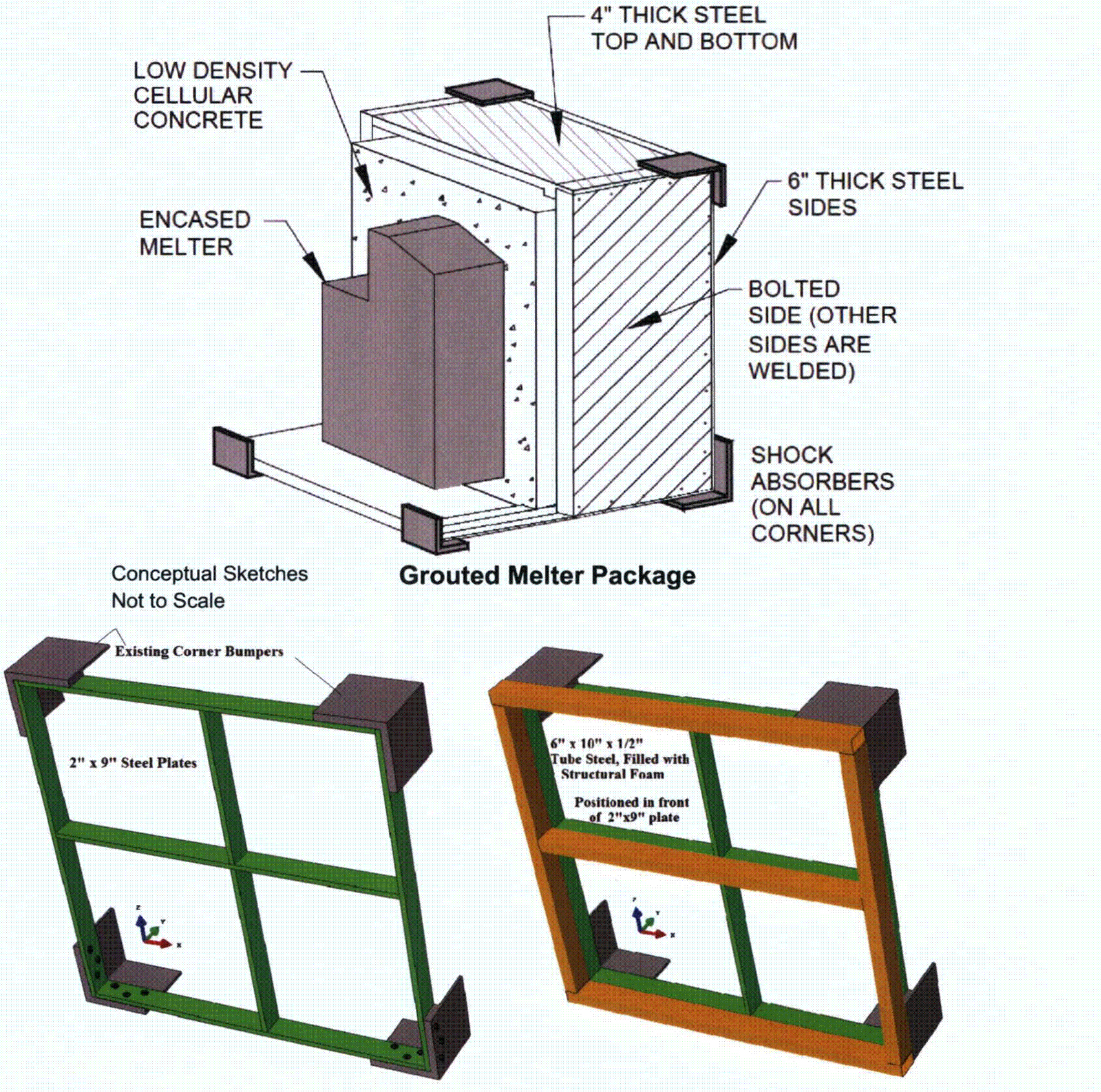
The melter is comprised of a stainless steel housing with an exterior structural steel frame all residing on a structural steel support beam structure. Part of the melter interior is fabricated with Inconel 690 to handle the high vitrification temperature and for abrasion resistance to the glass frit. The interior of the melter is lined with refractory materials. The dimensions of the melter envelope are 11'10" long by 10'9¾" wide by 10'5½" high. The melter was modified prior to placing it in the container. The modifications included:

- Heating electrodes were removed to reduced overall size, and
- All exterior surfaces of the melter equipment and its frame were coated with Bartlett's Polymeric Barrier System (PBS) contamination fixative.

Container

The outer structure in which the melter resides is a rectangular-shaped steel walled container with sacrificial shock absorbers welded to all eight corners. The material of construction is American Society of Mechanical Engineers (ASME) SA516 Grade 70 carbon steel plate for the 6" thick side walls, 4" thick top and bottom plates, 6" thick back plate, and the 6" thick bolted side door. The shock absorbers are 27" by 27" and are made of A36 carbon steel plate. The 27" length of the shock absorbers consists of 18" of 1" thick plate that overlaps the container and 9" of 3" plate that extends past the container. All plate-to-plate joints at corners of the container are groove welded on each side of the joint, with an additional fillet weld on the inside corner joints. The bolted side door was bolted in place after insertion of the payload, using 32, 1.5" diameter ASTM A193 B7

bolts, evenly spaced around the perimeter. The interstitial space between the melter and GMP was filled with LDCC to form a monolith that fits tightly and securely inside the GMP. The LDCC maintains positioning of the melter and absorbs shock loads to minimize structural demands on the melter. Figure 2-1 shows the GMP.



2" by 9" plates of IL (to secure wall) **6" by 10" Tube Steel of IL (for Crush)**

Figure 2-1. Components of the WVMP

Impact Limiter

The IL component is added to the bolted side door of the WVMP. The IL consists of a window frame-like structure of 2" by 9" structural plate (ASTM A36) that fits inside and is attached by welded pin connections to the 9" shock absorber extensions. This 2" by 9" plate prevents access to the front wall bolts and provides structural redundancy to the front wall bolts. The IL also includes

6" by 10" structural tube steel framework positioned in front of and welded to the 2" by 9" plates. The tube steel volume is filled with a rigid, closed-cell, 20 lb/ft^3 density polyurethane foam. The function of the rigid foam is to work with the structural tubing to cushion impacts that are prescribed in Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). The IL is shown in Figure 2-1. The engineering drawing appears in Appendix 1.3.3.

Table 2-1 lists the WVMP components and their function.

Table 2-1. WVMP Components and Structural Functions

Component		Function for NCT and HAC
IL	2" x 9" Plates	Provide structural support to aid in maintaining position of side door under free-drop conditions
	6" x 10" Tube Steel	Energy absorption in door-side down drops. Size and strength chosen to reduce impact G-loads to minimize LDCC crush
LDCC		Maintain the position of the melter within the container, absorb energy, and reduce the shock loads imposed on the melter
Container		Structural support to maintain LDCC configuration (confinement). Absorbs impact energy.

2.1.2 Design Criteria

Design criteria for the WVMP are derived from the following Regulatory documents:

- 10 CFR 71.41 through 71.51, and
- 49 CFR 173, *Shippers – General Requirements for Shipments and Packagings* (reference 2-2).

Design criteria for the WVMP are also consistent with the following Regulatory Guides (RGs):

- RG 7.6, *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels* (reference 2-3);
- RG 7.8, *Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material*, (reference 2-4); and
- RG 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)*, (reference 2-5).

Compliance of the WVMP with the design criteria is demonstrated by analysis.

Normal Conditions of Transport

The design criteria for the WVMP structural components are based on the criteria of RG 7.6. The allowable stresses under normal conditions are:

Primary membrane stresses, Pm < Sm

Primary membrane + bending stresses, Pm + Pb < 1.5 **Sm**

Where, ***Sm*** = Design stress intensity per ASME *Boiler and Pressure Vessel Code* (B&PVC, reference 2-6), II-D, Tables 2A and 2B.

For the ASME SA516 Grade 70 structural steel plates comprising the container, the normal conditions allowable stresses are:

Pm < Sm = 23,300 psi [Up to 200°F]

Pm + PB < 1.5Sm = 35,000 psi [Up to 200°F]

The 200°F condition bounds the NCT range of temperature established in Chapter 3. Per ASME II-D, Mandatory Appendix 2, the basis for the above criteria is the lesser of the following:

- One-third the specified minimum tensile strength at room temperature (70,000/3 = 23,300 psi for ASME SA516), or
- Two thirds the specified minimum yield strength at room temperature (2 × 38,000/3 = 25,300 psi for ASME SA516)

Sacrificial structures are shown to satisfy similar structural criteria in order to prevent excessive deformation (e.g., strain limits for foam), geometric instability (e.g., buckling), brittle fracture (including cold temperature conditions), and high temperature effects (annealing, softening, creep).

The WVMP performance under NCT and HAC loading conditions is evaluated at its actual weight. Consideration of minimum package or component size is not applicable.

HAC Criteria for GMP Container

HAC events are classified as a Level D Service Load. The structural criteria are per ASME B&PV Code, Section III, Appendix F-1341.23 (Plastic Analysis) and Appendix F-1331.1 (Elastic Analysis).

Primary membrane stresses, Pm < 0.7Su

Primary local , Pl < 0.9 **Su** (F 1341.23 plastic analysis)

< 150% Pm (F1341.23 elastic analysis)

Maximum Strains: Per ASME III-App F-1322.5, not to exceed material spec limits

Where, **Su** = Engineering Ultimate Strength of the material

For static HAC load events (e.g., internal/external pressure), elastic analysis was used with the following design criteria for the SA516-70 structure is (from -20°F to 800°F)

Pm < 0.7 × Su = 0.7 × 64,300 psi = 45,000 psi [Up to 800°F]

Pl < 1.5 × Pm = 1.5 × 45,000 psi = 67,500 psi [Up to 800°F]

For dynamic events (drops, puncture), plastic analysis was used, with the design criteria per ASME III Appendix F-1341.23. As derived in Appendix 2.12.2, the F 1342.23 criteria are implemented by imposing the following strain limits:

- 70% Stress Limits = 2.7% true strain, averaged through thickness, and over a general region.
- 90% Stress Limits = 11% true strain, averaged through thickness, and local.
- Maximum Strain Limit = 56% (to satisfy Appendix F-1322.5, accounts for multi-axial stresses. Value derived in Appendix 2.12.2 per ASME VIII-2 methods)

Bolting

The tensile and shear stresses in the 32 bolts attaching the bolted side door and the bolts for the five small circular plugs are evaluated (Appendix 2.12.2) during NCT and HAC analyses. The combined stress condition is compared to bolt yield and shear-out yield limits to establish bolt integrity. The 32 side door bolts had inadequate strength and number to survive all the HAC events, so the IL was added. The IL applies direct bearing stress onto the exterior surface of the door, eliminating the load path through the bolts; this makes the bolts redundant. The stress limits applied in this analysis are:

NCT Conditions: 2/3 Bolt Yield

HAC Conditions: MIN {Bolt Yield at Temperature, 70% Ultimate} (Drop condition, or HAC Fire)

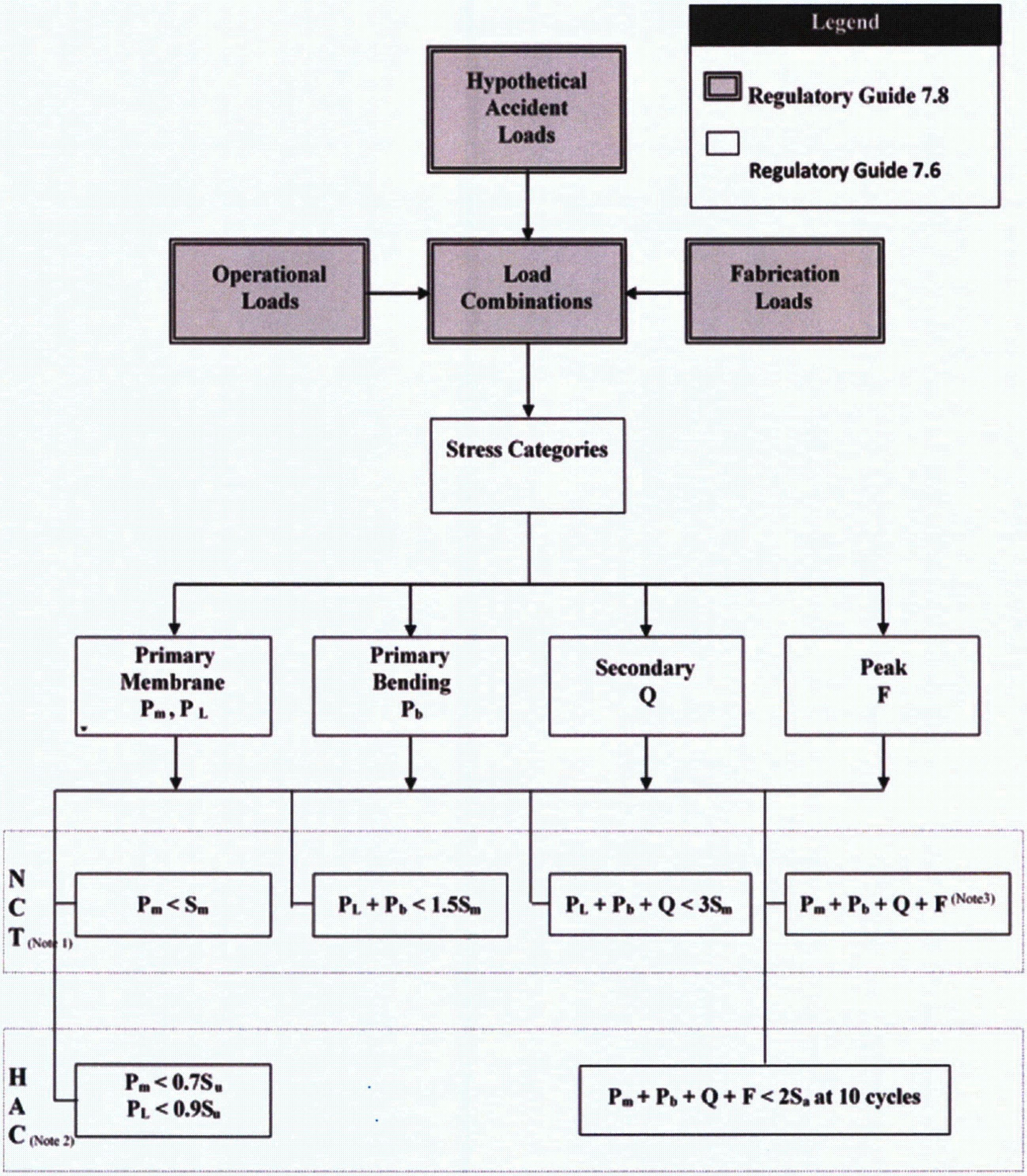
Positioning Devices and other Credited Components

The melter position within the container is maintained by the emplaced LDCC that fills the annular spaced between the melter and the container walls. The pressure loads on the LDCC during NCT and HAC are compared to the material's documented crush strength to assess LDCC damage.

Lifting and Tie-Down

Lifting devices are removed from the WVMP prior to shipment. The attachment points for these lugs are evaluated and demonstrated to be acceptable per 10 CFR 71.45 Tie-down components are evaluated to comply with 10 CFR 71.45. The acceptance criteria demonstrate no yielding would occur under the factored load conditions. Load factors are evaluated to meet 10 CFR 71 lifting requirements.

Figure 2-2 illustrates load combinations and stress intensity limits from RG 7.6 and RG 7.8 considered in the analyses.



Notes: (1) Level A Service Limits for Stress.
(2) Level D Service Limits for Stress, per B&PV Code, Section III, Appendix F, Article F-1341.2.
(3) The allowable stress intensity for the full range of fluctuations is 2 Sa per Figure NB-3222-1.

Figure 2-2. Load Combinations and Stress Intensity Limits from Regulatory Guides 7.6 and 7.8

2.1.3 Weights and Centers of Gravity

The weight basis for certification is shown below, based on summation of component weights tabulated in Appendix 2.12.2. Confirmation of the computed weights are presented in Appendix 2.12.2 by comparison to actual weights recorded during lifting and movement of components.

Container, With Shock Absorbers, Without Lift Lugs

Per drawing 4005-DW-001, sheet 2 of 8 (see Appendix 1.3.2), the container steel structure has a weight of 208,000 lbs. This includes the four lifting lugs (3,243 lbs total). The lugs are removed for the shipping configuration, resulting in a final weight of 208,000 lbs – 3,243 lbs = 204,757 lbs. This value is comparable with the more rigorously determined weight in Appendix 2.12.2 calculations of 204,864 lbs. This weight is located at the geometric center of the container.

Component Weight = 204,864 lbs

Melter

Per Appendix 2.12.2, the melter weight is 107,500 lbs.

LDCC

Per Appendix 2.12.2, a volume of 1,012 ft^3 was pumped into the structure. Per records, the average density was 69.9 lb/ft^3, corresponding to a weight of 1,012 ft^3 x 69.9 lb/ft^3 = 70,738 lbs

Component Weight = 70,738 lbs

Impact Limiter

Per Appendix 2.12.2, the added IL weight is 7,683 lbs.

Table 2-2 summarizes the component weights.

Table 2-2. WVMP Weight Summary

Component	Weight	Notes
Container	204,864 lbs	Geometrically centered
LDCC	70,738 lbs	4" below geometric center
Melter	107,500 lbs	8" below geometric center
IL	7,683 lbs	Located at one face
Total	**390,800 lbs**	Center of gravity (CG) shifts less than 3" from geometric center (down and toward the front) – See Figure 2-5

2.1.4 Identification of Codes and Standards for Package Design

The packaging design criteria are based on evaluation of the maximum radiological hazard (A_2 units) and curie (Ci) content for "normal form" radioactive material. The WVMP content form

and amount of radioactivity (normal form), the WVMP is categorized as a Type B, Category II package. Applicable codes and standards to be used for the design, fabrication, assembly, and testing of the WVMP are specified in Table 1.1 of NUREG/CR-3854, *Summary of Fabrication Criteria Based on the ASME Code* (reference 2-7).

The fabrication drawings and quality assurance (QA) information included with Chapter 1 detail specific sections of the ASME code that are applicable to the WVMP design.

Based on the content form and amount of radioactivity (normal form, radioactive contents between 30 A_2 and 3,000 A_2 and not greater than 30,000 Ci), the WVMP is categorized as a Type B, Category II package (reference 2-5). Based on the recommendations of NUREG/CR-3854, the fabrication, examination, and inspection of the containment boundary components of a Type II package should be per the ASME B&PV Code Section III, Subsection ND.

2.2 Materials

2.2.1 Material Properties and Specifications

Material specifications are identified in Table 2-3.

Table 2-3. Material Specifications for WVMP Construction

Component	Material Specification	Reference
Container plate and door	ASME SA516 Grade 70	Drawing 4005-DW-001[1]
Closure bolts for door	ASTM A193-B7	Drawing 4005-DW-001[1]
Shock absorbers	ASTM A36	Drawing 4005-DW-001[1]
LDCC	ASTM C869 ASTM C495 ASTM C172 ASTM C138 ASTM C150 ASTM C33	Melter Waste Package Grouting Implementation/QA Plan (Rev. 2, Oct 23, 2013)[2]
Melter lid	ASTM A240, Grade 304L	Drawing 900D-2786[3]
Internal melter components	Inconel 690	Drawing 900D-2786[3]
Melter Lower Section Water Jacket Inner Walls	ASTM A240, Grade 304L, Inconel 690	Drawing 900D-2783[3]
Melter Lower Section Water Jacket Outer Walls	ASTM A500 Grade B	Drawing 900D-2783[3]
Melter Base Frame Members	ASTM A36	Drawing 900D-2784[3]
2"x9" plates of IL	ASTM A36	Drawing R-R3-A-00063[4]
6"x10" Tube Steel of IL	ASTM A500 Grade B or C	Drawing R-R3-A-00063[4]
2" Pins of IL	ASTM A36	Drawing R-R3-A-00063[4]
Crushable Foam of IL	Commercial polyurethane foam, 20 pcf	Drawing R-R3-A-00063[4]

NOTES: (1) See Appendix 1.3.2.
(2) Reference 7-7 in Chapter 7 (provided).
(3) West Valley vitrification melter drawings.
(4) See Appendix 1.3.3.

SA516-Grade 70 (Container)

SA516-70 is the specification for pressure vessel plates, carbon steel, intended for moderate and lower temperature service. The plates were purchased and certified to the 2001 version of the ASTM specification. Since the plates are over 1.5" thickness, the specification requires the plates to be normalized. Per the certified material test reports (CMTR's) (reference 2-18), the plates were all normalized at 1,650°F, as required. The mechanical properties are obtained from the specification and from ASME B&PV Code, II-D.

E_{516} = Young's Modulus	= 28.3×10^6 psi		[Ref. II-D Table TM-1]
	= 27.3×10^6 psi @ 250°F		[Ref. II-D Table TM-1]
	= 27.0×10^6 psi @ 300°F		[Ref. II-D Table TM-1]
Density	= 0.284 pci		[Ref. 2-16]
Yield Stress =	Sy = 38,000 psi @ 70°F		[Ref. II-D Table Y-1 ...
	Sy = 35,700 psi @ 150°F		...page 544, Line 40]
	Sy = 34,800 psi @ 200°F		
	Sy = 31,000 psi @ 500°F	Sy = 27,200 psi @ 700°F	
	Sy = 29,100 psi @ 600°F	Sy = 24,700 psi @ 800°F	
Tensile Stress =	Su = 70,000 psi @ 70°F		[Ref. II-D Table U....
	Su = 70,000 psi @ 700°F		....page 464, line 29]
	Su = 69,100 psi @ 750°F		
	Su = 64,300 psi @ 800°F		
Elongation (2" Coupon) = 21%			[Ref 2-17, Table 2]
Expansion Coefficient	α = 8.5×10^{-6} °F^{-1} @ 70°F		
	α = 8.9×10^{-6} °F^{-1} @ 200°F		
	α = 9.2×10^{-6} °F^{-1} @ 300°F		[Ref. II-DTable TE-1]

Material CMTRs for the ASME SA516-70 steel slabs show an average yield above 42 ksi, tensile above 76 ksi, and elongation at 25 percent.

Bolted Side Door Closure Bolts - ASME SA-193 Grade B7

Size	heavy hex, 1 ½-6UNC2A, by 8" long	
E_{bolt} = Young's Modulus	= 29.×10^6 psi	[Ref. II-D Table TM-1
	= 28.5×10^6 psi @ 200°F	...Group A data]
	= 23.9×10^6 psi @ 800°F	
Min. Yield Stress = Sy.b	= 105,000 psi @ 70°F	[Ref. II-D Table Y-1
	= 98,000 psi @ 200°F	... page 560, Line 21]
	= 88,500 psi @ 500°F	

Min. Tensile Stress = Su.b	= 125,000 psi	@ 70°F	[Ref. II-D Table U
	= 125,000 psi	@ 600°F	... page 470, Line 34]
	= 119,600 psi	@ 700°F	
Expansion Coefficient	$\alpha = 6.4\times10^{-6}$ °F^{-1}	@ 70°F	[Ref. II-D Table TE-1
	$\alpha = 6.8\times10^{-6}$ F^{-1}	@ 250°F	...Mat Grp 1]
	$\alpha = 7.8\times10^{-6}$ F^{-1}	@ 350°F	
Spec Minimum Elongation	= 16% elongation		[Ref. 2-8]
Minimum Reduction in Area	= 50%		[Ref. 2-8]

CMTR's (reference 2-18) show bolts are 140 ksi yield, 152 ksi tensile, 16% elongation.

Closure Bolts on 5 plugged openings - ASME SA-574

Size Socket Head Cap Screws, 5/16-18UNC3A, by 2.75" long and 3.75" long

E_{SH_bolt} = Young's Modulus	= $29.\times10^{6}$ psi		[Ref. II-D Table TM-1
	= 28.5×10^{6} psi	@ 200°F	...Group A data]
	= 27.0×10^{6} psi	@ 500°F	
	= 23.9×10^{6} psi	@ 800°F	
Min. Yield Stress = Sy.b	= 140,500 psi	@ 70°F	[Ref. II-D Table Y-1]
	= 104,600 psi	@ 800°F	
Min. Tensile Stress = Su.b	= 180,000 psi	@ 70°F	[Ref. II-D Table U]
	= 155,000 psi	@ 800°F	
Expansion Coefficient	$\alpha = 6.4\times10^{-6}$ °F^{-1}	@ 70°F	[Ref. II-D Table TE-1
	$\alpha = 6.8\times10^{-6}$ F^{-1}	@ 250°F	...Mat Grp 1]
	$\alpha = 7.8\times10^{-6}$ F^{-1}	@ 350°F	
Spec Minimum Elongation	= 10% elongation		[See App 2.12.2]
Minimum Reduction in Area	= 30%		[See App 2.12.2]

Impact Limiter Tube Steel

See Appendix 2.12.2 for source material for material properties.

Specification	ASTM SA-500 Grade B or C
E_{tube} =	Young's Modulus = 29.4×10^{6} psi
Density	$\rho = 0.284$ pci
Yield Stress =	Sy = 46,000 psi @ 70°F
Tensile Stress =	Su = 58,000 psi @ 70°F
Elongation (2" coupon)	= 21%
Expansion Coefficient	$\alpha = 8.5\times10^{-6}$ °F^{-1} @ 70°F

ASTM A36 Steel in Shock Absorbers, Retaining Pins, and 2"x9" Plates in IL

See Appendix 2.12.2 for source material for material properties.

Specification	ASTM A36	
E36 =	Young's Modulus	= 29.4×106 psi
Density	ρ = 0.284 pci	
Yield Stress =	Sy = 36,000 psi @ 70°F	
Tensile Stress =	Su = 58,000 psi @ 70°F	
Elongation (2" Coupon)	= 20%	
Expansion Coefficient	α = 8.5×10-6 °F-1 @ 70°F	

CMTR's (reference 2-18) show A36 plates at 42 ksi yield, 75 ksi tensile, 25% elongation.

Low Density Cellular Concrete

The void space between the melter and the container is filled with LDCC. The LDCC consists of Portland cement (per ASTM C150) mixed with foaming agents (in accordance with ASTM C869) to create the cellular structure. The concrete sand structure is per ASTM C33. This LDCC was developed by GeoScience Groups to a 28-day, target strength of 1,000 psi specification with target density of 70 lb/ft^3. The LDCC was poured in late 2013. Six samples were taken from each of the seven pours. The strength and density records from these tests are documented in Appendix 2.12.2. From these data, a lower-bound strength of the actual LDCC was determined and used in the analysis. The relation between this lower-bound used and the average strength recorded from the test cylinder exceeds the statistical requirements from ACI-349, thus the value used in the analysis is a valid lower bound value.

Lower bound 28 day strength = 1,203 psi [Analysis used 1,200 psi]

Average density for all LDCC poured = 69.9 lb/ft^3

LDCC, like any concrete will continue to strengthen with time, depending on available moisture. Per ACI-308, strength increases can be significant (25% increase) after 365 days. This effect is not credited in the analysis.

Energy Absorbing Foam-Fill of Impact Limiter

The 6" by 10" tube steel members of the IL are filled with rigid polyurethane foam. The basic strength and variability with static and dynamic crush distance is developed in Appendix 2.12.2. The data are summarized in Table 2-4 and shown graphically in Figure 2-3.

Table 2-4. Mechanical Properties of Foam

Temp = 10°F			Temp = 75°F			Temp = 125°F		
E_{elas_mod} = 41,800 psi			E_{elas_mod} = 34,800 psi			E_{elas_mod} = 27,000 psi		
Eng. Strain	True Plastic Strain	Stress (psi)	Eng. Strain	True Plastic Strain	Stress (psi)	Eng Strain	True Plastic Strain	Stress (psi)
5.8%	0	2462.	5.7%	0	1983.	5.6%	0.0	1504.
10%	0.046	2462.	10%	0.048	1983.	10%	0.050	1504.
20%	0.167	2338.	20%	0.168	1905.	20%	0.169	1474.
30%	0.299	2391.	30%	0.300	1964.	30%	0.299	1543.
40%	0.448	2624.	40%	0.449	2140.	40%	0.447	1721.
50%	0.620	3042.	50%	0.621	2528.	50%	0.619	2014.
60%	0.822	3948.	60%	0.821	3323.	60%	0.817	2685.
65%	0.954	4003.	65%	0.951	3443.	65%	0.947	2777.
70%	1.079	5204.	70%	1.070	4684.	70%	1.059	3923.
Coefficient of Linear Thermal Expansion (in/in/°F)				3.5-5.0 10^{-5} (-320ºF to 200ºF)				
Density (Free Rise) (lb/ft³)				20				

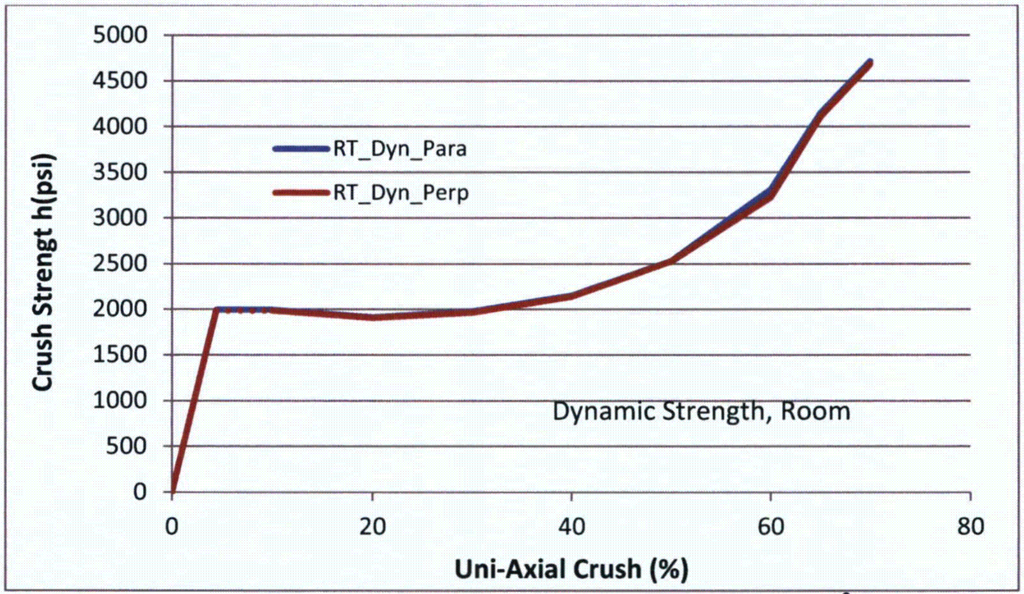


Figure 2-3. – Dynamic Engineering Stress-Strain Curve for 20 lb/ft³ Polyurethane Foam, Room Temperature

2.2.2 Chemical, Galvanic, or Other Reactions

Requirement: 10 CFR 71.43(d) – "A package must be made of materials and construction that assure that there will be no significant chemical, galvanic, or other reaction among the packaging components, among package contents, or between the packaging components and the package contents, including possible reaction resulting from in-leakage of water, to the maximum credible extent. Account must be taken of the behavior of materials under irradiation."

Evaluation: The materials from which the WVMP is fabricated (carbon steel, LDCC, polyurethane foam) and the contents (stainless steel, Inconel, glass, refractory brick) will not have significant chemical, galvanic, or other reactions in air or water atmospheres. The foam insulation is chemically inert and carries no detectable chlorides. The closed-cell nature of the foam precludes water absorption.

2.2.3 Effects of Radiation on Materials

Requirement: 10 CFR 71.43(d) – "A package must be made of materials and construction that assure that there will be no significant chemical, galvanic, or other reaction among the packaging components, among package contents, or between the packaging components and the package contents, including possible reaction resulting from in-leakage of water, to the maximum credible extent. Account must be taken of the behavior of materials under irradiation."

Evaluation: For the steel structure and bolting, no degradation or activation of the carbon steel structural components is expected at the neutron and photon dose rates as calculated in Chapter 5.

Polyurethane foam will be used inside the 6" by 10" tube steel. Radiation dose experiments were performed at the University of Michigan on the General Plastics Manufacturing Company polyurethane foam and no effect was found on the compressive strength and intumescent properties from radiation doses of 2×10^7, 4.21×10^7 and 2×10^8 rads (reference 2-9).

2.3 Fabrication and Examination

The WVMP is constructed in accordance with the design drawings provided in Appendix 1.3.2 and Quality Assurance requirements of Chapter 1.

2.3.1 Fabrication

For a Type B, Category II package, NUREG/CR-3854 recommends using ASME B&PV Code, Section III, Subsection ND, as the fabrication criteria. The WVMP container was fabricated in accordance with American Welding Society (AWS) Structural Code D1.1 (reference 2-10). Per Chapter 8, the combination of the AWS D1.1 fabrication requirements and the additional requirements imposed during construction (material certifications, heat treatments, and normalizations) are equivalent to the ASME III-ND fabrication requirements. The fabrication for the IL construction is per ASME Code, Section III, Subsection NF, in accordance with NUREG/CR-3854, Table 4-1.

2.3.2 Examination

For a Type-B, Category II package, NUREG/CR-3854 recommends using ASME B&PV Code, Section III, Subsection ND, as the examination criteria. Examinations performed during fabrication of the GMP were accordance with AWS D1.1. Per Chapter 8, the combination of the AWS D1.1 examination requirements and the additional requirements imposed during constructions (material certifications, heat treatments, and normalizations) are equivalent to the ASME III-ND examination requirements. The examination for the IL construction is per ASME Code, Section III, Subsection NF, in accordance with NUREG/CR-3854, Table 4-1.

2.4 General Requirements for All Packages

10 CFR 71.43(a) through (c) and (e) through (h) establish the general standards for packages. This section identifies these standards and provides the basis to demonstrate compliance.

2.4.1 Minimum Package Size

Requirement: 10 CFR 71.43(a) – "The smallest overall dimension of a package shall not be less than 10 cm (4")."

Evaluation: The smallest overall dimension of the WVMP is 12' 6.5", which exceeds the 4" minimum. Therefore, the minimum package size requirement is satisfied.

2.4.2 Tamper-Indicating Feature

Requirement: 10 CFR 71.43(b) – "The outside of the package must incorporate a feature, such as a seal, that is not readily breakable and that, while intact, would be evident that the package has not been opened by unauthorized persons."

Evaluation: The outside of the WVMP is a welded structure consisting of 4" thick and 6" thick steel walls. The walls have five penetrations of 4.5" diameter, stepped to 6.5" diameter for the outer half of the plate thickness. After grouting, inspections and final closure, a matched stepped, circular plug is then secured with three recessed socket head cap screws, resulting in a flush continuous surface. Tamper indicating device tape is placed over each. The 2" by 9" plates of the IL are pinned and welded to the container integral corner shock absorbers and these plates block access to the side door bolts. Attempts to defeat the closure devices would require mechanical destruction of structural components. Therefore, the requirement of the tamper-indicating feature is satisfied.

2.4.3 Positive Closure

Requirement: 10 CFR 71.43(c) – "Each package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by a pressure that may arise within the package."

Evaluation: The container consists of five steel slabs fully welded together, with the sixth being a bolted side door for the container. The closure joint consists of a 4" wide gasketed (1/4" neoprene) face seal around the wall surface edges. The side walls also feature a step-design that allows the bolted side door to be inset into this step, so that a perimeter seal is formed between the 6" thick edge of the wall panel and the step feature on the side walls. This region is filled with RTV to create a seal. The 2" face of the IL's 2" by 9" plates are then welded over this wall panel joint to provide the positive closure. Per the evaluation in Appendix 2.12.2, the container is capable of sustaining worst case combinations of Maximum Normal Operating Pressure (MNOP) and reduced/increased external pressure as well as the HAC fire event. The demands on this seal joint are also evaluated during NCT and HAC drop impacts, to demonstrate closure performance (See Figure 2-3).

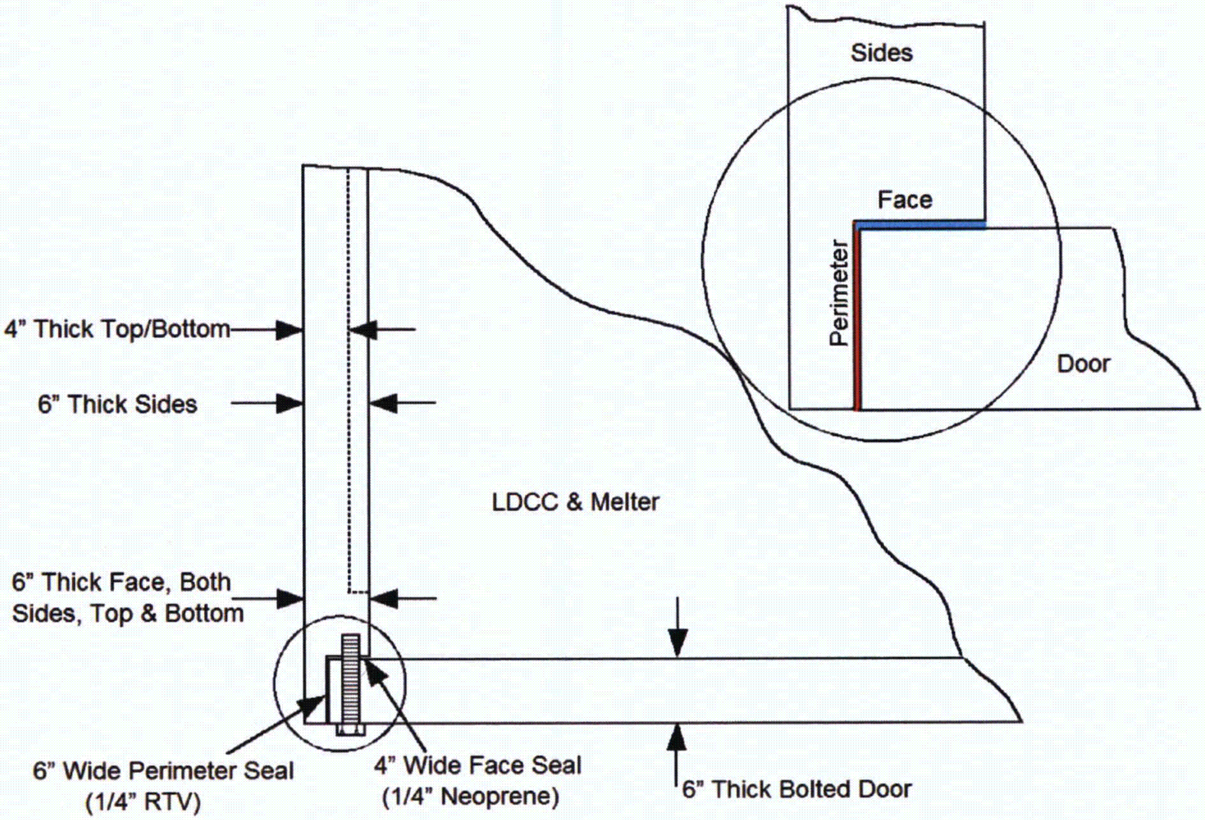


Figure 2-4. Schematic Showing Location and Naming Convention for Bolted Side Door Seal Closure

2.4.4 Package Valving

Requirement: 10 CFR 71.43(e) – "A package valve or other device, the failure of which would allow radioactive contents to escape, must be protected against unauthorized operation and, except for a pressure relief device, must be provided with an enclosure to retain any leakage."

Evaluation: The WVMP does not contain valves or other pressure relief devices. All containment penetrations made during fabrication have been closed. Therefore, the requirements of 10 CFR 71.43(e) have been satisfied.

2.4.5 Packaging Effectiveness

Requirement: 10 CFR 71.43(f) – "A package must be designed, constructed, and prepared for shipment so that under the tests specified in § 71.71 (*Normal Conditions of Transport*) there would be no loss or dispersal of radioactive contents, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging."

Evaluation: The WVMP is designed and shown through structural evaluation that under the NCT specified in 10 CFR 71.71 there is no release of radioactive contents, no significant increase in external surface radiation levels, and hence, no significant reduction in the effectiveness of the

packaging. Structural evaluation of NCT includes thermal effects, pressure effects, vibration and shock, water spray in-leakage, drop impacts, stacking compression, and penetration impact.

2.4.6 Transportation Use (Surface Temperature)

Requirement: 10 CFR 71.43(g) – "A package must be designed, constructed, and prepared for transport so that in still air at 38°C (100°F) and in the shade, no accessible surface of a package would have a temperature exceeding 50°C (122°F) in a nonexclusive use shipment, or 85°C (185°F) in an exclusive use shipment."

Evaluation: The WVMP is an exclusive use shipment, such that the 10 CFR 71.43(g) requirement is applicable, with a limit of 185°F. The Chapter 3 thermal analysis shows that the maximum temperature of the package under the 10 CFR 71.43(g) conditions is less than 110°F.

2.4.7 Continuous Package Venting

Requirement: 10 CFR 71.43(h) – "A package may not incorporate a feature intended to allow continuous venting during transport."

Evaluation: The WVMP does not incorporate any feature intended to allow continuous venting during transport.

2.5 Lifting and Tie-down Standards for All Packages

2.5.1 Lifting Devices

Requirement: 10 CFR 71.45(a) – "Any lifting attachment that is a structural part of a package must be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner, and it must be designed so that failure of any lifting device under excessive load would not impair the ability of the package to meet other requirements of this subpart. Any other structural part of the package that could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport, or must be designed with strength equivalent to that required for lifting attachments."

Evaluation: The lifting device for the WVMP is not a structural element of the package and will be removed before transport. Therefore, the design of the lifting lugs was not evaluated in the application for package approval. The lug attachment location on the WVMP is evaluated in the tie-down section below and shown capable of sustaining more than 3 times the WVMP weight. Therefore, the criteria of 10 CFR 71.45 are met.

2.5.2 Tie-Down Devices

Requirement: 10 CFR 71.45(b)(1) – "If there is a system of tie-down devices that is a structural part of the package, the system must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the

package with its contents, and a horizontal component in the transverse direction of five times the weight of the package with its contents."

10 CFR 71.45(b)(2) – "Any other structural part of the package that could be used to tie down the package must be capable of being rendered inoperable for tying down the package during transport, or must be designed with strength equivalent to that required for tie-down devices."

10 CFR 71.45(b)(3) – "Each tie-down device that is a structural part of a package must be designed so that failure of the device under excessive load would not impair the ability of the package to meet other requirements of this part."

Evaluation:

Restraint Loads

There are no tie-down devices that are an integral part of the package. There are structural aspects of the WVMP that could serve as tie-down attachments points. There are four weld-on plates located at the top of the GMP side walls (See Figure 2-5) that could serve as tie-down points for overturning stability. The extended plates of the eight corner shock absorbers could also be used to restrain overturning. The required forces at these locations are determined below, as if acting independently. The restraint forces are determined by moment equilibrium about the front lower corner. The 10G load case, with 2G upward is selected for calculation. Refer to Figure 2-5 for dimensions.

Using Upper Restraint Location	Using Lower Restraint Locations
Motm = 10G x 73" + 1G x 179"/2	Motm = 10G x 73" + 1G x 179"/2
= 819.5xG	= 819.5xG
Mres = 2xR2h x (sqrt(137^2+140^2)	Mres = 2xR2v x (179"- 5")
=392xR2h	=348xR2v
Motm = Mres⇒ 392xR2h =819.5xG	Motm = Mres⇒ 348xR2v =819.5xG
R2h = 2.1G = 2.1x390,800 lbs	R2v = 2.35G = 2.35x390,800 lbs
R2h = 821,000 lbs	R2v = 920,000 lbs

Requirements (1) & (2) for Upper Restraint Location

The upper wall of the WVMP features four 1" thick plate, 21" tall and 20.75" wide, welded to the 6" thick container wall with 1/2" fillet weld, all around (Appendix 1.3.2). There is also a central cutout in the center of this plate (9.25" by 15.25"). This inner edge is welded to the container wall, using a 1" fillet weld. The plate has eight threaded holes. The intent of the threaded holes is to secure a lift lug plate or tie-down plate that has intimate contact with the square edged perimeter of the welded on plate, thus loading the plate in shear.

Weld Strength = 0.3 x 70,000 psi = 21,000 psi (E70 electrodes on carbon steel, Reference 2-16)

Weld Area: Outer Welds: (20.75" + 2 x 21") x ½ fillet x 0.707 = 22 in^2
Inner Welds: 2x (9.25"+15.25") x 1" fillet x 0.707 = 34 in^2
Total Shear Load Capacity = 21,000 psi x (22 in^2 + 34 in^2) = 1.18E6 lbs

Demand: R2h = 821,000 lbs

The demand is less than capacity, therefore, the CFR requirement is met.

Requirements (1) and (2) for Lower Restraint Location

The corner shock absorbers of the container extend outward from the main structure, and could be used as a tie-down location, using an external structure that presses onto the surface of this extension, or presses onto the 2" by 9" plate of the IL, which then presses down onto the shock absorber surface. The 2" by 9" plate helps distribute the load, thus is beneficial, such that a bounding calculation need only consider the integrity of the shock absorber. The shock absorbers are evaluated for bending and shear loads from the required reaction for to resists the 10 CFR 71.45 loads.

Cross-Sectional Area = 3" x (24" + 27") = 153 in^2

Cross-Section Centroid: $x_{cg} = \dfrac{3"\cdot 27"\cdot 1.5"+3"\cdot 24"\cdot(3"+24"/2)}{153 in^2} = 7.85 in$

Mom of Inertia:

$$I = 3"\cdot 27"\cdot(7.85"-1.5")^2 + \frac{1}{12}\cdot 3"\cdot 24"^3 + 3"\cdot 24"\cdot(3"+24/2-7.85)^2 = 10{,}403 in^4$$

Section Modulus: I/(27in-7.85in) = 543in^3

Weld Area = The 3" extension has 1" groove weld on inside surface, 1" continuous Plate on the outside surface, Thus A_weld = 2/3 x 153 in^2 = A_weld = 102 in^2

Section Bending: Consider for acting the full 9" distance
Moment = R2v x 9" = 920,000 lbs x 9" = 8,280,000 in-lbs
Bending Stress = Moment/Section Mod = 8,280,000 in-lbs/543 in^3 = 15,250 psi

Shear Stress:

$$\text{Shear Stress} = \tau_{shr} = \frac{R2v}{A\_weld} = \frac{920{,}000 lb}{102 in^2} = 9{,}020 psi$$

Combined, Effective Mises Stress (w/ simplifying basis that component stresses are orthogonal):

$$\sigma_{eff} = \frac{\sigma_b}{2} + \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau_{shr}^2} = \frac{15{,}250}{2} + \sqrt{\left(\frac{15{,}250}{2}\right)^2 + 9{,}020^2} = 19{,}500 psi$$

The above stress for the factored load condition is only 54% of the A36 plate yield strength. There is sufficient reserve to address the 5G lateral load as well.

Requirement (3)

The upper plate is located at the upper edge, such that the loads would be transferred into the in-plane directions of the top plate or side wall. Therefore, simple area comparison confirms that the small 1" plate attached with ½" fillet welds and 1" fillet welds, when excessively loaded, would fail prior to the 6" and 4" thick steel walls of the WVMP. The HAC drop analysis demonstrates the shock absorbers can be excessively loaded (full plastic moment) without compromising the structure portion of the container walls. Therefore, the requirements of 10 CFR 71.45(b)(3) are met.

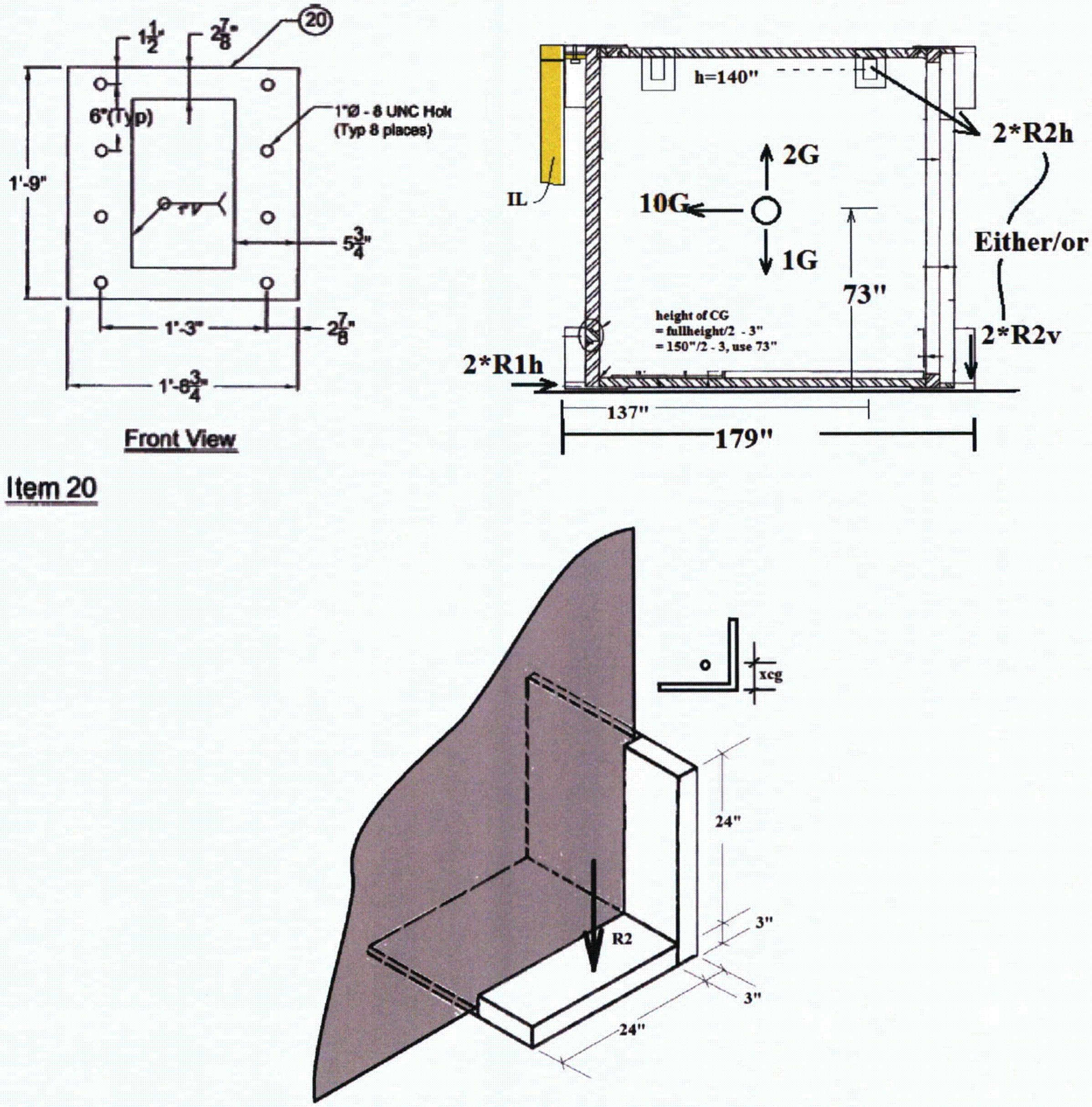


Figure 2-5. Sketches for Tie-Down Assessment

2.6 Normal Conditions of Transport

This section demonstrates that the WVMP is in compliance with the performance requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1), (b) and (c) so that, when prepared for transport, under the test conditions specified in 10 CFR 71.71 *Normal Conditions of Transport (NCT)*, there is no loss or dispersal of radioactive contents (as demonstrated to a sensitivity of $10^{-6}A_2$ per hr), no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging.

A summary of the NCT analyses performed that demonstrate the WVMP meets 10 CFR 71 is provided in the following sections.

2.6.1 Heat

Requirement: 10 CFR 71.71(c)(1) – "Exposure to an ambient temperature of 100°F in still air, and insolation according to Table 2-5."

Table 2-5. Insolation Data

Form and location of surface		Total Insolation for a 12-hour period (g cal/cm^2)
Flat surfaces transported horizontally;		
	Base	None
	Other Surfaces	800
Flat surfaces not transported horizontally		200
Curved surfaces		400

Evaluation: The WVMP is analyzed for the 100°F environment with and without solar insolation (See Chapter 3). The internal heat load of 9.21 watts is also included in the analysis. The MNOP is established based on the resulting WVMP cavity temperatures.

2.6.1.1 Summary of Pressures and Temperatures

The WVMP MNOP and component temperatures under NCT are determined in Chapter 3 and summarized below.

NCT Maximum Normal Operating Pressure 12 psig [Ref. Ch 3, Table 3-3]

<u>NCT Temperature with Solar</u>

Container walls:	= 209°F max, occurs in extremes of corners	[Ref Ch 3, Figure 3-7]
	= 200°F through wall average	
	= 10°F, max through wall gradient	
LDCC:	= 183°F max, only at extreme top surface	[Ref Ch 3, Figure 3-7]
	= < 150°F average temperature	
Melter:	= 145°F	[Ref Ch 3, Table 3-5]

<u>NCT Temperature without Solar, in 100°F Conditions</u>

The thermal analysis shows the maximum temperature increase anywhere in the WVMP is 5°F above the ambient condition (100°F).

2.6.1.2 Differential Thermal Expansion

The only significant temperature changes occur under the solar insolation condition. In this condition, the container sees the greatest temperature rise. Since this is the outermost component of the WVMP, its bulk thermal expansion is not a stress increase. The only significant stress occurs due to the relatively high temperature increase in the container top plate, which heats to an effective average of 200°F, whereas the upper portions of the side walls are only 160°F. Stresses from this differential expansion are shown in the next subsection.

2.6.1.3 Stress Calculations

<u>Pressure Stresses</u>

Appendix 2.12.2 computes the stress in the WVMP container walls from the combined MNOP and worst case reduced/increased external pressure. The resulting pressure demand (12 psi + 11.2 psi = 23.2 psi) was shown to result in a 5,000 psi stress on the container top plate (4" thick).

<u>Thermal Stresses</u>

Considering the plate to act as a beam with ends fixed by the side walls, the maximum thermal stress developed as the thermal expansion ($\alpha \Delta TL$) is converted into strain ($\varepsilon = \alpha \Delta TL / L$) and then into stress, given by the equation below:

$$\sigma = E\alpha\Delta T = (29.0e6psi) * 8.5e-6 * (200-160^{\circ}F) = 9{,}900psi$$

<u>Combined</u>

Stresses from pressure loadings and thermal loads were computed in Appendix 2.12.2 resulting in the following values:

Pm = insignificant, the flat plate resists pressure load via bending	
Pm + Pb = 5,000 psi	[Ref App 2.12.2]
Sm = 9,900 psi	[Section 2.6.1.3]
Pm + Pb + Sm = 14,900 psi	

<u>Closure Bolt Stress</u>

Pressure load on side door	= 12 psi × 144" × 144" = ~250,000 lbs
Number of bolts	= N = 32
Load per bolt:	= Total/N = 7,813 lb
Load Capacity for Bolt	= Appendix 2.12.2, Accounting for thread shear, tensile failure, etc.
2/3 of the yield Load	= 2/3 × 136,700 lbs = 91,100 lbs

2.6.1.4 Comparison with Allowable Stresses

Allowable stresses are based on the 200°F through wall average temperature. The allowable stresses are derived in Appendix 2.12.2 and summarized below for the ASME SA516-70 steel structure:

$P_m \leq S_m = 23{,}200 psi$

$P_{m+b} \leq 150\% P_{m=} = 34{,}800 psi$

$P_L \leq 150\% P_{m=}$

Secondary (includes thermal) < 3Sm = 69,600 psi

The comparison is shown in Table 2-6.

Table 2-6. Comparison of Stresses with Allowables, NCT Condition

	ASME Designation	Stress	Allowable	Comparison Stress/Allowable
Primary Membrane	P_m	~	23,200 psi	~
Primary Membrane + Bending	$P_L + P_b$	5,000 psi	34,800 psi	14%
Secondary	S_{m+b}	9,900 psi	~	~
Primary plus Secondary	$P_{L+b} + S_{m+b}$	14,900 psi	69,600 psi	21%
Bolts	~	Load = 7,813 lbs	91,100 lbs	8.5%

2.6.2 Cold

Requirement: 10 CFR 71.71(c)(2) *Cold* – "An ambient temperature of -40°C (-40°F) in still air and shade."

Evaluation: Per Appendix 2.12.2, the minimum temperature in which the package can be transported has been set to a minimum of 3°F lowest service temperature (LST).

LST = 3°F

The determination of the above is documented in section 5.3 of Appendix 2.12.2, and is based on the guidance in NUREG/CR-1815, *Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick* (reference 2-11) and NUREG/CR-3826, *Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Greater than Four Inches Thick* (reference 2-12), and the rules of ASME VIII-2 and API-579, *Fitness-for-Service* (reference 2-13). Although ASTM SA516-70 is intended for moderate and low temperature applications, the 3°F LST is set to protect from low temperature embrittlement.

Other components in the WVMP include the type 304L austenitic stainless steel and Inconel 690 within the melter. As stated in RG 7.11, stainless steel is effective at low temperatures, particularly regarding impact strength, making it a proper selection for -40°F applications. The structural properties of items like the LDCC do not vary significantly for the temperature range of the WVMP.

2.6.3 Reduced External Pressure

Requirement: 10 CFR 71.71(c)(3) *Reduced external pressure* – "An external pressure of 25 kPa (3.5 lbf/in^2) absolute."

Evaluation: The reduced external pressure condition is equivalent to an increase in internal pressure. The reduced external pressure load was evaluated in Appendix 2.12.2. The resulting pressure effect was already added to the MNOP analysis presented subsection 2.6.1.1.

2.6.4 Increased External Pressure

Requirement: 10 CFR 71.71(c)(4) *Increased external pressure* – "An external pressure of 140 kPa (20 lbf/in^2) absolute."

Evaluation: The increased external pressure condition was evaluated in Appendix 2.12.2. This pressure condition was shown to be bounded by the combined MNOP and reduced external pressure condition. The resulting pressure effect was already added to the MNOP analysis presented subsection 2.6.1.1.

An increased external pressure will have no adverse effect on the ability of the packaging to satisfy the requirements of NCT.

2.6.5 Vibration

Requirement: 10 CFR 71.71(c)(5) – "Vibration normally incident to transportation."

Evaluation: An analysis of random vibrations reported in Appendix 2.12.2 demonstrates that vibration and shock loadings are small and would not cause any fatigue concerns or bolt loosening during normal transport (Appendix 2.12.2).

Based on the Appendix 2.12.2 analysis, vibration normally incident to transportation will have no adverse effect on the ability of the packaging to satisfy the requirements of NCT.

2.6.6 Water Spray

Requirement: "The package design is evaluated for the effects of water spray of approximately 2in/hour for at least one hour as required by 10 CFR 71.71(c)(6)."

Evaluation: The package exterior is constructed of steel with no openings and water spray would have no effect.

2.6.7 Free Drop

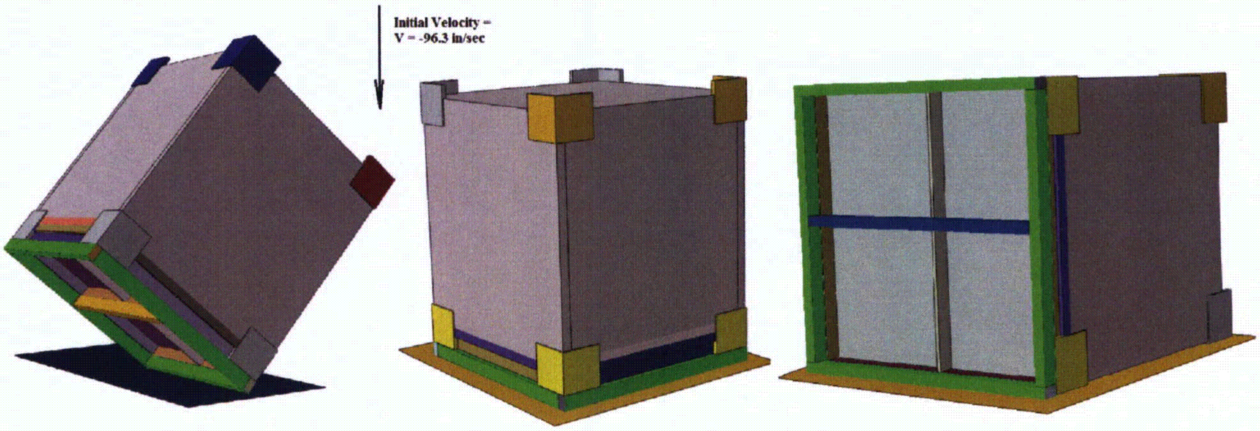
Requirement: 10 CFR 71.71(c)(7) – *Free drop.* "Between 1.5 and 2.5 hours after the conclusion of the water spray test, a free drop through the distance of 1' (for packages weighing more than 11,000 lbs) onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected."

Evaluation: The WVMP is evaluated for the 1' free drop by analytical simulations using the ABAQUS/Explicit dynamics computer code. Three drop orientations were simulated for NCT, as well as tip-over and slap-down. These are:

- CG over edge (expected to maximize IL deformation),
- Bolted side door down (to challenge the IL's protection of the bolted side door), and
- Bottom down (reflective of most probable NCT drop).

  (Left or right side down drop, which is structurally same as bottom down)

Figure 2-6 shows these drop orientations.



CG over Edge — Bolted Side Door Down — Bottom Down

Figure 2-6. Drop Orientations Evaluated in NCT

The analysis and results are documented in Appendix 2.12.2 with a summary of bounding drops presented below in Table 2-7.

Table 2-7. Results for NCT Drop Analysis

Position	G-Level	Limiter Deformation	LDCC Damage	Door Bolts	Door Seal Status
CG over edge	5.0 G	Minor denting on lowermost tube steel	< 0.005%	D/A = 50% (note 1)	Maintained
Bolted side door down	49 G	Insignificant	0.06%	D/A = 96%	Maintained
Bottom down	76 G	None	0.05%	D/A at 100% D/C = 73%	Maintained

Note: (1) D/A = Demand/Allowable, D/C = Demand to Capacity

The analysis shows that the bolted side door closure seal remains intact and undisturbed, the closure bolts do not fail, and the LDCC damage is inconsequential (0.06%). The IL is shown to eliminate any concerns associated with the bolted side door during NCT. With the IL, the most

demanding drops on the LDCC are orientations targeting the non-limiter sides, such as bottom drops, or side wall drops. Even in these bounding cases, the LDCC damage is inconsequential. Figure 2-7 shows the finite element analysis (FEA) simulation results from the CG over front corner, which represented the most damage to the IL. As shown, the damage level is low, such that its performance in subsequent HAC would be unaffected.

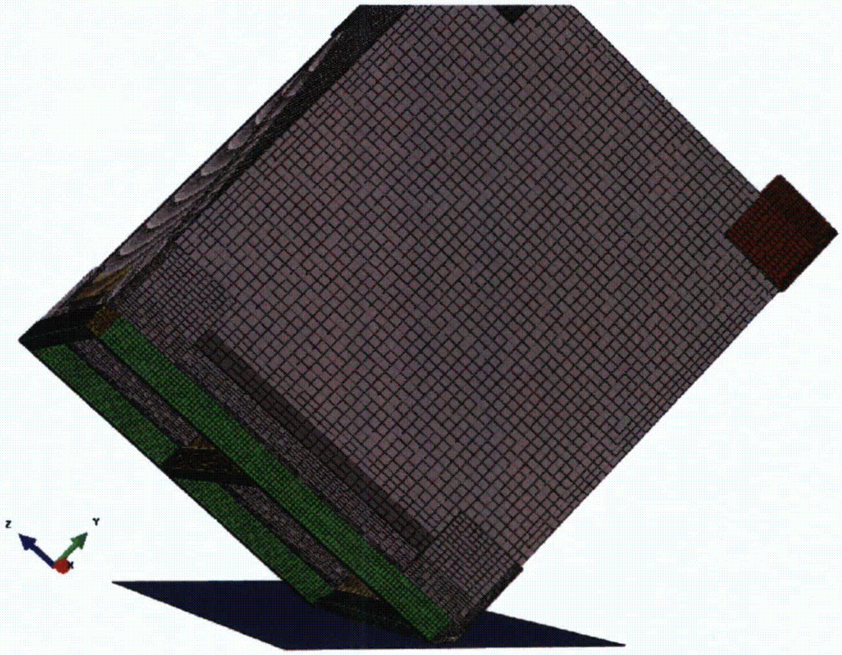


Figure 2-7. Deformed Shapes of WVMP from NCT 1 foot Drop, CG over Front Corner

2.6.8 Corner Drop

Requirement*:* 10 CFR 71.71(c)(8) – *Corner Drop*. "A free drop onto each corner of the package in succession, or in the case of a cylindrical package onto each quarter of each rim, from a height of 0.3 m (1') onto a flat, essentially unyielding, horizontal surface. This test applies only to fiberboard, wood, or fissile material rectangular packages not exceeding 50 kg (110 lbs) and fiberboard, wood, or fissile material cylindrical packages not exceeding 100 kg (220 lbs)."

Evaluation: The requirement is not applicable, since the WVMP is a rectangular package exceeding 50 kg and is not a fiberboard, wood, or fissile material cylindrical package.

2.6.9 Compression

Requirement: 10 CFR 71.71(c)(9) – *Compression*. "For packages weighing up to 5,000 kg (11,000 lbs), the package must be subjected, for a period of 24 hours, to a compressive load applied uniformly to the top and bottom of the package in the position in which the package would normally be transported. The compressive load must be the greater of the following:

(i) The equivalent of 5 times the weight of the package; or

(ii) The equivalent of 13 kPa (2 lbf/in^2) multiplied by the vertically projected area of the package."

Evaluation: The requirement is not applicable, since the WVMP weight of 390,800 lbs exceeds the 11,000 lb criterion.

2.6.10 Penetration

Requirement: 10 CFR 71.71(c)(10) – *Penetration*. "Impact of the hemispherical end of a vertical steel cylinder of 3.2 cm (1.25") diameter and 6 kg (13 lbs) mass, dropped from a height of 1 m (40") onto the exposed surface of the package that is expected to be most vulnerable to puncture. The long axis of the cylinder must be perpendicular to the package surface."

Evaluation: The WVMP would be unaffected by this threat and is bounded by the successful puncture analysis.

2.7 Hypothetical Accident Conditions

This section demonstrates that the WVMP satisfies the performance requirements of 10 CFR 71.51(a)(2) when subjected to the HAC as defined in 10 CFR 71.73. Compliance is demonstrated by analysis, as allowed by 10CFR 71.41(a) and Regulatory Guide 7.6. The HAC include:

(1) Free drop - a free drop of 30 feet onto a flat, essentially unyielding surface,

(2) Crush – not applicable,

(3) Puncture - a free drop through a distance of 40", striking a bar 6" in diameter,

(4) Thermal - exposure to an environment of 1475°F for 30 minutes,

(5) Immersion (fissile material) – not applicable, and

(6) Immersion (all) - immersion in water of an undamaged package to a minimum depth of 50 feet for at least 8 hours.

2.7.1 Free Drop

Requirement: 10 CFR 71.73 (c)(7) – *Free Drop*. "A free drop of the specimen through a distance of 9 m (30') onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected."

Evaluation: Compliance is demonstrated through dynamic FEA as described in the following sections. A total of seven package orientations were evaluated and documented in the Appendix 2.12.2 calculations. The seven orientations were each chosen to maximize demands on different components (e.g., WVMP structure, vs. LDCC, vs. IL). The worst case drop orientation was the CG over side edge (Figure 2-8).

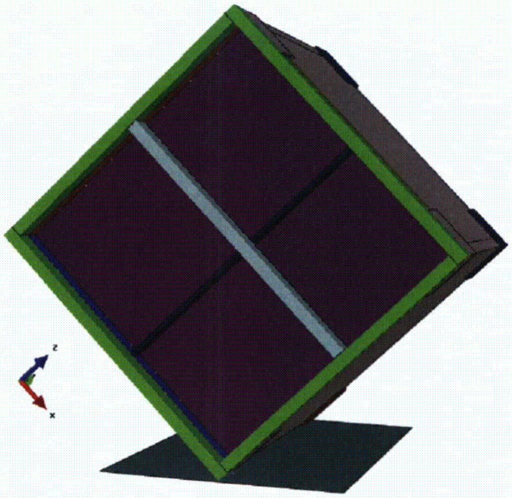


Figure 2.8. HAC Condition, 30 foot Drop, CG over Side Edge

The HAC drops are severe enough to fail the closure bolts in nearly all cases. The exceptions are for orientations that have the bolted side door tilted either upward, downward, or normal to the impact surface (side drops). The results produced the following general trends:

- The WVMP survives the HAC drops without appreciable deformation or material strains. The most localized damage to the container walls occurred in the CG over corner, where the corner experienced high compression. The most general deformation occurred in the CG over side edge, where the impact causes pressure loads on the two adjacent walls, thus bending in the corner joint. The maximum strains of 10% were within the material and weld-joint capacity.
- The closure bolts fail in most drops, exceptions being impacts onto flat sides.
- An inverse relation was shown between LDCC crush and door seal deformation. The high G impact drops that damaged the largest percentage of LDCC came from side-down impacts and back-side down impacts. These drop scenarios were associated with lower demands on the bolted side door seal joint. Orientations that challenged the bolted side door seal were the front corner drops (on edge or corner). These drops were associated with minimal LDCC damage, as the IL was effective in reducing the impact G-level.

For the 30 foot drops that resulted in bolted side door seal displacements, the maximum LDCC crush was 30%. The side drops produced 35% LDCC crush, but no displacement of the face seal. The displacements of the face seal and perimeter seal joints were tracked throughout the seven HAC drops, before, during and after, to demonstrate the integrity of the joint in each case (See Appendix 2.12.2). The results of the HAC drop simulations are summarized in the following sections.

2.7.1.1 End Drop

The end drop simulated was with the bolted side door oriented down. With the IL in place, the bolted side door seal sees very little to no tensile demands. The inertial pressures of the contents are transferred directly to the 2" by 9" plate, which is cushioned by the foam filled tube steel.

Impact G-Level = 97.5 G

Deformation of WVMP: insignificant

Maximum Strains in WVMP container walls <10%

Condition of bolts: most fail, but due to shear from wall bending, not bolt tension

LDCC damage = 5.5%

Bolted side door seal displacements: face seal = 0.18"
perimeter seal = 0.10"

2.7.1.2 Side Drop

The side drops represented the highest G-load, highest LDCC crush, but the smallest bolted side door seal displacement. The 6" walls of the container are able to resist the high G loads, and there was no significant displacement of the bolted side door face seal joint. The lower most plate of the container does bend in a transient manner at impact (the one inch thick shock absorbers elevate the center region of the WVMP above the impacted surface). This bending does result in a small displacement of the perimeter seal. However, the face seal is not impacted.

Impact G-level = 546 G

Deformation of WVMP: insignificant

Maximum strains in WVMP walls < 10%

Condition of bolts: only a few fail

LDCC damage = 35%

Bolted side door seal displacements: Face Seal = ~0"
Perimeter Seal = 0.33" (only on the bottom side – see Appendix 2.12.2)

2.7.1.3 Corner Drop

The corner drop of interest was the drop onto one of the corners at the bolted side door joint. The eight shock absorbers were specifically designed to limit the impact damage in this drop condition. The effectiveness is shown in the Appendix 2.12.2 results, where the impact G-level was held to a relatively low 53 G. This drop also resulted in a low fraction of LDCC damage, at 11%. Complete results are shown in Appendix 2.12.2, and a summary is shown below:

Impact G-Level = 53 G

Deformation of WVMP: Some failure of the lowermost shock absorber, slight compression of the container corner, limited to the 2" thick face seal extension surrounding the bolted side door.

Maximum strains in WVMP Walls: <30%

Condition of bolts: Nearly all bolts fail

LDCC damage = 11%

Bolted side door seal displacements: face seal = 1.5"
perimeter seal = 3.2"

2.7.1.4 Oblique Drop

Several oblique drops were investigated, as shown below. These orientations all involved positioning the CG over one of the edges. The goal was to maximize demand on the bolted side door closure and the LDCC.

- CG over side edge,
- Inverted with top side down, CG over top front edge,
- CG over back edge, and
- CG over front bottom edge

The most damaging impact orientation is with the CG over a side edge. This impact caused the largest displacements at the seal joints coupled with higher levels of LDCC crush.

Impact G-Level = 47G to 137G

Deformation of WVMP: Essentially zero for drops over front or back edges, where the shock absorbers and front IL are effective. In the CG over side edge impact, the two sides that meet the impacted edge will have a transient deflection.

Maximum strains in WVMP walls: 31% localized, <11% general bending, both within allowable

Condition of bolts: Nearly all bolts fail.

LDCC damage = 7% to 10% for front back edges, 21% for top down any edge, 30% for side edge

Bolted side door seal displacements:	face seal	= 1.2"
	perimeter seal	= 5.8"

2.7.1.5 Summary of Results

The results of the various analyses of free drop test may be summarized as follow:

- End drop: Insignificant deformation of WVMP, most bolts fail due to wall bending, 5.5% LDCC damage, minor face and perimeter seal displacement;
- Side drop: Insignificant deformation of WVMP, a few bolts fail, 35% LDCC damage, no face seal displacement, and minor perimeter seal displacement;
- Corner drop: Minor damage to lowermost shock absorber and slight compression of container corner, nearly all bolts fail, 11% LDCC damage, minor face and perimeter seal displacement; and
- Oblique drop: In limiting orientation (CG over side edge), maximum strain in WVMP walls of 31% (localized) and <11% general bending, nearly all bolts fail, up to 30% LDCC damage, and minor face and perimeter seal displacement.

The analyses show the WVMP meets the requirements.

2.7.2 Crush

Requirement: 10 CFR 71.73(c)(2) – *Crush*. "Subjection of the specimen to a dynamic crush test by positioning the specimen on a flat, essentially unyielding horizontal surface so as to suffer maximum damage by the drop of a 1,100-lb mass from 30' onto the specimen. The mass must consist of a solid mild steel plate 40" square and must fall in a horizontal attitude. The crush test is required only when the specimen has a mass not greater than 1,100 lb, an overall density not greater than 62.4 lb/ft^3 based on external dimension, and radioactive contents greater than 1000 A_2 not as special form radioactive material. For packages containing fissile material, the radioactive contents greater than 1000 A_2 criterion does not apply."

Evaluation: The 10 CFR 71.73(c)(2) crush test is not applicable to the WVMP, which exceeds the 1,100 lb limit, has an overall density greater than 62.4 lb/ft^3, and radioactive content less than 1,000 A_2.

2.7.3 Puncture

Requirement: 10 CFR 71.73(c)(3) – *Puncture*. "A free drop of the specimen through a distance of 40" in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 6" in diameter, with the top horizontal and its edge rounded to a radius of not more than 0.25" and of a length as to cause maximum damage to the package, but not less than 8" long. The long axis of the bar must be vertical."

Evaluation: The WVMP is evaluated for puncture by combination of explicit FEA and supporting engineering calculations in order to demonstrate that sequential HAC puncture test will not adversely affect the performance of the package before being subjected to thermal testing.

Three bounding puncture locations are assessed:

1. Puncture bar targeting near the bottom front edge of the container, to maximize damage at the bolted side door joint.
2. Puncture bar targeting the IL, to attempt to shear off the IL. After the HAC 30 foot drops, the IL is the only creditable structure maintaining position of the bolted side door.
3. Puncture bar targeting the center region of the container bottom.

Figure 2-9 shows these puncture locations.

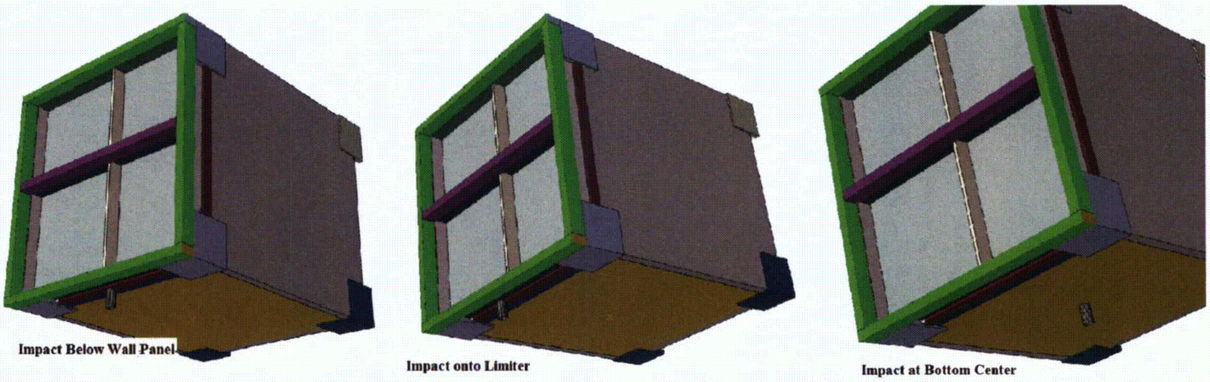


Figure 2-9. Puncture Analysis Orientations

General Assessment

In the puncture tests, a mild steel bar of 6" diameter is specified. The bar length must not be less than 8". Relative to the 390,800 lbs WVMP with 4" and 6" thick walls, it can be shown that the mild steel bar does not have sufficient strength or size to challenge the WVMP.

Mild steel bars range in yields strengths from 20 ksi (for example ASTM A1008) to 50 ksi (for example ASTM A500 Grade C), with the more common ASTM A36 having an intermediate value. The ultimate strength for mild steel has less variance, with ASTM specification minimums being 58 ksi to 80 ksi for structural steels (A36, A500, A1008, for example). For an upper bound, ASTM A36 imposes an upper strength limit of 80 ksi. Therefore, the maximum stiffness and force that can be imposed during the puncture is that of the shortest length bar (8" for the 10 CFR 71.73 requirement) with the highest material strength:

$$K = \frac{EA}{L} = \frac{29E6\,psi \cdot (\pi/4) * (6in)^2}{8inch} = 103{,}000{,}000 in - lb$$

$$F_{\max} = \sigma_{flow} * A = 80{,}000\,psi * (\pi/4) * (6in)^2 = 2.3E6lbs$$

With the maximum impact force being limited to around 2.3 E+6 lbs, the maximum G-level of the WVMP during the puncture tests is limited to:

$$G_{\max} = {}^{F_{\max}}\!/_{Wgt} = {}^{2.3E6lbs}\!/_{390{,}800lbs} = 5.9G$$

By comparison, the HAC 30 foot drop simulations showed that the WVMP could sustain G-levels ranging from 50 G to 550 G, without significant damage to the WVMP container. The NCT 1' drops showed impact G levels in the 5 G range resulting in essentially no structural damage and no LDCC crush.

WVMP Plate Steel Puncture (Shear) vs WVMP Plate Bending vs. Puncture Bar Crush

If the WVMP wall thickness is sufficient to preclude penetration, then the structural response is limited to either bending (and compression) of the WVMP walls or plastic collapse of the puncture bar.

The Nelm's Equation (reference 2-14) predicts the required plate thickness (t_{req}) to prevent penetration from the puncture bar. The equation is based on the weight (Wgt) of the component dropped and the ultimate strength (S_u) of the steel.

$$t_{req} = \left(\frac{Wgt}{S_u} \right)^{0.7} = \left(\frac{390{,}800}{70{,}000} \right)^{0.7} = 3.33 inch$$

vs. 4" available thinnest plate of WVMP.

The above equation does not incorporate the relative strength of the bar, and is overly conservative for high weight packages and mild steel puncture bars. Even with that conservatism, the analysis still shows the 4" plate thickness is sufficient to preclude penetration or puncture by the bar. From a qualitative standpoint, the above comparison does not suggest that the penetration would be (3.33"/4") but that the 4" thickness is sufficient to preclude penetration. The subsequent FEA indicates zero penetration.

Puncture Strike to WVMP Bottom below Bolted Side Door

In this orientation, the impact is resisted by the in-plane strength of the container. Any door gaps existing from the prior 30' drops would have the tendency to be closed by the impact with the puncture bar. The three possible puncture responses are discussed below:

- WVMP shear: as shown, the 4" plate thickness is sufficient to preclude penetration,
- WVMP bending: with the bar targeting near the container, the high in-plane stiffness would preclude any bending response.
- Bar crush: Due to the sufficient shear and bending resistance, this scenario would resolve itself into crush of the puncture bar, and the WVMP would experience a less than 6 G impact. Based on comparison to the HAC drops, no additional damage would occur at this low impact level. This impact level is similar to the NCT events, which showed no damage. Therefore, this puncture impact would not result in damage that would alter its thermal performance. Since the WVMP response would be of near-zero deformation and extremely low G value, no additional LDCC damage would occur. Therefore, this puncture is not considered further.

Puncture Strike onto the Impact Limiter

The IL is external to the GMP and was not credited in the HAC fire thermal analysis. Penetration or perforation of a local region of the IL, which sequentially occurs after the drop and crush, is not of a structural concern. There are six 2" by 9" by approximately 12' long structural plate sections comprising the structural part of the IL. After the HAC drops, the puncture test could eliminate, at most, one of the six members. The remaining five members would still be nestled within the

container shock absorbers and provide the necessary displacement control on the bolted side door. Therefore, this puncture is not considered further.

Puncture Strike at Center of any Wall Panel

The two prior puncture target locations demonstrate targeting the container hard points or the IL will not challenge the structural steel integrity, impose additional damage to the LDCC, nor jeopardize its configuration for the pending thermal tests. The last remaining scenario is to target the center of a container wall, to impart a bending response to the plate steel. As demonstrated in the HAC drops, the LDCC is most vulnerable to loads that cause diaphragm bending of a wall panel, since the non-ductile LDCC cannot respond without damage.

Puncture Simulation Results

The analysis shows that the initial response to the puncture simulation is bending of the target wall surface. As the wall bends, it stiffens, not only due to its own response but due to compression of the adjacent LDCC. At time = 0.024 seconds into the impact, the WVMP deformation ceases to accumulate as the upper credibility strength of the 6" mild steel bar is surpassed. This is confirmed by comparing the deformed shape of the WVMP at time = 0.024 seconds (Figure 2-12) and at time = 0.06 second (Figure 2-13), both plots showing 4.2" of plate deformation. The energy history plot (Figure 2-10) shows less than 10G (matching the estimate on previous page), and also shows that the plastic dissipation of the LDCC has essentially reached a plateau at the 0.024 sec.

The maximum strains in the WVMP wall are shown in Figure 2-14, 10% in surface strain (vs. 56% allowed local, 11% allowed bending) and less than 2% membrane. The LDCC crush is insignificant (Figure 2-15), with less than 1% damaged, and in a region away from the bolted side door. Based on the structural characteristics of the WVMP container walls, the center strike is the most challenging to the LDCC, as punctures threats targeted toward the plate periphery would be reacted with a much stiffer plate, with little to no deformation.

Based on the FEA simulation and the supplemental discussion and analysis, it is shown that the WVMP meets the 10 CFR 71 requirements for HAC puncture resistance.

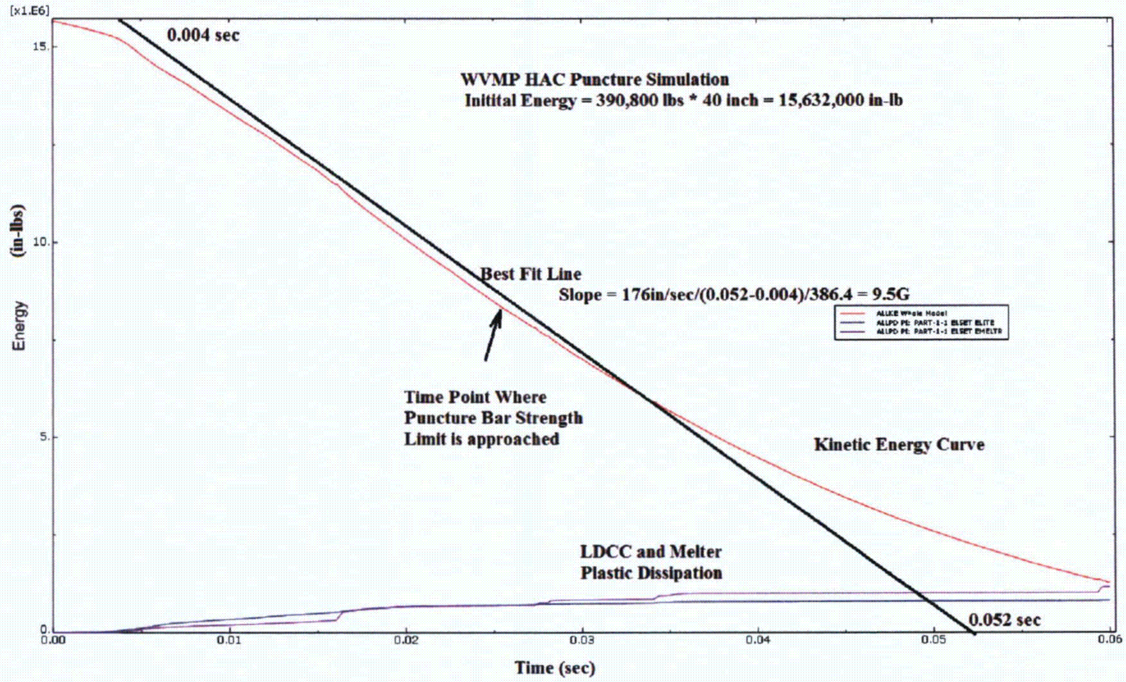


Figure 2-10. Kinetic Energy History Plot during HAC Puncture Simulation

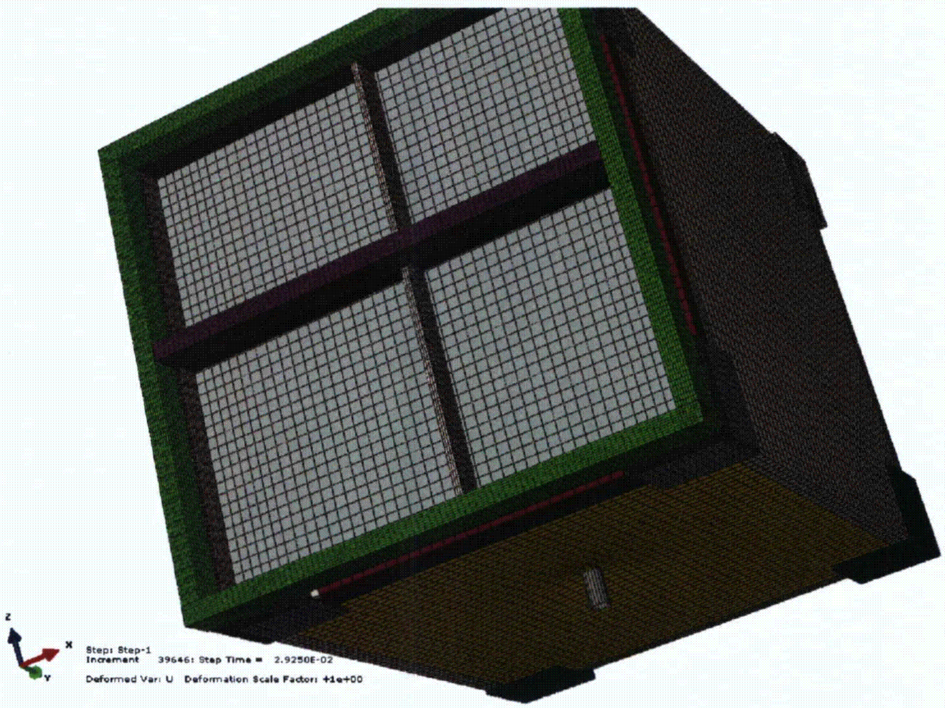


Figure 2-11. Deformed Shape of WVMP after Puncture Simulation

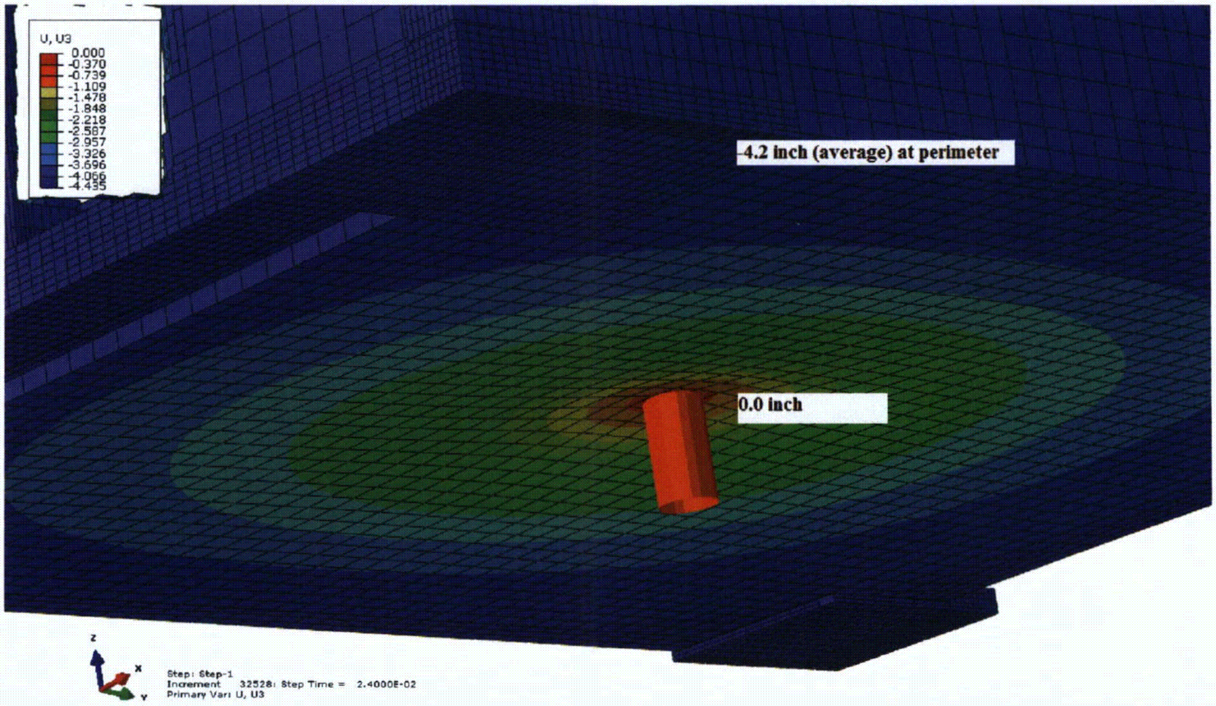


Figure 2-12. Deflection Contour at Time = 0.024 Seconds, Showing 4.2" Differential between Plate Center and Plate Edges Time instance when WVMP Deformations have diminished

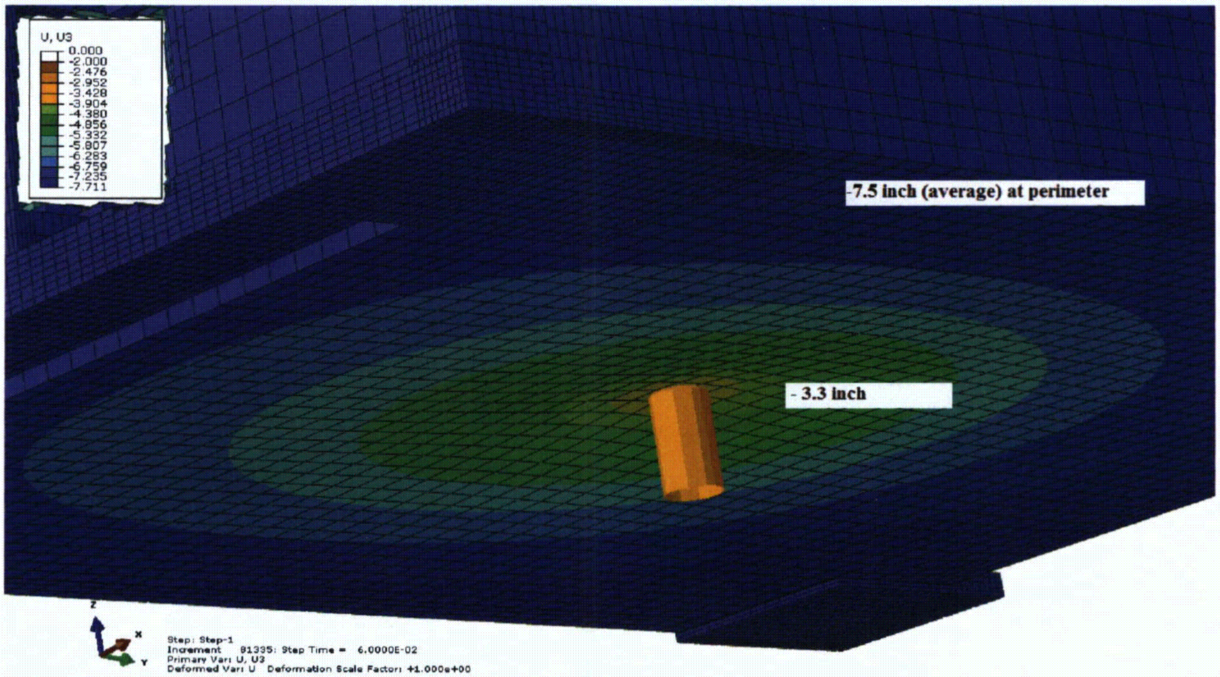


Figure 2.13. Deflection Contour at Time = 0.060 sec (End of Puncture Simulation), Showing 4.2" Differential between Plate Center and Plate Edges

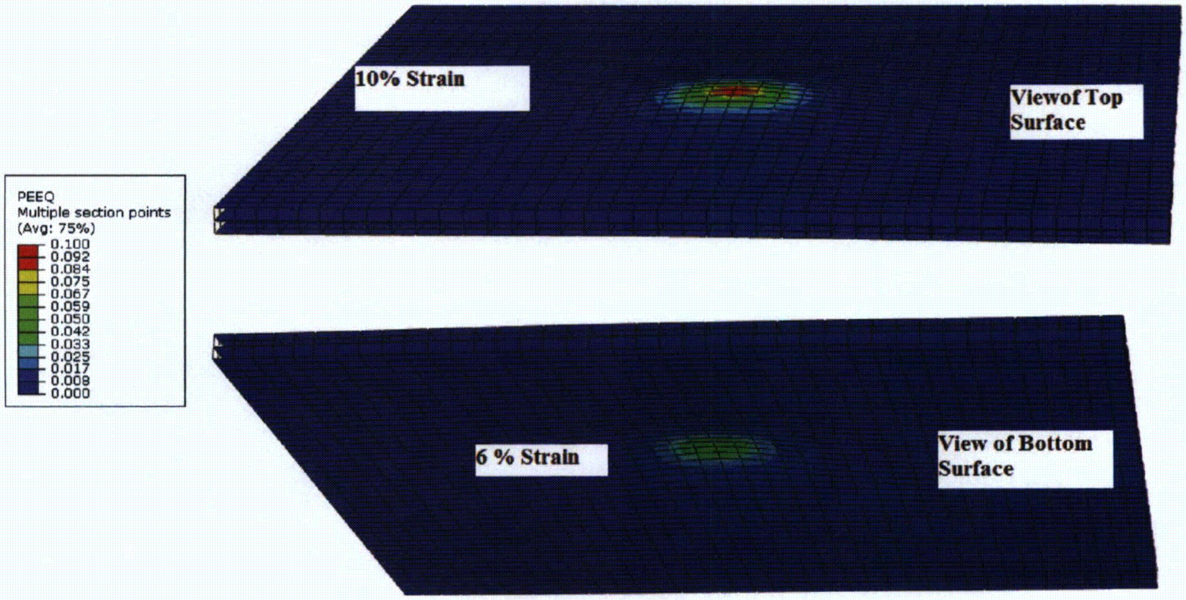


Figure 2-14. Contour Plot of Total Accumulated Plastic Strains after WVMP Puncture Test Simulation, Showing 6% to 10% Surface Strains. Membrane Strains are less than 2% (Per FEA Strain Query, not Shown)

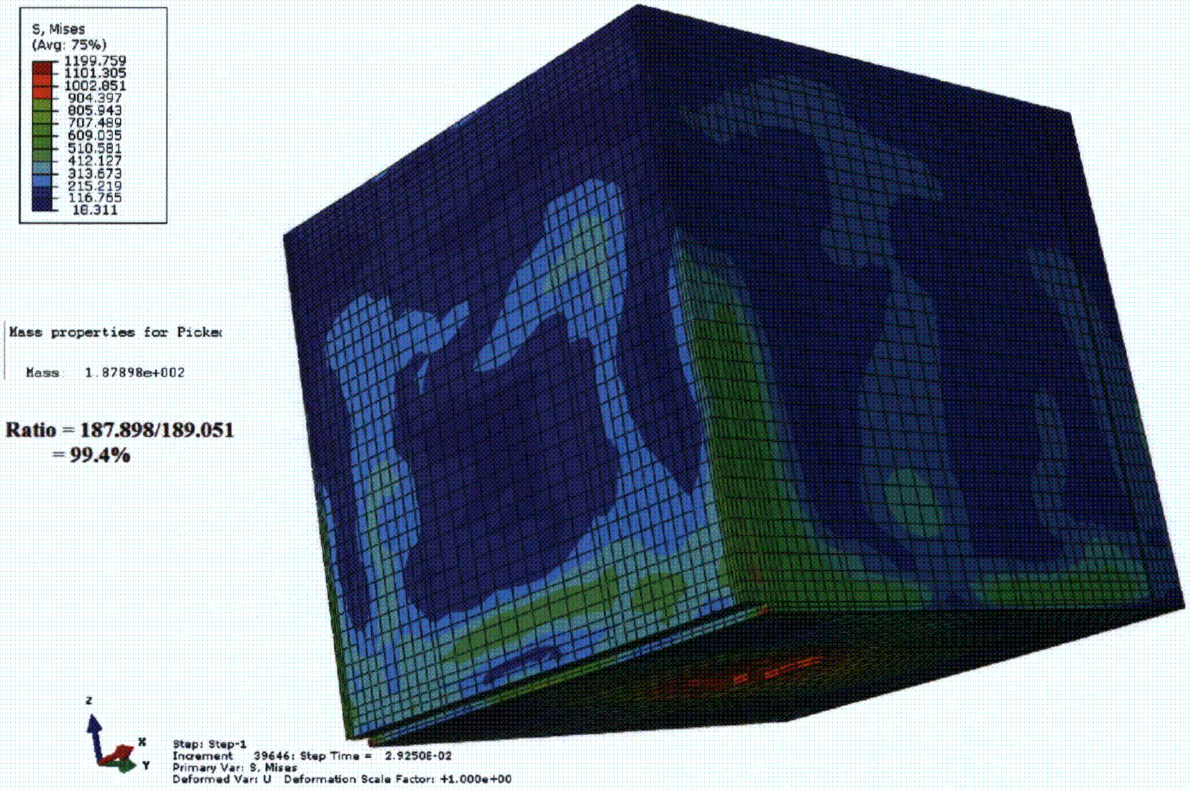


Figure 2-15. Stress Contour Plot of LDCC, with potential damages to LDCC removed from element selection, showing less than 1% damaged

2.7.4 Thermal

Requirement: 10 CFR 71.73(c)(4) – *Thermal.* "Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 1475°F for a period of 30 minutes. The fuel source must extend horizontally at least 40", but may not extend more than 10', beyond any external surface of the specimen, and the specimen must be positioned 40" above the surface of the fuel source. For purposes of calculation, the surface absorptivity coefficient must be either that value which the package may be expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials of construction, must be allowed to proceed until it terminates naturally."

Evaluation: A numerical thermal evaluation of the WVMP under the fully engulfing fire has been performed, as documented in Section 3.4 of the SAR. Structural evaluation of the WVMP under the resulting temperatures and pressures was performed in Appendix 2.12.2.

2.7.4.1 Summary of Pressures and Temperatures

The large thermal mass of the WVMP container (204,000 lbs of steel) minimizes thermal penetration of the HAC fire temperatures. The thermal analysis was based on no credit for the IL. If the WVMP was not pressure tight after the HAC drops, then no internal pressure would develop and the only structural load demands would be from differential thermal expansion. Conservatively, a HAC pressure was computed based on intact seals and maximum evaporation of the moisture in the LDCC, based on temperature demand. Per Section 3.4 of the SAR:

HAC fire condition internal pressure: 73 psig

HAC fire condition temperature:

WVMP walls:	= 1221°F max, occurs in extremes of corners	[Ref Table 3-6]
	= 750°F through wall average	[Ref. App 2.12.2]
	= 155°F, max through wall gradient	[Ref. App 2.12.2]
LDCC:	= 693°F max, only at extreme outside surface	[Ref. 2-15, Fig 11]
	= 204°F average temperature	[Ref Table 3-6]
Melter:	= 145°F, essentially unchanged from pre-fire	[Ref Table 3-6]

2.7.4.2 Differential Thermal Expansion

Differential thermal expansion is evaluated in Appendix 2.12.2 for the HAC fire condition. The analysis evaluated stresses from thermal gradients within a single component (e.g., bending due to through wall temperature gradients) and stresses arising from differential thermal expansion of adjoining components.

The maximum thermal stress from through-wall temperature gradients was shown to be 21 ksi. When added to the maximum primary stress during HAC fire conditions (26.1 ksi), the combined stress remains less than their respective allowables.

The analysis of bulk thermal expansion shows that the WVMP steel and bolting have the same thermal expansion coefficients, thus they expand and contract uniformly with temperature. The thermal expansion of the container exceeds that of the LDCC during the fire (based on steel's higher thermal expansion coefficient and the steel's much higher temperature during the fire), such that the LDCC will not apply a load on the container. The thermal analysis shows that the melter experiences an insignificant temperature rise during the HAC fire, so the melter will not apply a load against the hotter LDCC.

2.7.4.3 Stress Calculations

Stresses from pressure loadings and thermal loads were computed in Appendix 2.12.2, resulting in the following values:

Pm = insignificant, the flat plate resists pressure load via bending

Pm+Pb = 26.1 ksi [Ref App 2.12.2]

Sm = 21 ksi [Ref App 2.12.2]

Pm + Pb + Sm = 47.1 ksi

2.7.4.4 Comparison with Allowable Stresses

Allowable stresses are based on the 750°F through-wall average temperature. For additional conservatism and to address any uncertainly in the thermal analysis, the structural assessment will be based on material allowables at 800°F. The allowable stresses are derived in Appendix 2.12.2 and summarized below.

For the ASTM SA516-70 steel structure, these limits are (from -20°F to 800°F):

$$P_m \leq 0.7S_u = 0.7 * 64{,}300psi = 45{,}000psi$$

$$P_L \leq 150\%P_m$$

P + S, ASME does not require evaluation of secondary stress levels for Level D service limits. For conservatism, the level A service limit of 3Sm is imposed.

The comparison is shown below in Table 2-8.

Table 2-8. Comparison of Stresses with Allowables, HAC Fire Condition

Location	ASME Designation	Stress	Allowable	Comparison Stress/Allowable
Primary Membrane	P_m	~	45 ksi	~
Primary Membrane + Bending	$P_L + P_b$	26.1 ksi	45 ksi	58%
Secondary	S_{m+b}	21 ksi	~	~
Primary plus Secondary	$P_{L+b} + S_{m+b}$	47.1 ksi	3Sm = 54.3 ksi	87%

2.7.5 Immersion – Fissile Material

Requirement: 10 CFR 71.73(c)(5) – *Immersion--fissile material.* "For fissile material subject to § 71.55, in those cases where water in-leakage has not been assumed for criticality analysis, immersion under a head of water of at least 3' in the attitude for which maximum leakage is expected."

Evaluation: Contents do not include fissile material subject to 10 CFR 71.55.

2.7.6 Water Immersion – All Packages

Requirement: 10 CFR 71.73(c)(6) – *Immersion--all packages.* "A separate, undamaged specimen must be subjected to water pressure equivalent to immersion under a head of water of at least 50'. For test purposes, an external water pressure of 21.7 lbf/in^2 gauge is used."

Evaluation: The 21.7 psig external pressure is bounded by the HAC internal pressure of 73 psig. Since the flat plates have the same stress response to internal pressure as they do external pressure, and the allowable stresses at the water immersion temperature is bounding verses the allowable stresses at the HAC fire pressure condition, the WVMP is shown to meet this requirement.

2.7.7 Deep Water Immersion Test (for Type B Packages Containing More Than 10^5 A_2)

Requirement: 10 CFR 71.61 – *Special requirements for Type B packages containing more than 10^5 A_2.* "A Type B package containing more than 10^5 A_2 must be designed so that its undamaged containment system can withstand an external water pressure of 290 psi for a period of not less than 1 hour without collapse, buckling, or inleakage of water."

Evaluation: Not applicable. The WVMP contains less than 10^5 A_2.

2.7.8 Summary of Damage

The WVMP was evaluated by analysis for the NCT drops, water immersion, HAC drops, HAC puncture, and HAC fire. The analysis shows essentially no damage to the WVMP, including the IL, during and after the NCT.

The HAC drop analysis did predict deformations to the IL and shock absorbers. The most significant damage experienced by the WVMP was failure of the bolts at the bolted side door. It was shown that the structural portion of the IL acts to maintain the position of the bolted side door, with only small movements of the face and perimeter seal regions. The container itself remained essentially un-deformed and plastic strains were within ASME service level D limits.

The HAC impacts results in significant G-levels, and/or transient diaphragm bending of the walls that results in the mitigation of LDCC crush. The total LDCC crushed ranged from 5% for drop orientations associated with the highest bolted side door seal displacements, to 35% for drop orientations associated with no bolted side door seal displacements. The bounding damage was for a drop onto the side edge, which showed 30% LDCC crush and seal motion of:

Face seal displacement	= 1.2" (vs. available 6" before breach path exposed)
Perimeter seal displacement	= 5.8" transient
	= 4" to 4.5" final
	(3.75" face overlap before breach path exposed)

Therefore, based on analysis the WVMP satisfies the performance intents of 10 CFR 71.51(a)(2) under HAC given in 10 CFR 71.73.

2.8 Accident Conditions for Air Transport of Plutonium

Not applicable.

2.9 Accident Conditions for Fissile Material Packages for Air Transport

Not applicable.

2.10 Special Form

Not applicable.

2.11 Fuel Rods

Not applicable.

2.12 Appendix

This appendix contains the following information:

2.12.1 List of references

2.12.2 Structural Evaluation of WVMP to Specific Requirements of 10 CFR 71.71 (appended to reference section of the SAR)

APPENDIX 2.12.1 – REFERENCES

2-1 10 CFR Part 71, *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Washington, D.C., December 2006.

2-2 49 CFR Part 173, *Shippers - General Requirements for Shipments and Packaging,* Code of Federal Regulations, Washington, D.C., January 2007.

2-3 *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels,* Regulatory Guide 7.6, Revision 1, U.S. Nuclear Regulatory Commission, March 1978.

2-4 *Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material,* Regulatory Guide 7.8, Revision 1, U.S. Nuclear Regulatory Commission, Washington, D.C., March 1989.

2-5 *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m),* Regulatory Guide 7.11, Revision 0, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1991.

2-6 *ASME Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, New York, N.Y., 2013

2-7 *Fabrication Criteria for Shipping Containers*, NUREG/CR-3854, U.S. Nuclear Regulatory Commission, Washington, D.C., March 1985.

2-8 ASME SA-193, *Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications*, ASTM International, 2001

2-9 General Plastics LAST-A-FOAM FR-3700 for Crash & Fire Protection of Nuclear Material Shipping Containers, http://pbadupws.nrc.gov/docs/ML0504/ML050410066.pdf

2-10 *Structural Welding Code – Steel*, D1.1, American Welding Society, 2000

2-11 *Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick*, NUREG/CR-1815, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1981.

2-12 *Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Greater than Four Inches Thick*, NUREG/CR-3826, U.S. Nuclear Regulatory Commission, Washington, D.C., April 1984.

2-13 *Fitness-For-Service*, API 579-1/ ASME FFS, American Petroleum Institute, Washington, D.C., 2007.

2-14 *Cask Designers Guide*, ORNL-NSIC-68, Shappert, L.B., et al., Oak Ridge National Laboratory, February 1970.

2-15 *Thermal Analysis for West Valley Melter Package*, M-CLC-A-00498, Revision 0, Savannah River National Laboratory, Aiken, South Carolina, September 2014. (see Chapter 3)

2-16 AISC Steel Construction Manual, AISC-325-11, 14th Edition.

2-17 ASTM A516/A516M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate and Lower-Temperature Service*, ASTM International, 2001 Edition.

2-18 Receiving Inspection & Material validation – Steel Plate, Document 40945-000, West Valley Purchase Order 53634. (provided)

3.0 THERMAL EVALUATION

This chapter provides a thermal evaluation for the shipment of the West Valley Melter Package (WVMP) as part of the safety analysis for this shipment. The thermal evaluation performed for the WVMP demonstrates compliance with the performance requirements for Normal Conditions of Transport (NCT) as specified in 10 CFR 71.71 (reference 3-1), and for Hypothetical Accident Conditions (HAC) as specified in 10 CFR 71.73 (reference 3-2). The WVMP is comprised of (1) the Grouted Melter Package (GMP), consisting of the melter and Low Density Cellular Concrete (LDCC) inside the steel container; and (2) the Impact Limiter (IL). Figure 3-1 shows the components of the WVMP.

3.1 Description of Thermal Design

Thermal analyses are provided for NCT and HAC (Appendix 3.5.4). The conditions for NCT and HAC are stipulated in 10 CFR 71. NCT covers conditions for outdoor storage of the waste package, including heat transfer to ambient air and sun exposure (insolation). The HAC assume exposure to a 1475°F fire. The thermal analysis does not account for the presence of the Impact Limiter (IL) added to the exterior of the WVMP. For the thermal analysis, the omission of the IL is conservatively bounding since it does not include the insulation it provides. The WVMP without the IL component is referred to as the Grouted Melter Package (GMP) component.

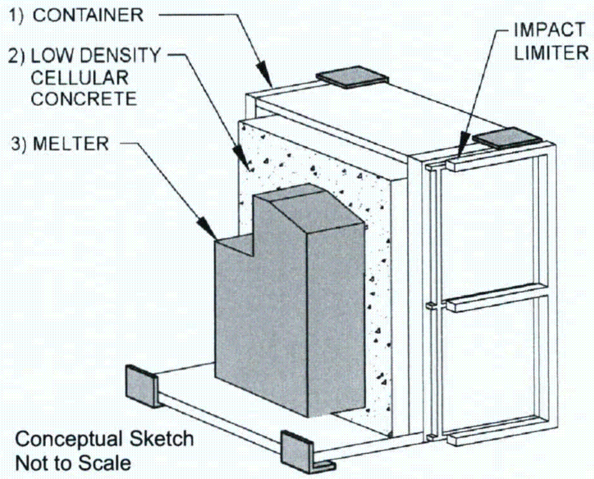


Figure 3-1. WVMP Components

The analysis of temperatures for NCT follows the requirements of 10 CFR 71.71. The required temperatures are:

(1) The maximum temperatures for exposure to 100°F air at steady state.

(2) The maximum temperatures for exposure to 100°F still air with insolation of 800 cal/cm^2 on the top surface and 200 cal/cm^2 on the side surfaces for a period of 12 hours. The package bottom is assumed to be an insulated (adiabatic) surface.

(3) The minimum (surface) temperature for exposure to a cold environment of -20°F, with no insolation.

(4) The minimum (surface) temperature for exposure to a maximum cold environment of -40°F, with no insolation.

Key Terms and Acronyms in this Chapter

GMP	Grouted Melter Package (consisting of the melter and LDCC inside the container)
HAC	Hypothetical Accident Conditions
IL	Impact Limiter
LDCC	Low Density Cellular Concrete
NCT	Normal Conditions of Transport
WVMP	West Valley Melter Package (consisting of the GMP with the IL installed)

The WVMP accessible surface temperature in still air at 100°F, with no insolation, must not exceed the exclusive use shipment limit of 185°F, as specified in 10 CFR 71.43(g) (reference 3-3). In addition, there must be no loss of the radioactive contents, no significant increase in external surface radiation level, and no significant decrease in package effectiveness, as stated in 10 CFR 71.43(f) (reference 3-3) and 71.51(a)(1) (reference 3-4). To address this requirement, the maximum pressure that can develop inside the WVMP during NCT is calculated for use in the structural analysis.

The analysis of temperatures for HAC follows the requirements of 10 CFR 71.73. These requirements specify the package is exposed to an engulfing 1475°F (800°C) fire for 30 minutes, followed by a cool down to ambient conditions. The fire emissivity is specified as 0.9 and the surface emissivity for the surface of the package is set at 0.8. The requirements also specify the use of a convective heat transfer coefficient appropriate for the fire.

The HAC analysis must demonstrate the activity release during the HAC will not exceed the limits established by 10 CFR 71.51(a)(2) (reference 3-4). To demonstrate no release of activity will occur, the maximum pressure that can develop inside the WVMP during the HAC is calculated for use in a structural analysis.

3.1.1 Design Features

The WVMP consists of a container with a 12'4.75" long by 11'4" wide by 11'4" high volume (reference 3-5). The melter is grouted in place inside this container by Low Density Cellular Concrete (LDCC). The LDCC fills the container to within 10" of the inside top surface (reference 3-6). The top and bottom container thickness is 4"; the sides of the container are 6" thick (reference 3-5). The container also includes steel rails, gaskets, and sacrificial shock absorbers at each of the eight corners (reference 3-5); these components are not modeled in the heat transfer analysis. Exclusion of these components yields conservatively bounding values for the calculated temperatures, since they provide added insulation for the interior of the WVMP when it is heated by either insolation or by the fire.

The mass of the melter is 107,500 lbm (48,761 kg), (reference 3-6). The LDCC mass is 70,738 lbm (32,086 kg) (reference 3-6). The mass of the melter glass is 467.2 kg (1,030 lbm) (reference 3-7).

The volumes occupied by each type of material can be calculated by dividing the estimated mass of material by its density. The WVMP interior volume, i.e., the interior volume minus the volume of the glass remaining in the melter, is estimated indirectly from the equation.

$$V_{ref} = V_i - V_{air,1} - \frac{m_{LDCC}}{\rho_{LDCC}} - \frac{m_{glass}}{\rho_{glass}} \quad (3.1.1\text{-}1)$$

where

V_{ref} = WVMP interior volume minus volume of glass, m^3

V_i = *total interior volume of WVMP*, m^3

$V_{air,1}$ = volume air pocket above LDCC inside WVMP, m^3

m_{LDCC} = mass of LDCC, kg

ρ_{LDCC} = LDCC density, kg/m^3

m_{glass} = mass of glass in melter, kg

ρ_{glass} = glass density, kg/m^3

The melter structure is comprised of Inconel®[1], Type 304 stainless steel, and Type 304L stainless steel (reference 3-5). As an approximation, the properties of the melter steel are set equal to the properties of Type 304L stainless steel. The refractory material is a combination of Monofrax™[2] K-3 and Zirmul™ (reference 3-7). Accordingly, the volume of the structural metal inside the melter is given by

$$V_{ss} = \frac{m_m - \rho_{Mono} V_{Mono} - \rho_{Zirm} V_{Zirm}}{\rho_{ss}} \quad (3.1.1\text{-}2)$$

where

V_{ss} = volume of metal inside melter, m^3

m_m = total melter mass, kg

ρ_{Mono} = density of Monofrax™, kg/m^3

V_{mono} = volume of Monofrax™ refractory inside melter, m^3

ρ_{Zirm} = density of Zirmul™, kg/m^3

V_{Zirm} = volume of Zirmul™ refractory inside melter, m^3

ρ_{ss} = density of Type 304L stainless steel, kg/m^3

Any portion of the melter volume that is not metal or refractory is assumed to be an air pocket. The melter air pocket volume is calculated by subtracting the metal and refractory volumes from the total refractory volume given by equation (3.1.1-1):

$$V_{air,2} = V_{ref} - V_{ss} - V_{Mono} - V_{Zirm} \quad (3.1.1\text{-}3)$$

where

$V_{air,2}$ = volume of air pocket inside melter, m^3

3.1.2 Content's Decay Heat

The heat generation rate in the glass is calculated from a RADCALC analysis of the activity in the glass (references 3-7, 3-8, 3-9, and 3-10) and tabulations of the energy emissions for each radionuclide from the International Committee on Radiological Protection (ICRP) tables (reference 3-11). The full list of radionuclides from the RADCALC®[3] output is included in the tabulation. The radiolytic heat generation calculations are summarized in Appendix 3.5.2. The maximum decay heat is 9.21 W.

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[1] Inconel is a registered trademark of Special Metals Corporation of New Hartford, New York.

[2] Monofrax™ is a trademark of RHI Monofrax Ltd. of Falconer, New York. Zirmul™ is a contraction of the mineral names zirconia (ZrO^2) and mullite ($3Al_2O_3 \cdot 2SiO_2$). Zirmul™ is a registered trademark of North American Refractories Company of Pittsburgh, Pennsylvania.

[3]RADCALC is a registered tradename of LifeLine Software, Inc., of Austin, Texas.

3.1.3 Summary Tables of Temperatures

The following tables summarize maximum and minimum temperatures for NCT and, for HAC, the time interval between the beginning of the fire exposure and the peak temperatures.

Table 3-1. Temperatures for NCT

NCT, No Insolation, 100°F Ambient Air	
Component	**Maximum Temperature**
Overall	105.4°F
Glass	105.4°F
Melter	101.5°F
LDCC	101.0°F
Air Pocket	100.3°F
Container	100.2°F
NCT, No Insolation, -20°F Ambient Air	
Component	**Minimum Temperature**
Overall	-19.9°F
Glass	-18.7°F
Melter	-19.2°F
LDCC	-19.9°F
Air Pocket	-19.9°F
Container	-19.9°F
NCT, No Insolation, -40°F Ambient Air	
Component	**Minimum Temperature**
Overall	-39.9°F
Glass	-38.7°F
Melter	-39.2°F
LDCC	-39.9°F
Air Pocket	-39.9°F
Container	-39.9°F
With Insolation, 100°F Ambient Air	
Component	**Maximum Temperature**
Overall	209.4°F
Glass	146.3°F
Melter	144.6°F
LDCC	183.5°F
Air Pocket	208.9°F
Container	209.4°F

Table 3-2. Limiting Conditions for HAC

HAC, With Insolation, 100°F Ambient Air, 1475°F Fire Exposure for 30 minutes		
Component	**Maximum Temperature(°F)**	**Time for Maximum Temperature (minutes)**
Overall	1221.1°F	30
Glass	146.3°F	750+(1)
Melter	145.2°F	750+(1)
LDCC	693.0°F	68
Air Pocket	727.9°F	68
Container	1221.1°	30

NOTE: (1) The glass and melter temperatures had not peaked 750 minutes after the start of the fire (720 minutes after the end of the fire exposure), but are judged to have been within 1°F of their peak values.

3.1.4 Summary Table of Maximum Pressures

The following table lists maximum pressures for NCT and HAC. These maximum pressures are calculated for the air pocket at the top.

Table 3-3. Maximum Pressures for NCT and HAC

Condition	Maximum Pressure
NCT	12.0 psig
HAC	73.0 psig

3.2 Material Properties and Component Specifications

Evaluation of thermal conductivities, densities, and heat capacities is required for the thermal analysis. The LDCC contains waters of hydration that may dehydrate to form water vapor when the WVMP is exposed to the sun under NCT or, more particularly, to fire under HAC. The dehydration reaction is endothermic, so the dehydration process will act as a heat sink in the thermal analysis. The water vapor from dehydration will pressurize the container. Therefore, the fractional dehydration as a function of temperature and the heats of hydration and vaporization are needed inputs. Finally, the radionuclide contents of the melter glass and the decay heats for each of the isotopes in the glass are needed to compute the rate of radiolytic heating of the glass.

3.2.1 Material Properties

The density of the glass is 2600 kg/m^3 (reference 3-7).

The average LDCC density is conservatively assumed to be equal to the density of the concrete batch with the lowest measured compressive strength, which was 71.2 lbm/ft^3 (1140 kg/m^3) (reference 3-6).

The total refractory volume is 92.7 ft^3, of which 61.88 ft^3 is Monofrax™ K-3 and 30.82 ft^3 is Zirmul™ (reference 3-7). The thermal analysis uses the crystalline densities of these materials, 3900 kg/m^3 for Monofrax™ K-3 and 3140 kg/m^3 for Zirmul™, and the corresponding thermal conductivities at

100°C, 4.19 W/m/K for Monofrax™ K-3 and 0.20 W/m/K for Zirmul™ (reference 3-12). The heat capacities are calculated from the compositions of Monofrax™ K-3 and Zirmul™ (reference 3-12) and the estimated heat capacities of the crystalline phases of the oxide constituents (references 3-13 and 3-14). The compositions and density calculations are summarized in Table 3-4; the resulting heat capacities are 774 J/kg/K for Monofrax™ K-3 and 709 J/kg/K for Zirmul™. The Monofrax™ and Zirmul™ heat capacities are computed using the weighted averages of only those constituents listed in Table 3-4, despite the fact that their weight fractions do not sum to one.

Table 3-4. Compositions and Heat Capacities for Monofrax™ K-3 and Zirmul™

Oxide	Mol. Wt. (g/mole)	Heat Capacity (J/mol/K)	Monofrax™ K-3		Zirmul™	
			wt %	J/g/K	wt %	J/g/K)
Al_2O_3	101.96	79	44	0.341	70	0.542
CaO	56.08	42	0.18	0.001	0	0
Cr_2O_3	151.99	118.7	19	0.148	0	0
Fe_2O_3	159.69	103.9	5.85	0.038	0	0
Na_2O	62	69.1	0.2	0.002	0	0
MnO_2	86.94	54.1	0.06	0.000	0	0
MgO	40.3	37.2	3.71	0.034	0	0
SiO_2	60.08	44.4	0.6	0.004	10.2	0.075
TiO_2	79.88	55	0.16	0.001	0	0
ZrO_2	123.22	56.2	0	0.001	19.5	0.089
Total				**0.774**		**0.709**

As stated previously, the melter metal is assigned the properties of Type 304L stainless steel. The container walls are fabricated from Type SA516 carbon steel (reference 3-5). The density of Type 516 carbon steel is 483.8 lbm/ft^3 (7,749.7 kg/m^3), and the density of Type 304L stainless steel is 499.4 lbm/ft^3 (7,999.6 kg/m^3) (reference 3-15). The heat capacities and thermal conductivities are correlated as functions of temperature as shown in Figures 3-2 and 3-3 (reference 3-15).

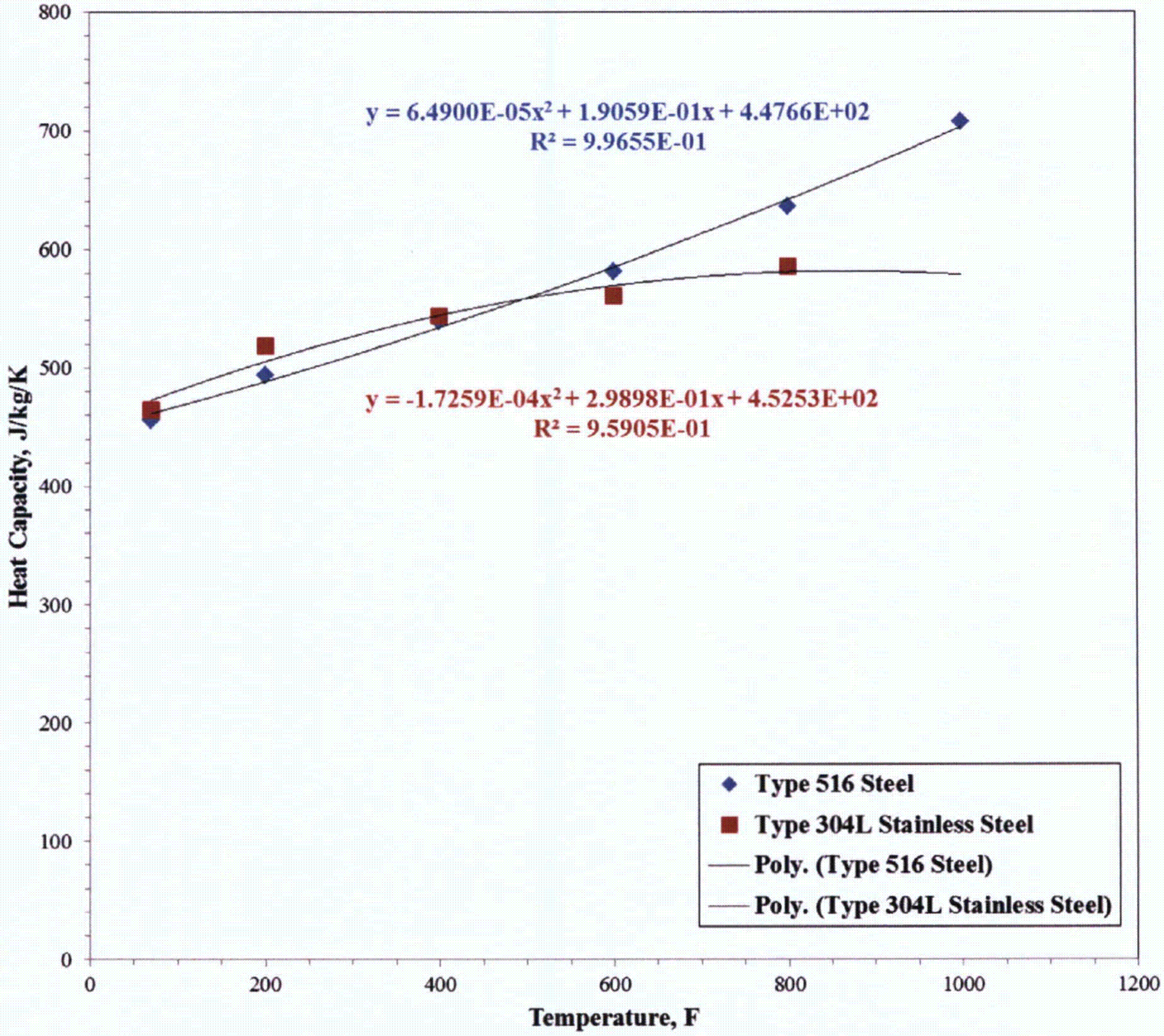


Figure 3-2. Correlation of Heat Capacities for Types SA516 and 304L Steels (reference 3-16)

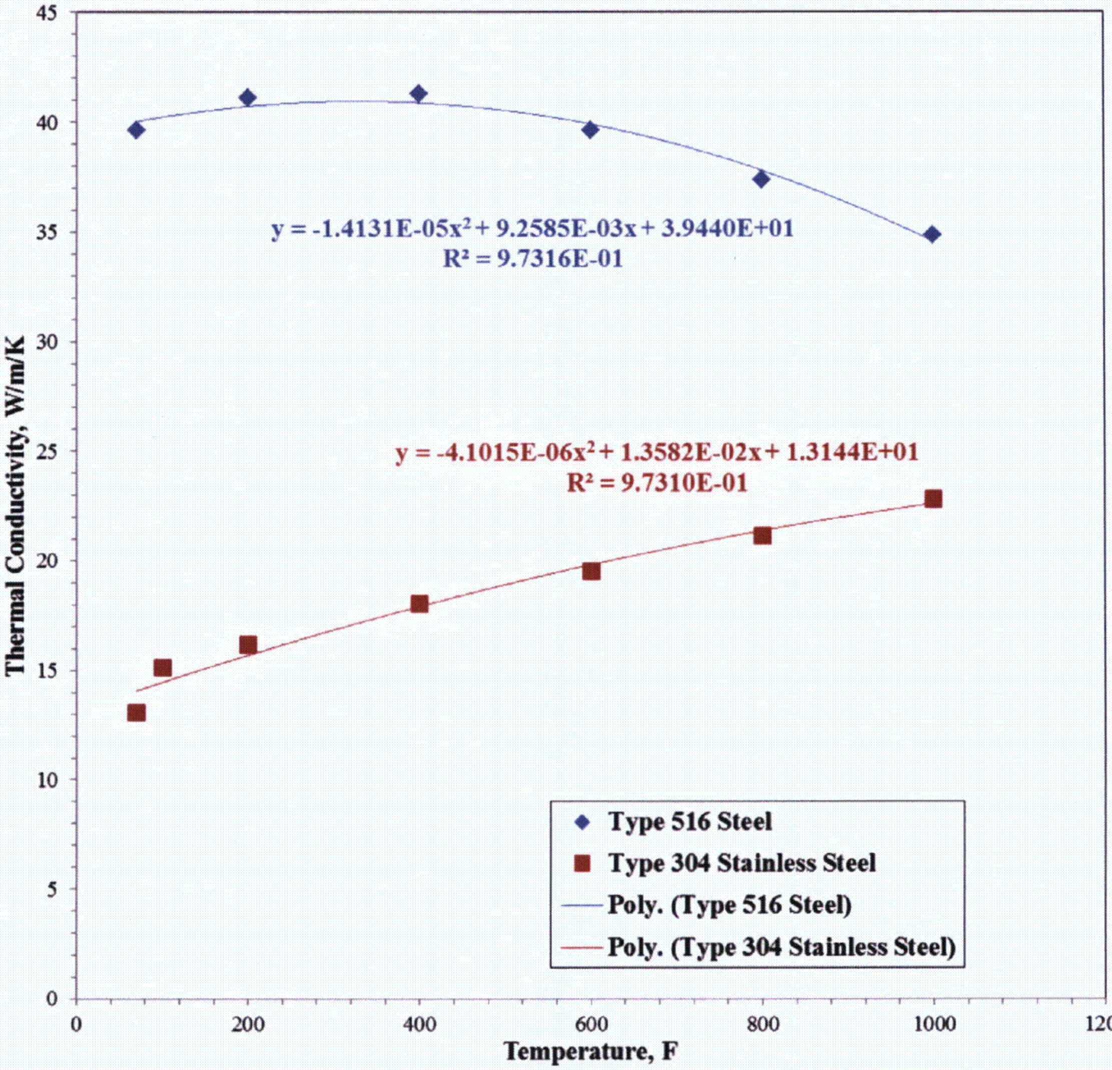


Figure 3-3. Correlation of Thermal Conductivities for Types SA516 and 304L Steels (reference 3-16).

The glass heat capacity is fit to typical values for borosilicate glass (reference 3-16), using the empirical correlation

$$c_{p,gl} = \min\left(\frac{0.19242 + 0.001081\ T_{gl}}{1 + 0.00251\ T_{gl}}, 0.2\right) \qquad (3.2.1\text{-}1)$$

where

$c_{p,gl}$ = thermal conductivity of the melter glass, cal/g/K

T_{gl} = glass temperature, °C

The heat capacity of the LDCC is set equal to a typical value for a cement mix with a water content close to that estimated for LDCC. LDCC contains on average 510 lbm/yd^3 cement, with added water amounting to 20% of the cement by weight, and enough sand to increase the density to the specified value. The result for the given density of 71.2 lbm/ft^3 is 18.89 lbm/ft^3 cement, 48.53 lbm/ft^3 sand (SiO_2), and 3.78 lbm/ft^3 water (references 3-17 and 3-18). The water content is

5.3 wt %. The closest value for which a cement heat capacity is reported is a mix with 3 wt % water, for which the heat capacity was measured to be 765 J/kg/K (reference 3-19).

The thermal conductivities for the glass are set at its minimum value for borosilicate glass of 0.42 W/m/K (reference 3-16). The LDCC thermal conductivity is set at its minimum value for its density, which is approximately 0.26 W/m/K (reference 3-20).

3.2.2 Component Specifications

There are no internal components that will be outside the range of allowable service temperatures or pressures for either NCT or HAC conditions. The glass, metal, refractory, and LDCC will withstand any temperatures extremes that would occur under NCT or HAC. The melter is thermally insulated from the HAC fire, so its temperature will be significantly lower than the container temperature during the fire. The only significant change to component properties during the fire exposure would be dehydration of the LDCC, i.e., loss of the cement waters of hydration.

During the HAC fire exposure, the container plates may exceed their service temperature, which is 700°F for nuclear service and 1,000°F for ordinary service (reference 3-21). The structural analysis in Chapter 2 addresses the structural integrity of the WVMP during HAC.

The Arrhenius correlation of the fractional dehydration is based on data for crystalline calcium silicates, which are by far the major constituents of typical cement. It is assumed that the LDCC is fully cured so that there is no free water in the cement pores and so that, consequently, all dehydration involves the breaking of crystalline bonds, followed by evaporation of liquid water. For tricalcium silicate hydrate ($3CaO:SiO_2:2H_2O$), the fractional dehydration is correlated as an Arrhenius function of the form (reference 3-22).

$$\alpha = A_r \exp\left(-\frac{E_a}{R_g T}\right) \qquad (3.2.2\text{-}1)$$

where

α = cumulative fraction of calcium silicate oxides that have undergone dehydration
A_r = pre-exponential Arrhenius constant for cement dehydration, dimensionless
E_a = activation energy for cement dehydration, J/mole
R_g = gas constant, J/mole/K

The Arrhenius equation was fit to the dehydration data as shown by Figure 3-4.

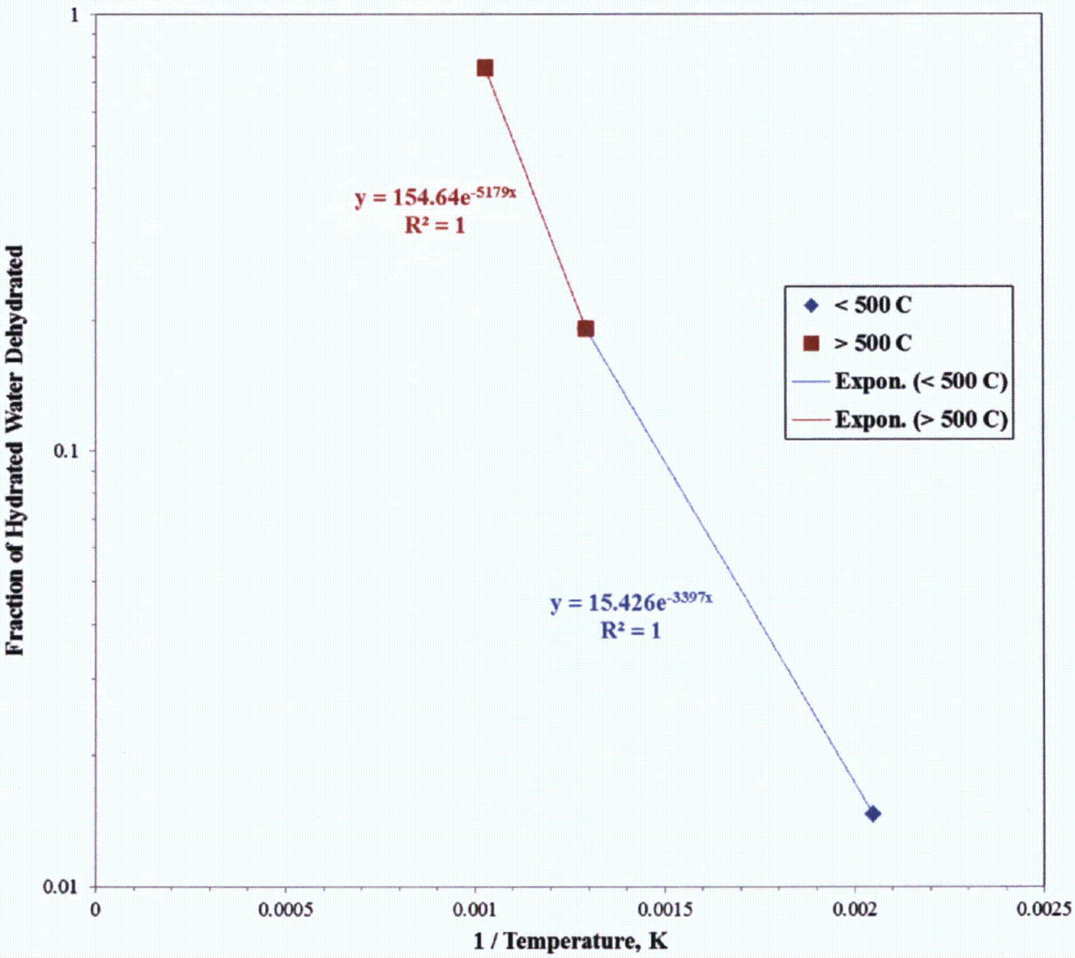


Figure 3-4. Correlation of Measurements for Dehydration of $3CaO:SiO_2:2H_2O$

As indicated by the figure, the Arrhenius constants, for temperatures below 500°C, are

$$A_r = 15.426\,,\ \frac{E_a}{R_g} = 3397 \text{ K} \tag{3.2.2-2}$$

The heat of hydration for tricalcium silicate is 65.59 kJ/mole H_2O (reference 3-23), and the heat of hydration for calcium oxide is 63.92 kJ/mole H_2O (reference 3-24). The tricalcium silicate heat of hydration is used in the thermal analysis, since it is more representative of the LDCC composition.

The heat of vaporization for water is added to the heat of reaction for dehydration. The heat of vaporization is correlated as a function of temperature by (reference 3-25).

$$\lambda = \lambda_b \left(\frac{1 - T_r}{1 - T_{r,b}} \right)^{0.38} \tag{3.2.2-3}$$

where

λ = heat of vaporization, J/mole

λ_b = heat of vaporization at the normal boiling point (373.15 K), J/mole

T_r = relative temperature

$T_{r,b}$ = relative temperature at the normal boiling point

The relative temperature is normalized with respect to the critical temperature for water, which is 373.99°C or 647.14°K (reference 3-26). The heat of vaporization of water at the normal boiling point is 40,657 J/mole (reference 3-26).

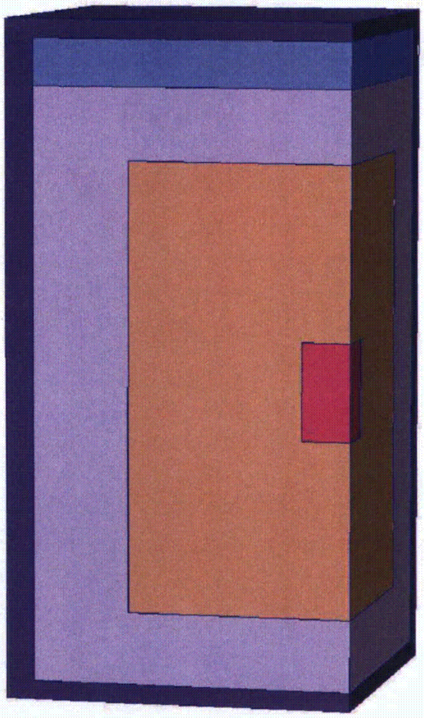
3.3 Thermal Evaluation under Normal Conditions of Transport

The thermal analysis is performed using Version 4.3a of the finite element modeling code COMSOL®[4] Multiphysics. COMSOL® Multiphysics is approved for use in heat transfer modeling at the Savannah River National Laboratory and has been used to calculate NCT and HAC temperatures for other waste transfer packages (references 3-27 and 3-28). The COMSOL® model uses the actual outer dimensions for the container and approximates the contents of the WVMP as a nested series of cubes, with the innermost cube comprised of the radioactive glass in the melter heel, the spout, and any glass dispersed into the refractory of the melter. In the model, this inner core is surrounded by a layer comprised of the melter refractory and structural steel, a layer of the LDCC used to stabilize the melter in the package, and the steel container walls. There also is a 10" thick air space between the top surface of the LDCC and the top container wall. This air pocket is present because the WVMP was not completely filled with LDCC.

To simplify the heat transfer analysis, it is assumed that the glass, steel, refractory, and LDCC layers form concentric, symmetrical cubes within the container walls and upper air pocket. The symmetry provides a conservative, lower bound to the actual overall rate of heat transfer in that it averages out any variations in the thicknesses of the insulation provided by the LDCC and the refractory. Any asymmetrical variations would increase the local, and the average, rate of heat transfer. A lower bound to the heat transfer rate is desired because it maximizes the surface temperature for insolation and fire exposure and maximizes increases in the glass temperature due to radiolytic heating for the case of no insolation. (The maximum glass temperature is used to estimate the bounding surface temperature without insolation, to account for asymmetries in the thickness of the LDCC around the melter.)

The COMSOL® model utilizes bilateral symmetry along the length and width of the WVMP to reduce the volume analyzed to a one-quarter corner of the WVMP that extends from the top surface to the bottom surface. Figure 3-5 depicts the simplified COMSOL® model, with the various materials shown. Figure 3-6 shows the discretization mesh for the finite element calculations. The total number of calculation nodes is 125,148. Trial calculations were performed to ensure that the discretization was sufficiently fine to calculate the WVMP temperature profile with a high degree of precision. Appendix 3.5.3 provides a list of parameters and variables used for the COMSOL® model.

[4]COMSOL® is a registered trade name of COMSOL, Inc., of Burlingame, Massachusetts.



Key:

Dark Blue	**Container**
Medium Blue	**Air Space**
Light Violet	**LDCC**
Tan	**Melter Structural Steel and Refractory**
Pink	**Glass**

Figure 3-5. Schematic of COMSOL® Multiphysics model of West Valley Melter Package

Figure 3-6. Meshing for COMSOL® Multiphysics Model of West Valley Melter Package

3.3.1 Thermal Analysis

The COMSOL® heat transfer equation for the glass takes the form

$$\rho c_p \frac{\partial T}{\partial t} - \nabla \bullet k \nabla T = \frac{Q}{V_{glass}} \tag{3.3-1}$$

where

ρ = density of the material, kg/m^3

c_p = heat capacity of the material, J/kg/K

∇ = dispersion operator, 1/m

t = time, s

k = thermal conductivity of material, W/m/K

T = temperature, K

Q = internal heat generation rate for radiolytic heating of the glass, W

V_{glass} = glass volume, m^3

The radiolytic heat generation rate is expressed as the sum of the products of the specific activity of the isotopes that are present in the glass and the decay energy for each isotope:

$$Q = \sum_j a_j e_j \tag{3.3-2}$$

where

a_j = activity of the jth isotope, Ci

e_j = decay energy of the jth isotope, W/Ci

The total radiolytic heat generation rate is the sum of the individual heat generation rates for the glass in the melter heel, the glass in the melter spout, and the glass embedded in the melter refractory. In the model it is assumed that radiolytic heating occurs at a uniform rate throughout the glass. In itself, this is not necessarily a conservative assumption. However, because the melter glass has a relative high thermal conductivity compared to the LDCC, when it is modeled as a monolith, the melter glass should be at a relatively uniform temperature regardless of the distribution of the radiolytic heating. The assumption that the glass is concentrated in one central volume should yield a conservatively high estimate for the maximum temperature in the glass.

The heat transfer equation for the melter steel and refractory and the LDCC is

$$\rho c_p \frac{\partial T}{\partial t} - \nabla \bullet k \nabla T = 0 \tag{3.3-3}$$

The equivalent thermal conductivity of the melter steel and refractory is computed by taking the volume average of the individual thermal conductivities of the steel and refractory:

$$k_{eq} = \frac{V_{ref} k_{ref} + V_{ss} k_{ss}}{V_{ref} + V_{ss} + V_{air,2}} \tag{3.3-4}$$

where

k_{eq} = equivalent thermal conductivity for mixture of melter refractory and steel, W/m/K

k_{ss} = thermal conductivity of melter steel, W/m/K

V_{fb} = volume of refractory, m^3

This linear averaging method is consistent with an arrangement where structural steel beams radiate outward from the melter glass to the inner edge of the LDCC and provide a continuous path for heat transfer through the steel. The averaging accounts for the fraction of the total cross-sectional heat transfer area occupied by the refractory. Linear averaging provides a more realistic model for heat transfer in the melter than reciprocal averaging, which would follow from an assumption that the refractory and structural steel were randomly mixed. Melter glass temperatures calculated using a reciprocal averaging method for the combined thermal conductivity of the refractory and steel would yield calculated glass temperatures that would be unrealistically high. The same linear volume averaging is used to compute the equivalent density and heat capacity for the melter steel and refractory.

Heat losses and heat transfer associated with dehydration of cement hydrates in the LDCC are included in the COMSOL® model by incorporating the heat of dehydration into the effective heat capacity for the LDCC. The contribution of the combined heats of dehydration and evaporation equals the product of the heats of dehydration and evaporation, the mass fraction of hydrate in the LDCC, and the derivative of the fractional dehydration with respect to temperature.

Differentiation of the Arrhenius expression for the fraction dehydration (equation (3.2.2-1)) and substitution in the expression for the effective LDCC heat capacity yields the following equation.

$$c_p = c_{p,s} + \frac{(\Delta H_r + \lambda) m_{H_2O} A_r E_a}{m_{LDCC} M_{H_2O} R_g T^2} \exp\left(-\frac{E_a}{R_g T}\right) \quad (3.3\text{-}5)$$

where

$c_{p,s}$ = ordinary heat capacity for cement solids exclusive of reaction or phase change, J/kg/K

ΔH_r = heat of reaction for breaking hydrate bond, J/mole H_2O

M_{H_2O} = molecular mass of water, 0.018 kg/mole

m_{H_2O} = mass of water in LDCC hydrate, kg

m_{LDCC} = total mass of LDCC, kg

During NCT, the heat transfer equation for the steel frame is

$$\rho c_p \frac{\partial T}{\partial t} - \nabla \bullet k \nabla T = q''_i A_i - h_i A_i (T_{s,i} - T_a) \quad (3.3\text{-}6)$$

where

q''_i = surface heat flux due to insolation over the i^{th} surface (applies only to surface nodes), W/m^2

A_i = surface area for the i^{th} surface, m^2

h_i = surface heat transfer coefficient for the i^{th} surface (applies only to surface nodes), $W/m^2/K$

$T_{s,i}$ = temperature of the i^{th} surface, K

T_a = ambient temperature (or fire temperature for the HAC), K

For the fire exposure portion of the HAC transient, the heat transfer equation for the frame is

$$\rho c_p \frac{\partial T}{\partial t} - \nabla \bullet k \nabla T = \varepsilon_i \sigma A_i \left(T_{fire}{}^4 - T_{s,i}{}^4\right) + h_i A_i \left(T_{fire} - T_{s,i}\right) \tag{3.3-7}$$

where

ε_i = emissivity for i^{th} surface, dimensionless

σ = Stefan-Boltzmann constant, $W/m^2/K^4$

T_{fire} = fire temperature, K

During the cool down portion of the HAC transient, the heat transfer equation for the frame becomes

$$\rho c_p \frac{\partial T}{\partial t} - \nabla \bullet k \nabla T = q''_i A_i - \varepsilon_i \sigma A_i \left(T_{s,i}{}^4 - T_a{}^4\right) - h_i A_i \left(T_{s,i} - T_a\right) \tag{3.3-8}$$

As stipulated by 10 CFR 71.71, it is assumed that the air surrounding the WVMP during NCT is still. Consequently, the heat transfer coefficients are based on natural convection from exterior surfaces. Different correlations are applied for natural convection to the top surface of the WVMP, to the vertical side surfaces, and to the bottom surface. All three correlations are for turbulent natural convection; due to the large size of the WVMP, the natural convection flow is in the turbulent range for any significant temperature differences. The COMSOL® correlation for the side walls is given by Churchill and Chu (references 3-29 and 3-30).

$$h_v = \left(\frac{k_{air}}{L_v}\right)\left(0.825 + \frac{0.387 Ra^{1/6}}{\left(1 + \left(\frac{0.492}{Pr}\right)^{9/16}\right)^{8/27}}\right)^2 \tag{3.3-9}$$

where

h_v = heat transfer coefficient for natural convection to the sides of the WVMP, $W/m^2/K$

k_{air} = thermal conductivity of air, W/m/K

L_v = GMP height, m

Ra = Rayleigh number

$\Pr$ = Prandtl number

For natural convection from the top of the WVMP, COMSOL® uses a natural convection correlation recommended by Lloyd and Moran (references 3-29 and 3-31):

$$h_u = \left(\frac{k_{air}}{L_u}\right) 0.15 Ra^{1/3} \quad (3.3\text{-}10)$$

where

h_u = heat transfer coefficient for natural convection to the top of the WVMP, $W/m^2/K$

L_u = GMP width at the top of the WVMP, m

Finally, for convection from the bottom surface of the WVMP, COMSOL® utilizes the following generalized correlation (reference 3-32).

$$h_d = \left(\frac{k_{air}}{L_d}\right) 0.27 Ra^{1/4} \quad (3.3\text{-}11)$$

where

h_d = heat transfer coefficient for natural convection to the bottom of the WVMP, $W/m^2/K$

L_d = WVMP width at the bottom of the WVMP, m

The heat transfer coefficient given by equation (3.3-11) is used only for the HAC analysis.

The Rayleigh number in the preceding correlations is defined by

$$Ra = \frac{\rho_{air} \Delta\rho_{air} c_{p,air} g L^3}{\mu_{air} k_{air}} \quad (3.3\text{-}12)$$

where

ρ_{air} = air density, kg/m^3

$\Delta\rho_{air}$ = difference between the density of air at ambient temperature and the average density at the WVMP surface, kg/m^3

$c_{p,air}$ = air heat capacity, J/kg/K

g = gravitational acceleration, m/s^2

L = GMP component height or equivalent width, m

μ_{air} = air viscosity, kg/m/s

The Prandtl number is given by

$$Pr = \frac{c_{p,air}\mu_{air}}{k_{air}} \quad (3.3\text{-}13)$$

All gas properties except the density difference are evaluated at a temperature midway between the ambient temperature and the average temperature at the WVMP surface.

Surface heat losses during HAC are modeled using the same natural convection correlations. These correlations give a conservative estimate of heat losses for HAC because they assume that there is no forced convection associated with the presence of the flames.

3.3.2 Heat and Cold

Bounding temperatures for NCT with insolation are evaluated using a transient calculation in which 12 hour periods of insolation at the specified rates are followed by 12 hour of no insolation. This approach is consistent with the intent of 10 CFR 71.71, which implies that the limiting condition is continual outdoor exposure of the WVMP, with insolation during daylight hours and no insolation at night. The heat losses to the ambient air are assumed to continue day and night. The ambient air temperature is set equal to 100°F for nighttime exposure as well as daytime exposure. The COMSOL® calculations were extended to 30 days to assure an approach to a limiting diurnal temperature cycle. The limiting NCT conditions are evaluated at the end of the 12-hour period of insolation on the thirtieth day.

Table 3-5 summarizes the results of the NCT thermal analysis. The maximum temperature for exposure to 100°F air is 105.4°F, for the melter glass. Although the COMSOL® model predicts a surface temperature very close to the ambient air temperature, the glass temperature must be assigned as the bounding maximum surface temperature, because of the close approach of one arm of the melter to the bolted side door on one side of the WVMP. The maximum glass temperature of 105.4°F does not closely approach the limiting surface temperature of 185°F. The minimum temperatures for exposure to -20°F and -40°F ambient air are -19.9°F and -39.9°F, respectively. The maximum temperature with insolation is 209.4°F, for the container.

In keeping with the intent of 10 CFR 71.71, the maximum temperature is evaluated only at the end of 30 days, when the postulated diurnal temperature variations approach their cyclic limit. Although the maximum temperature after one day of insolation exceeds the maximum temperature for this limit, the one-day results are not used, because the calculation approach is not representative of the actual temperature cycles for heating of the WVMP by insolation. The maximum pressure is computed only for the case of insolation and exposure to 100°F air.

Figures 3-7 and 3-8 illustrate the development of the NCT temperature profile at the end of the 12-hour heating cycle, after 10 days and 30 days. It may be seen that the transient temperature distribution approaches a limiting profile reasonably closely after one cycle and quite closely after 10 days. The maximum temperature is 209.4°F and the minimum temperature is 133.1°F. Temperatures in the melter and the LDCC are close to the minimum temperature due to the relatively low thermal conductivity of the LDCC. The temperature increases toward the maximum only in the air pocket and the top wall of the WVMP.

The WVMP is a unique content package analyzed for a single use shipment. Therefore, the requirement for analysis of the effects of degradation in heat transfer due to expansion and contraction and other aging phenomena is not applicable, and these effects were not investigated. The effect of air gaps on material thermal conductivity is incorporated, either explicitly, as for the air pockets above the LDCC layer and inside the melter, or implicitly, in the bulk thermal conductivity of the LDCC.

Table 3-5. Limiting Conditions for NCT

NCT, No Insolation, 100°F Ambient Air		
Component	**Maximum Temperature**	
Overall	105.4°F	
Glass	105.4°F[(1)]	
Melter	101.5°F	
LDCC	101.0°F	
Air Pocket	100.3°F	
Container	100.2°F	
NCT, No Insolation, -20°F Ambient Air		
Component	**Minimum Temperature**	
Overall	-19.9°F	
Glass	-18.7°F[(1)]	
Melter	-19.2°F	
LDCC	-19.9°F	
Air Pocket	-19.9°F	
Container	-19.9°F	
NCT, No Insolation, -40°F Ambient Air		
Component	**Minimum Temperature**	
Overall	-39.9°F	
Glass	-38.7°F[(1)]	
Melter	-39.2°F	
LDCC	-39.9°F	
Air Pocket	-39.9°F	
Container	-39.9°F	
With Insolation, 100 °F Ambient Air		
Component	**Maximum Temperature**	**Maximum Pressure (psig)**
Overall	209.4°F	12.0
Glass	146.3°F	-
Melter	144.6°F	-
LDCC	183.5°F	-
Air Pocket	208.9°F	-
Container	209.4°F	-

NOTE: (1) The glass temperature exceeds the melter temperature due to radiolytic heating.

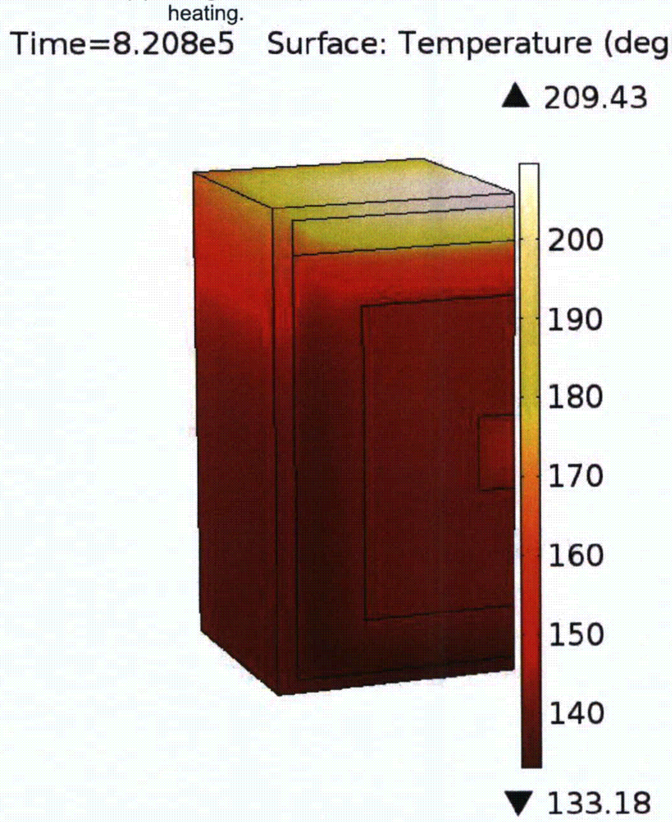


Figure 3-7. Temperature Profile for NCT with Insolation after 10 Days

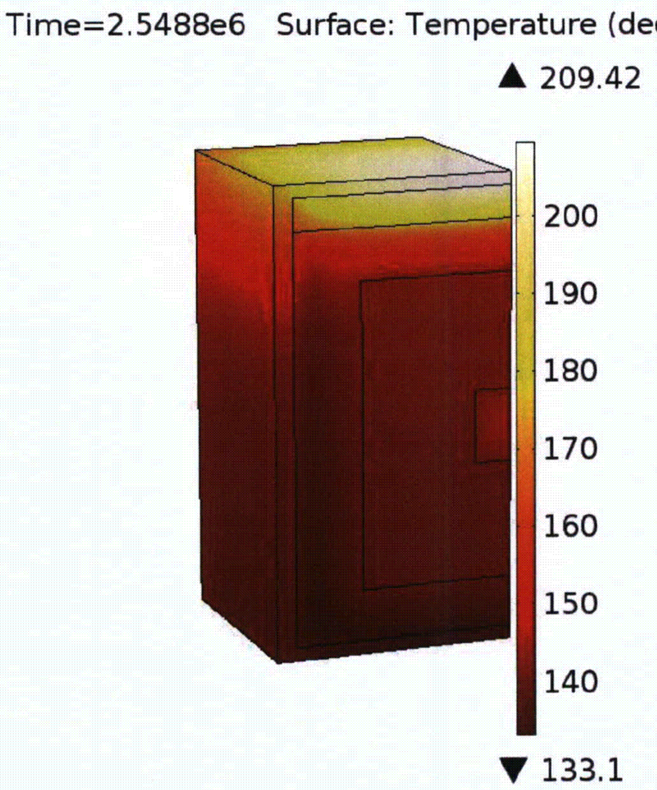


Figure 3-8. Temperature Profile for NCT with Insolation after 30 Days

3.3.3 Maximum Normal Operating Pressure

The maximum pressure is calculated by assuming all of the hydrated water content is released as vapor due to heating of the LDCC and accumulates in the upper air pocket. It is assumed any pressure that might develop internally in the concrete pores is contained within the LDCC layer. The gas volume inside the LDCC pores is conservatively neglected in the pressure calculation. The air pocket pressure computation is based on the ideal gas law and is performed separately from the COMSOL® heat transfer calculations. The equation for the maximum pressure is

$$P = P_0\left(1+\frac{n_{H_2O}}{n_{air}}\right)\frac{T}{T_0} \qquad (3.3.2\text{-}1)$$

where

P = maximum pressure for NCT or HAC, atm or psia

P_0 = initial pressure, assumed to be equal to atmospheric pressure, atm or psia

n_{H_2O} = number of moles of water vapor generated by dehydration of the LDCC

n_{air} = number of moles of air initially in the air gap

T = average temperature in the air gap, K

T_0 = initial temperature in the air gap, assumed to be equal to 20 °C or 293.15 K

The number of moles of air at the start of the NCT transient is calculated using the ideal gas law relation

$$n_{air} = \frac{P_0 V_{air}}{R_g T_0} \qquad (3.3.2\text{-}2)$$

where

V_{air} = volume of the air gap, m^3

R_g = gas law constant, 8.2057E-5 m^3 atm/mol/K

The number of moles of water evaporated is computed by taking the difference between the number of moles of hydrated water initially in the LDCC and the minimum number of moles that remain hydrated at any time during the HAC fire or cool-down period:

$$n_{H_2O} = \left(\rho_{H_2O,LDCC,0} - \overline{\rho}_{H_2O,LDCC}\right)V_{LDCC} \qquad (3.3.2\text{-}3)$$

where

$\rho_{H_2O,LDCC,0}$ = initial concentration of hydrated water in the LDCC, kg/m^3

$\overline{\rho}_{H_2O,LDCC}$ = minimum average bulk concentration of hydrated water in the LDCC, kg/m^3

V_{LDCC} = total LDCC volume, m^3

The maximum WVMP pressure of 12.0 psig is calculated from an assumption that the active pressurization of the container is from the air pocket at the top of the WVMP. The calculated pressure is based on heating of this air from an assumed initial temperature of 68°F to an average temperature of 184.30°F. The pressurization also accounts for the vaporization of 62 moles of hydrated water to add to the 126 moles of air initially present in the air pocket.

3.4 Thermal Evaluation under Hypothetical Accident Conditions

The HAC is modeled using a transient calculation in which the WVMP is fully engulfed by the 1475°F fire. The analysis method is the same as that used for NCT, described in Section 3.2.

3.4.1 Initial Conditions

The initial temperature distribution is set equal to the limiting NCT temperature distribution, at the end of 12 hour insolation, at rates of 800 cal/cm^2 on the top surface and 200 cal/cm^2 on the side surfaces.

The orientation of the WVMP during HAC is not specified by 10 CFR 71.73. To maximize the temperature of the air pocket inside the WVMP and hence the pressurization due to heating, it was assumed that the WVMP is upside down, so that natural convection heat losses from the wall adjacent to the air pocket were minimized during the cool-down period, when the interior temperatures reached their maximum values. (The natural convection heat transfer coefficient for heated surfaces facing down is less than the corresponding heat transfer coefficients for heated surfaces facing up or for vertical surfaces.)

The structural analysis in Chapter 2 demonstrates minimal effects on the WVMP due to HAC accidents. Based on these analyses the thermal analysis does not incorporate any effects to the WVMP dimensions or material properties due to HAC drops and crushes. The HAC temperatures and pressures calculated by the thermal analysis are bounding for HAC accidents.

3.4.2 Fire Test Conditions

The fire is applied for 30 minutes, after which time it is assumed that the WVMP loses heat to 100°F ambient air and receives insolation at the same rate as during NCT. The transient calculation is continued 720 minutes into the cool-down period to ensure that maximum local temperatures are reached and that the maximum amount of dehydration has occurred. (It is assumed that the dehydration reaction is reversible in the sense that the cement will rehydrate as it cools.)

3.4.3 Maximum Temperatures and Pressure

Table 3-6 reports the results of the HAC thermal analysis. The maximum temperature of 1221.1°F is located at the corners of the WVMP. The average temperature of the LDCC increases to 204.0°F, and the average temperature of the air pocket rises to 599.4°F. The temperatures of the melter and the melter glass are virtually unaffected by the 30 minute fire. The maximum pressure for HAC of 73.0 psig is calculated based on the maximum average air pocket temperature and a maximum amount of evaporation of 249 moles of water. The maximum pressure conditions occur after the end of the fire exposure, during the cool-down period. The exact time at which the

pressure peaks is not listed because the maximum pressure is based on a combination of the maximum air pocket temperature and the maximum amount of hydrated water that evaporates; these maximums are reached at different times.

Table 3-6. Limiting Conditions for HAC

With Insolation, 100°F Ambient Air, 1475°F Fire Exposure for 30 minutes				
Component	**Maximum Temperature**	**Average Temperature**	**Maximum Pressure (psig)**	**Time for Maximum Temp. (minutes)**
Overall	1221.1°F	-	73.0	30
Glass	146.3°F	-	-	750+(1)
Melter	145.2°F	-	-	750+(2)
LDCC	693.0°F	204.0°F	-	68
Air Pocket	727.9°F	599.4°F	-	68
Container	1221.1°F	-	-	30

NOTES: (1) The maximum glass temperature for HAC is the same as for NCT.

(2) The glass and melter temperatures had not peaked 750 minutes after the start of the fire (720 minutes after the end of the fire exposure), but are judged to have been within 1°F of their peak values.

Figure 3-9 shows the variation of the average LDCC and WVMP air pocket temperatures during the HAC fire transient. The average LDCC temperature reaches its maximum value of 204.0°F 592 minutes after the start of the fire (and 562 minutes after the end of the fire exposure), and the average air pocket temperature peaks at 599.4°F 68 minutes after the start of the fire. Figure 3-10 depicts the variation of the average bulk hydrated water content of the LDCC during the fire transient. The minimum hydrated water content, with the evaporation of a maximum 249 moles of water, occurs 256 minutes after the start of the fire.

Figure 3-11 shows the HAC temperature profile at the end of the 30 minutes fire exposure, when the WVMP wall temperature is at its maximum. It may be noted that the 1221.1°F maximum temperature is confined to the eight corners of the WVMP. The average container plate temperatures remain below 800°F. The average temperature of the hottest plate, adjacent to the WVMP air pocket, is 782.2°F on the outer surface and 626.9°F on the inside surface. The average plate temperature is approximately equal to the average of these two temperatures, which is 711.1°F. Except for that portion of the LDCC closest to the container and the air pocket at the end of the WVMP, the temperatures inside the WVMP do not vary significantly from their initial values for NCT with insolation.

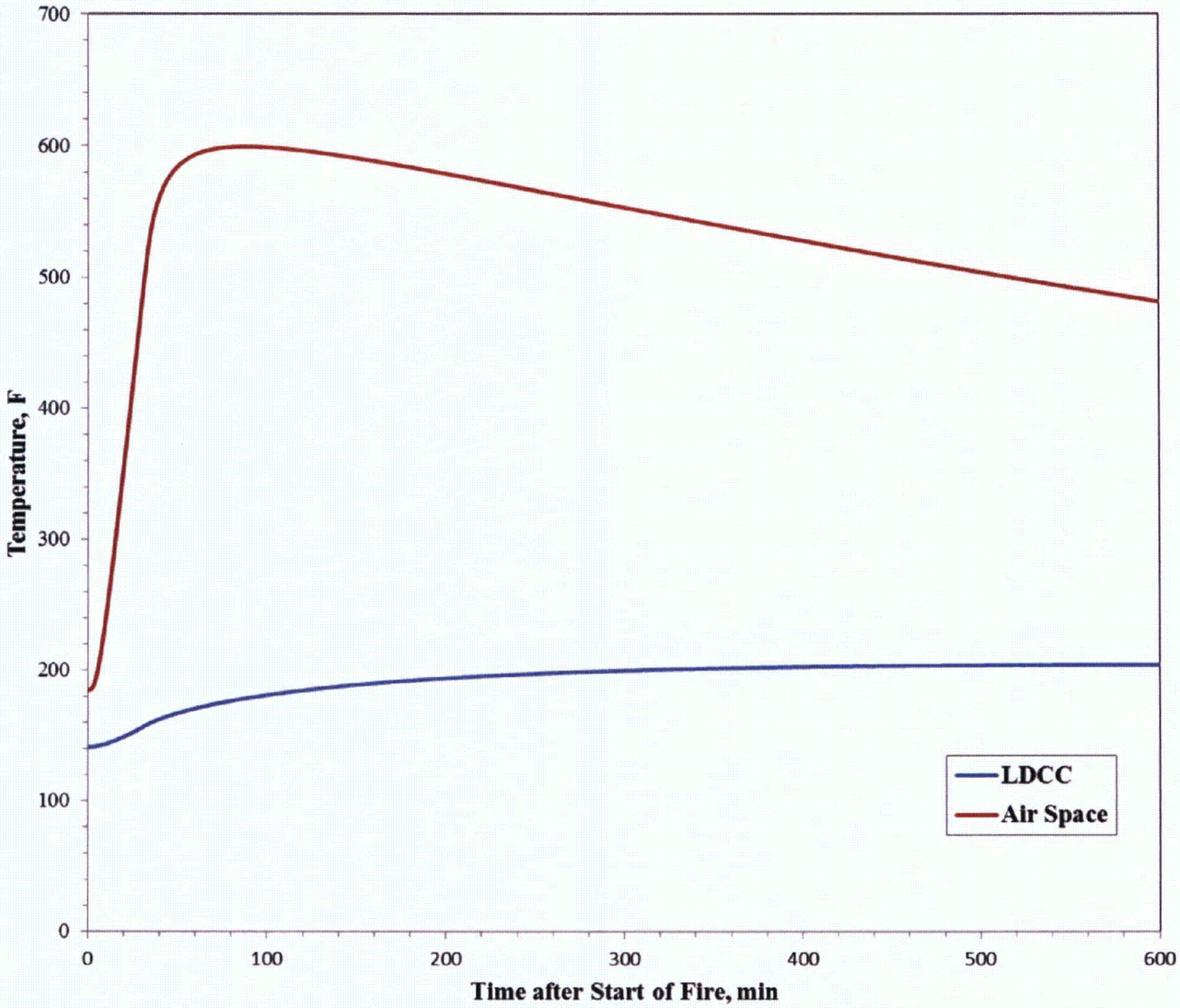


Figure 3-9. Variation of Average LDCC and WVMP Air Pocket Temperatures during the HAC Fire Scenario

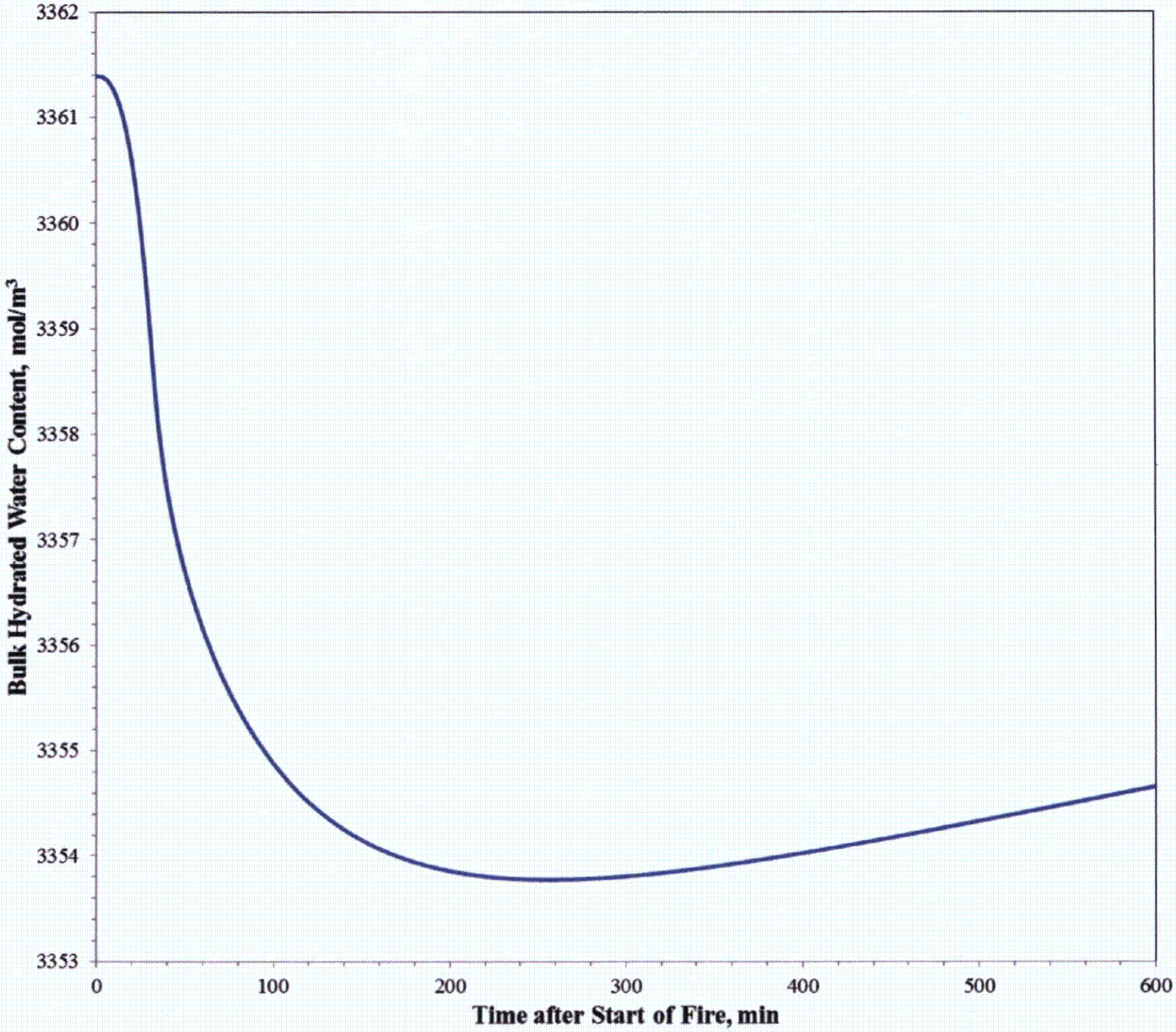


Figure 3-10. Variation of Average Bulk Hydrated Water Content in LDCC During HAC Fire Scenario

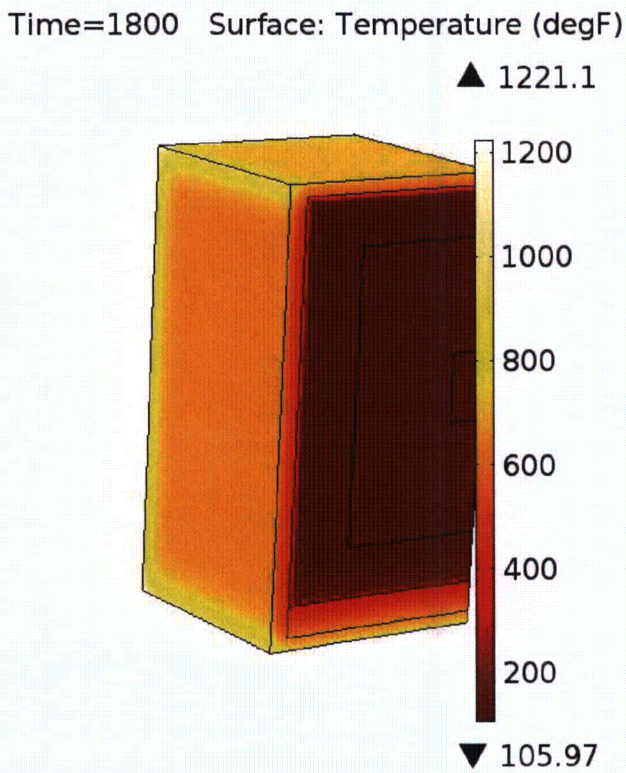


Figure 3-11. Surface Temperature Profile for HAC after 30 Minutes Fire Exposure

3.4.4 Maximum Thermal Stresses

The WVMP does not include any components for which there would be adverse consequences due to a thermal stress failure. Thermal stresses in the container walls are addressed in Chapter 2 of this SAR. Therefore, a thermal stress analysis is not included as part of the HAC thermal evaluation.

3.4.5 Accident Conditions for Fissile Material Packages for Air Transport

Not applicable.

3.5 Appendix

This appendix contains the following information:

3.5.1 References

3.5.2 Summary of the Radionuclide Content and Radiolytic Heating for the Grouted Melter Package

3.5.3 Parameter and Variable List for COMSOL® Multiphysics Model

3.5.4 *Thermal Analysis for West Valley Melter Package*, Calculation Number M-CLC-A-00498, Savannah River National Laboratory, October 2014. (provided)

APPENDIX 3.5.1 – REFERENCES

3-1 10 CFR Part 71.71, *Packaging and Transportation of Radioactive Material: Normal conditions of transport*, Code of Federal Regulations, July 2013.

3-2 10 CFR Part 71.73, *Packaging and Transportation of Radioactive Material: Hypothetical accident conditions*, Code of Federal Regulations, July 2013.

3-3 10 CFR Part 71.43, *General Standards for All Packages*, Code of Federal Regulations, July 2014.

3-4 10 CFR Part 71.51, *Additional Requirements for Type B Packages*, Code of Federal Regulations, July 2014.

3-5 *West Valley Melter Container*, Drawing 4005-DW-001, Revision 7, WMG, Inc., Peekskill, New York, June 26, 2013. (provided in Chapter 1)

3-6 Structural Evaluation of WVMP to Specific Requirements of 10 CFR Part 71.71," M-CLC-A-00497, Revision 0, C. A. McKeel, Savannah River National Laboratory, September 2014. (see Chapter 2)

3-7 *West Valley Demonstration Project Waste Characterization of Vitrification Melter*, WVDP-577, Brandjes, C., CH2M Hill-B&W West Valley, LLC, West Valley, New York, September 2014. (provided)

3-8 *Refractory with Ave. Geomean 6-77 Act.rad*, C. Brandjes, Ameriphysics, LLC, Knoxville, Tennessee, June 26, 2014. (provided)

3-9 *Melter Heal (sp) with Shard Data_062714.rad*, C. Brandjes, Ameriphysics, LLC, Knoxville, Tennessee, June 27, 2014. (provided)

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APPENDIX 3.5.2 – SUMMARY OF RADIONUCLIDE CONTENT AND RADIOLYTIC HEATING FOR WVMP

Table A-1. Radionuclide Content and Radiolytic Heating for Glass in Melter

Isotope	Ci	Mev/d	W/Ci	W
C-14	3.47E-03	0.0495	2.93E-04	1.02E-06
K-40	1.50E-02	0.6785	4.02E-03	6.03E-05
Mn-54	1.44E-06	0.8402	4.98E-03	7.16E-09
Co-60	3.16E-03	2.6007	1.54E-02	4.87E-05
Ni-63	1.52E-01	0.0174	1.03E-04	1.57E-05
Sr-90	3.12E+01	0.1957	1.16E-03	3.62E-02
Y-90	3.12E+01	0.9331	5.53E-03	1.73E-01
Zr-95	1.30E-20	0.8506	5.04E-03	6.55E-23
Nb-95	2.86E-20	0.8091	4.80E-03	1.37E-22
Nb-95m	1.49E-22	0.2497	1.48E-03	2.20E-25
Tc-99	2.01E-03	0.1013	6.01E-04	1.21E-06
Cs-137	5.42E+02	0.1884	1.12E-03	6.05E-01
Ba-137m	5.12E+02	0.6617	3.92E-03	2.01E+00
Eu-154	8.12E-02	1.5223	9.02E-03	7.33E-04
Hg-206	9.79E-16	0.5426	3.22E-03	3.15E-18
Tl-206	6.88E-14	0.5399	3.20E-03	2.20E-16
Tl-207	2.56E-09	0.4975	2.95E-03	7.55E-12
Tl-208	2.72E-03	3.9716	2.35E-02	6.40E-05
Tl-209	8.09E-08	2.8302	1.68E-02	1.36E-09
Tl-210	6.54E-11	4.0331	2.39E-02	1.56E-12
Pb-209	3.75E-06	0.1974	1.17E-03	4.38E-09
Pb-210	5.16E-08	0.0457	2.71E-04	1.40E-11
Pb-211	2.57E-09	0.5187	3.07E-03	7.89E-12
Pb-212	7.56E-03	0.3217	1.91E-03	1.44E-05
Pb-214	3.11E-07	0.5481	3.25E-03	1.01E-09
Bi-209	8.10E-25	----	----	----
Bi-210	5.14E-08	0.3889	2.31E-03	1.18E-10
Bi-211	2.57E-09	6.733	3.99E-02	1.02E-10
Bi-212	7.56E-03	2.8247	1.67E-02	1.27E-04
Bi-213	3.75E-06	0.6963	4.13E-03	1.55E-08
Bi-214	3.11E-07	2.1436	1.27E-02	3.96E-09
Bi-215	2.10E-15	0.9228	5.47E-03	1.15E-17
Po-210	4.71E-08	5.4075	3.21E-02	1.51E-09
Po-211	7.01E-12	7.5944	4.50E-02	3.15E-13
Po-212	4.84E-03	8.9541	5.31E-02	2.57E-04
Po-213	3.67E-06	8.537	5.06E-02	1.86E-07
Po-214	3.11E-07	7.8335	4.64E-02	1.45E-08
Po-215	2.57E-09	7.5263	4.46E-02	1.14E-10
Po-216	7.56E-03	6.9064	4.09E-02	3.10E-04
Po-218	3.11E-07	6.1135	3.62E-02	1.13E-08
At-215	1.03E-14	8.178	4.85E-02	4.97E-16
At-217	3.75E-06	7.2011	4.27E-02	1.60E-07
At-218	5.92E-11	6.8053	4.03E-02	2.39E-12
At-219	2.17E-15	6.1343	3.64E-02	7.87E-17
Rn-217	4.50E-10	7.8856	4.67E-02	2.10E-11
Rn-218	5.92E-14	7.2626	4.31E-02	2.55E-15
Rn-219	2.57E-09	6.9456	4.12E-02	1.06E-10
Rn-220	7.56E-03	6.4047	3.80E-02	2.87E-04
Rn-222	3.11E-07	5.5903	3.31E-02	1.03E-08

Table A-1. Radionuclide Content and Radiolytic Heating for Glass in Melter (continued)

Isotope	Ci	Mev/d	W/Ci	W
Fr-221	3.75E-06	6.4582	3.83E-02	1.43E-07
Fr-223	3.61E-11	0.4415	2.62E-03	9.44E-14
Ra-223	2.57E-09	5.9895	3.55E-02	9.11E-11
Ra-224	7.56E-03	5.7893	3.43E-02	2.60E-04
Ra-225	3.76E-06	0.1194	7.08E-04	2.66E-09
Ra-226	3.12E-07	4.8716	2.89E-02	9.00E-09
Ra-228	5.14E-05	0.0163	9.66E-05	4.97E-09
Ac-225	3.75E-06	5.9338	3.52E-02	1.32E-07
Ac-227	2.61E-09	0.0853	5.06E-04	1.32E-12
Ac-228	5.14E-05	1.3166	7.80E-03	4.01E-07
Th-227	2.55E-09	6.1955	3.67E-02	9.36E-11
Th-228	7.56E-03	5.5202	3.27E-02	2.47E-04
Th-229	3.78E-06	5.1772	3.07E-02	1.16E-07
Th-230	6.05E-05	4.7702	2.83E-02	1.71E-06
Th-231	6.15E-05	0.1891	1.12E-03	6.89E-08
Th-232	6.74E-05	4.0829	2.42E-02	1.63E-06
Th-234	3.74E-04	0.0728	4.32E-04	1.61E-07
Pa-231	1.55E-08	5.158	3.06E-02	4.75E-10
Pa-233	1.05E-03	0.438	2.60E-03	2.73E-06
Pa-234	5.61E-07	1.8755	1.11E-02	6.24E-09
Pa-234m	3.74E-04	0.8334	4.94E-03	1.85E-06
U-232	7.31E-03	5.4135	3.21E-02	2.35E-04
U-233	3.35E-03	4.9085	2.91E-02	9.75E-05
U-234	1.60E-03	4.8587	2.88E-02	4.62E-05
U-235	6.15E-05	4.6891	2.78E-02	1.71E-06
U-235m	2.61E-02	0	0.00E+00	0.00E+00
U-236	1.84E-04	4.5723	2.71E-02	4.99E-06
U-237	7.37E-06	0.3433	2.04E-03	1.50E-08
U-238	3.74E-04	4.2691	2.53E-02	9.46E-06
Np-237	1.05E-03	4.9529	2.94E-02	3.09E-05
Np-239	5.97E-03	0.4469	2.65E-03	1.58E-05
Pu-238	1.04E-01	5.593	3.32E-02	3.44E-03
Pu-239	2.61E-02	5.2442	3.11E-02	8.11E-04
Pu-240	2.01E-02	5.2559	3.12E-02	6.25E-04
Pu-241	2.99E-01	0.0054	3.20E-05	9.57E-06
Am-241	4.95E-01	5.6379	3.34E-02	1.66E-02
Am-243	5.97E-03	5.4402	3.22E-02	1.93E-04
Cm-242	3.08E-10	6.2156	3.68E-02	1.14E-11
Cm-243	2.16E-03	6.1624	3.65E-02	7.90E-05
Cm-244	4.70E-02	5.9014	3.50E-02	1.64E-03
Totals:	**1.12E+03**			**2.85E+00**

Table A-2. Radionuclide Content and Radiolytic Heating for Glass in Spout

Isotope	Ci	Mev/d	W/Ci	W
C-14	2.22E-03	0.0495	2.93E-04	6.51E-07
K-40	8.60E-03	0.6785	4.02E-03	3.46E-05
Mn-54	5.00E-07	0.8402	4.98E-03	2.49E-09
Co-60	5.47E-03	2.6007	1.54E-02	8.43E-05
Ni-63	9.80E-02	0.0174	1.03E-04	1.01E-05
Sr-90	6.33E+01	0.1957	1.16E-03	7.35E-02
Y-90	6.33E+01	0.9331	5.53E-03	3.50E-01
Zr-95	3.17E-22	0.8506	5.04E-03	1.60E-24
Nb-95	6.99E-22	0.8091	4.80E-03	3.35E-24
Nb-95m	3.63E-24	0.2497	1.48E-03	5.37E-27
Tc-99	1.57E-02	0.1013	6.01E-04	9.43E-06
Cs-137	8.57E+02	0.1884	1.12E-03	9.57E-01
Ba-137m	8.09E+02	0.6617	3.92E-03	3.17E+00
Eu-154	1.04E-01	1.5223	9.02E-03	9.41E-04
Hg-206	7.14E-16	0.5426	3.22E-03	2.30E-18
Tl-206	5.01E-14	0.5399	3.20E-03	1.60E-16
Tl-207	1.86E-09	0.4975	2.95E-03	5.49E-12
Tl-208	1.73E-03	3.9716	2.35E-02	4.08E-05
Tl-209	5.58E-08	2.8302	1.68E-02	9.36E-10
Tl-210	4.50E-11	4.0331	2.39E-02	1.07E-12
Pb-209	2.58E-06	0.1974	1.17E-03	3.02E-09
Pb-210	3.76E-08	0.0457	2.71E-04	1.02E-11
Pb-211	1.87E-09	0.5187	3.07E-03	5.74E-12
Pb-212	4.82E-03	0.3217	1.91E-03	9.20E-06
Pb-214	2.14E-07	0.5481	3.25E-03	6.95E-10
Bi-209	5.97E-25	----	----	----
Bi-210	3.75E-08	0.3889	2.31E-03	8.63E-11
Bi-211	1.87E-09	6.733	3.99E-02	7.46E-11
Bi-212	4.82E-03	2.8247	1.67E-02	8.08E-05
Bi-213	2.58E-06	0.6963	4.13E-03	1.07E-08
Bi-214	2.14E-07	2.1436	1.27E-02	2.72E-09
Bi-215	1.53E-15	0.9228	5.47E-03	8.35E-18
Po-210	3.45E-08	5.4075	3.21E-02	1.11E-09
Po-211	5.10E-12	7.5944	4.50E-02	2.30E-13
Po-212	3.09E-03	8.9541	5.31E-02	1.64E-04
Po-213	2.53E-06	8.537	5.06E-02	1.28E-07
Po-214	2.14E-07	7.8335	4.64E-02	9.94E-09
Po-215	1.87E-09	7.5263	4.46E-02	8.33E-11
Po-216	4.82E-03	6.9064	4.09E-02	1.97E-04
Po-218	2.14E-07	6.1135	3.62E-02	7.76E-09
At-215	7.47E-15	8.178	4.85E-02	3.62E-16
At-217	2.58E-06	7.2011	4.27E-02	1.10E-07
At-218	4.07E-11	6.8053	4.03E-02	1.64E-12
At-219	1.57E-15	6.1343	3.64E-02	5.72E-17
Rn-217	3.10E-10	7.8856	4.67E-02	1.45E-11
Rn-218	4.07E-14	7.2626	4.31E-02	1.75E-15
Rn-219	1.87E-09	6.9456	4.12E-02	7.69E-11
Rn-220	4.82E-03	6.4047	3.80E-02	1.83E-04
Rn-222	2.14E-07	5.5903	3.31E-02	7.10E-09
Fr-221	2.58E-06	6.4582	3.83E-02	9.89E-08
Fr-223	2.62E-11	0.4415	2.62E-03	6.87E-14
Ra-223	1.87E-09	5.9895	3.55E-02	6.63E-11
Ra-224	4.82E-03	5.7893	3.43E-02	1.66E-04

Table A-2. Radionuclide Content and Radiolytic Heating for Glass in Spout (continued)

Isotope	Ci	Mev/d	W/Ci	W
Ra-225	2.59E-06	0.1194	7.08E-04	1.83E-09
Ra-226	2.14E-07	4.8716	2.89E-02	6.19E-09
Ra-228	3.41E-05	0.0163	9.66E-05	3.29E-09
Ac-225	2.58E-06	5.9338	3.52E-02	9.09E-08
Ac-227	1.90E-09	0.0853	5.06E-04	9.61E-13
Ac-228	3.41E-05	1.3166	7.80E-03	2.66E-07
Th-227	1.85E-09	6.1955	3.67E-02	6.81E-11
Th-228	4.82E-03	5.5202	3.27E-02	1.58E-04
Th-229	2.60E-06	5.1772	3.07E-02	7.99E-08
Th-230	3.89E-05	4.7702	2.83E-02	1.10E-06
Th-231	3.95E-05	0.1891	1.12E-03	4.43E-08
Th-232	4.34E-05	4.0829	2.42E-02	1.05E-06
Th-234	2.41E-04	0.0728	4.32E-04	1.04E-07
Pa-231	1.07E-08	5.158	3.06E-02	3.26E-10
Pa-233	7.09E-04	0.438	2.60E-03	1.84E-06
Pa-234	3.62E-07	1.8755	1.11E-02	4.02E-09
Pa-234m	2.41E-04	0.8334	4.94E-03	1.19E-06
U-232	4.66E-03	5.4135	3.21E-02	1.50E-04
U-233	2.16E-03	4.9085	2.91E-02	6.29E-05
U-234	1.03E-03	4.8587	2.88E-02	2.98E-05
U-235	3.95E-05	4.6891	2.78E-02	1.10E-06
U-235m	3.01E-02	0	0.00E+00	0.00E+00
U-236	1.19E-04	4.5723	2.71E-02	3.23E-06
U-237	4.56E-06	0.3433	2.04E-03	9.27E-09
U-238	2.41E-04	4.2691	2.53E-02	6.10E-06
Np-237	7.09E-04	4.9529	2.94E-02	2.08E-05
Np-239	4.55E-03	0.4469	2.65E-03	1.20E-05
Pu-238	1.14E-01	5.593	3.32E-02	3.78E-03
Pu-239	3.01E-02	5.2442	3.11E-02	9.35E-04
Pu-240	2.29E-02	5.2559	3.12E-02	7.15E-04
Pu-241	1.85E-01	0.0054	3.20E-05	5.92E-06
Am-241	3.80E-01	5.6379	3.34E-02	1.27E-02
Am-243	4.55E-03	5.4402	3.22E-02	1.47E-04
Cm-242	1.05E-11	6.2156	3.68E-02	3.86E-13
Cm-243	1.85E-03	6.1624	3.65E-02	6.77E-05
Cm-244	4.07E-02	5.9014	3.50E-02	1.42E-03
Totals:	**1.79E+03**			**4.57E+00**

Table A-3. Radionuclide Content and Radiolytic Heating for Glass in Refractory

Isotope	Ci	Mev/d	W/Ci	W
Co-60	1.33E-02	2.6007	1.54E-02	2.05E-04
Sr-90	1.07E+02	0.1957	1.16E-03	1.24E-01
Y-90	1.07E+02	0.9331	5.53E-03	5.91E-01
Tc-99	5.22E-02	0.1013	6.01E-04	3.13E-05
Cs-137	2.13E+02	0.1884	1.12E-03	2.38E-01
Ba-137m	2.01E+02	0.6617	3.92E-03	7.89E-01
Eu-154	5.53E-01	1.5223	9.02E-03	4.99E-03
Hg-206	2.54E-16	0.5426	3.22E-03	8.16E-19
Tl-206	1.78E-14	0.5399	3.20E-03	5.70E-17
Tl-207	2.96E-09	0.4975	2.95E-03	8.73E-12
Tl-208	1.81E-04	3.9716	2.35E-02	4.25E-06
Tl-209	1.43E-08	2.8302	1.68E-02	2.41E-10
Tl-210	1.67E-11	4.0331	2.39E-02	4.00E-13
Pb-209	6.64E-07	0.1974	1.17E-03	7.77E-10
Pb-210	1.34E-08	0.0457	2.71E-04	3.62E-12
Pb-211	2.97E-09	0.5187	3.07E-03	9.13E-12
Pb-212	5.03E-04	0.3217	1.91E-03	9.58E-07
Pb-214	7.96E-08	0.5481	3.25E-03	2.59E-10
Bi-209	1.46E-25	----	----	----
Bi-210	1.33E-08	0.3889	2.31E-03	3.07E-11
Bi-211	2.97E-09	6.733	3.99E-02	1.18E-10
Bi-212	5.03E-04	2.8247	1.67E-02	8.42E-06
Bi-213	6.64E-07	0.6963	4.13E-03	2.74E-09
Bi-214	7.96E-08	2.1436	1.27E-02	1.01E-09
Bi-215	2.43E-15	0.9228	5.47E-03	1.33E-17
Po-210	1.22E-08	5.4075	3.21E-02	3.92E-10
Po-211	8.10E-12	7.5944	4.50E-02	3.65E-13
Po-212	3.22E-04	8.9541	5.31E-02	1.71E-05
Po-213	6.50E-07	8.537	5.06E-02	3.29E-08
Po-214	7.96E-08	7.8335	4.64E-02	3.70E-09
Po-215	2.97E-09	7.5263	4.46E-02	1.32E-10
Po-216	5.03E-04	6.9064	4.09E-02	2.06E-05
Po-218	7.96E-08	6.1135	3.62E-02	2.89E-09
At-215	1.19E-14	8.178	4.85E-02	5.75E-16
At-217	6.64E-07	7.2011	4.27E-02	2.83E-08
At-218	1.51E-11	6.8053	4.03E-02	6.10E-13
At-219	2.50E-15	6.1343	3.64E-02	9.10E-17
Rn-217	7.97E-11	7.8856	4.67E-02	3.73E-12
Rn-218	1.51E-14	7.2626	4.31E-02	6.51E-16
Rn-219	2.97E-09	6.9456	4.12E-02	1.22E-10
Rn-220	5.03E-04	6.4047	3.80E-02	1.91E-05
Rn-222	7.96E-08	5.5903	3.31E-02	2.64E-09
Fr-221	6.64E-07	6.4582	3.83E-02	2.54E-08
Fr-223	4.17E-11	0.4415	2.62E-03	1.09E-13
Ra-223	2.97E-09	5.9895	3.55E-02	1.05E-10
Ra-224	5.03E-04	5.7893	3.43E-02	1.72E-05
Ra-225	6.66E-07	0.1194	7.08E-04	4.72E-10
Ra-226	7.97E-08	4.8716	2.89E-02	2.30E-09
Ra-228	3.21E-05	0.0163	9.66E-05	3.10E-09
Ac-225	6.64E-07	5.9338	3.52E-02	2.34E-08
Ac-227	3.02E-09	0.0853	5.06E-04	1.53E-12
Ac-228	3.21E-05	1.3166	7.80E-03	2.51E-07
Th-227	2.95E-09	6.1955	3.67E-02	1.08E-10

Table A-3. Radionuclide Content and Radiolytic Heating for Glass in Refractory (continued)

	Isotope	Ci	Mev/d	W/Ci	W
	Th-228	5.02E-04	5.5202	3.27E-02	1.64E-05
	Th-229	6.70E-07	5.1772	3.07E-02	2.05E-08
	Th-230	1.52E-05	4.7702	2.83E-02	4.31E-07
	Th-231	6.92E-05	0.1891	1.12E-03	7.76E-08
	Th-232	4.18E-05	4.0829	2.42E-02	1.01E-06
	Th-234	1.16E-04	0.0728	4.32E-04	5.01E-08
	Pa-231	1.78E-08	5.158	3.06E-02	5.43E-10
	Pa-233	8.49E-04	0.438	2.60E-03	2.21E-06
	Pa-234	1.74E-07	1.8755	1.11E-02	1.93E-09
	Pa-234m	1.16E-04	0.8334	4.94E-03	5.73E-07
	U-232	4.41E-04	5.4135	3.21E-02	1.41E-05
	U-233	5.85E-04	4.9085	2.91E-02	1.70E-05
	U-234	2.84E-04	4.8587	2.88E-02	8.18E-06
	U-235	6.92E-05	4.6891	2.78E-02	1.92E-06
	U-235m	3.72E-02	0	0.00E+00	0.00E+00
	U-236	2.08E-04	4.5723	2.71E-02	5.64E-06
	U-237	5.08E-06	0.3433	2.04E-03	1.03E-08
	U-238	1.16E-04	4.2691	2.53E-02	2.94E-06
	Np-237	8.49E-04	4.9529	2.94E-02	2.49E-05
	Np-239	6.72E-03	0.4469	2.65E-03	1.78E-05
	Pu-238	1.41E-01	5.593	3.32E-02	4.67E-03
	Pu-239	3.72E-02	5.2442	3.11E-02	1.16E-03
	Pu-240	2.85E-02	5.2559	3.12E-02	8.87E-04
	Pu-241	2.06E-01	0.0054	3.20E-05	6.61E-06
	Am-241	8.45E-01	5.6379	3.34E-02	2.82E-02
	Am-243	6.72E-03	5.4402	3.22E-02	2.17E-04
	Cm-242	4.49E-11	6.2156	3.68E-02	1.65E-12
	Cm-243	3.04E-03	6.1624	3.65E-02	1.11E-04
	Cm-244	6.77E-02	5.9014	3.50E-02	2.37E-03
Totals:		**6.30E+02**			**1.79E+00**

Table A-4. Total Radiolytic Heating Rate

Glass in Melter	2.85 W
Glass in Spout	4.57 W
Glass in Refractory	0.79 W
Total	**9.21 W**

APPENDIX 3.5.3 – PARAMETER AND VARIABLE LISTS FOR COMSOL® MULTIPHYSICS MODEL

Parameter List for COMSOL® Multiphysics Model

Parameter	Value or Formula
SidePlateTh	6[in]
TopPlateTh	4[in]
BottomPlateTh	4[in]
GlassSide	1.851377[ft]
FireBrick	7.838387[ft]
SteelCase	7.838387[ft]
Tamb	100[degF]
k_304L	20[W/m/K]
rho_304L	7850[kg/m^3]
cp_304L	475[J/(kg*K)]
FireT	1475[degF]
Rig	8.314[J/mol/K]
CaO_init	1 / 3 * CementRho / CaO_MW
CaSiO_init	2 / 3 * CementRho / CaSiO_MW
CaO_MW	56[g/mol]
CaSiO_MW	84[g/mol]
LDCC_Bulk	71.2[lb/ft^3]
CementRho	18.89[lb/ft^3]
Sand_rho	48.53[lb/ft^3]
BoundWater	3.78[lb/ft^3]
Total	BoundWater + Sand_rho + CementRho
BH2O_init	BoundWater / H2O_MW
H2O_MW	18[g/mol]
delH1	63.92[kJ/mol]
delH2	65.59[kJ/mol]
DelH_vap_Norm	40657[J/mol]
Tc	647.14[K]
AirGap	10[in]
Ea_Rg	3397[K]
Ar	15.426
ConcreteCP	765[J/kg/K]
glass_rho	2.6[g/cm^3]
glass_cp	810.9179[J/kg/K]

Variable List for COMSOL® Multiphysics Model

Variable	**Formula**
FireT	(1475[degF] - Tamb) * (t[1/s] <= 1800) + Tamb
alpha	Ar * exp(-Ea_Rg / mod1.T)
delH_Vap	gamma_func(mod1.T)
Tr	mod1.T / Tc
Trb	100[degC] / Tc
Concrete_effCp	ConcreteCP + (delH2 + delH_Vap) * BoundWater / Total / H2O_MW * Ea_Rg /T^2 * exp(-Ea_Rg / T)
CCaO	CaO_init * (1 - alpha)
CCaSiO	CaSiO_init * (1 - alpha)
CBH2O	BH2O_init - ((CaO_init - CCaO) + (CaSiO_init - CCaSiO))
CycleTime	flc2hs(sin(pi*t[1/s] / 43200), 0.01)
SS_516_k	(-1.4131e-5 * (T[1/degF])^2 + 0.0092585 * (T[1/degF]) + 39.440)[W/m/K]
SS_516_Cp	(6.49e-5 * (T[1/degF])^2 + 0.19059 * (T[1/degF]) + 447.66)[J/kg/K]
SS_516_rho	7749.7[kg/m^3]

Note: flc2hs is a continuous variable Heaviside step function in which the step change is applied using a continuous ramp. The first argument of this function is the independent variable value at the midpoint of the ramp, and the second argument is the width of the ramp from the midpoint to either end.

Note: mod1.T is the nodal temperature.

Note: The unit 1/degF in the formulas for SS_516_k and SS_516_Cp are input as a reciprocal unit to cancel the temperature units.

Note: Some parameters and variables are entered directly into the COMSOL® user interface and thus do not appear in the preceding lists.

4.0 CONTAINMENT

This chapter identifies the West Valley Melter Package (WVMP) containment system and describes how this package provides equivalent safety with the containment requirements of 10 CFR 71 (reference 4-1). Figure 4-1 shows a simplified cutaway view of the WVMP.

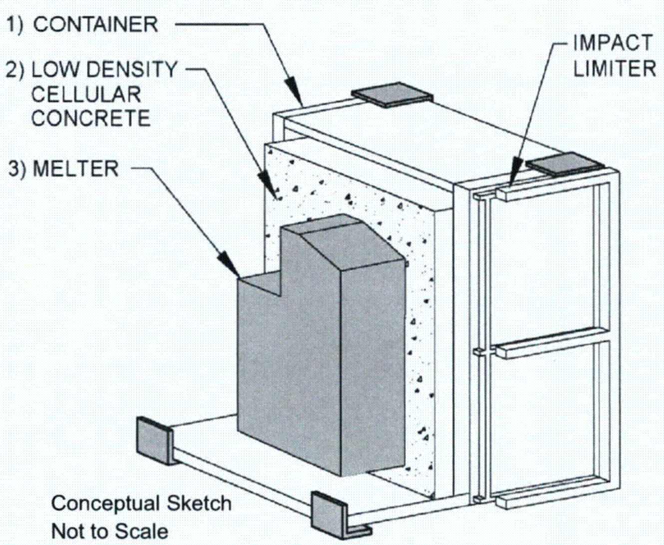

Figure 4-1. Components of the WVMP

The following information summarizes how the WVMP provides equivalent safety with the containment requirements, with more detailed information on the containment system and its performance under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) following this discussion.

Although the WVMP is not leaktight, several factors ensure that under NCT or HAC, a release of radioactive contents will not reach the release limits specified under 10 CFR 71. In addition, the WVMP contains no valves, pressure relief mechanisms, or closure devices that could be operated intentionally or unintentionally.

Aspects of the WVMP that ensure any release remains less than the limits include:

Key Terms and Acronyms in this Chapter	
ARF	Airborne Release Fraction
DR	Damage Ratios
HAC	Hypothetical Accident Conditions
LDCC	Low Density Cellular Concrete
LPF	Leak Path Factor
NCT	Normal Conditions of Transport
PBS	Polymeric Barrier System
RF	Respirable Fraction
RTV	Room Temperature Vulcanizing
WVMP	West Valley Melter Package (consisting of the container, the LDCC, and the melter with the Impact Limiter installed)

(1) Total radioactive content consists of 215 A_2 values, approximately 98 percent of the A_2s are contained within the residual borosilicate glass matrix adhered to the inside of the melter (reference 4-2). Based on the documented properties of the borosilicate glass, only a small fraction of the glass will become damaged, with an even smaller fraction becoming dispersible even under HAC.

(2) The melter in the WVMP remains intact after HAC, thus minimizing impact to the borosilicate glass and the Low Density Cellular Concrete (LDCC) located inside the melter.

(3) Radioactive contamination on the outside of the melter has been previously fixed in place using Bartlett's nuclear contamination control Polymeric Barrier System (PBS), a well-proven, hard-to- remove, impermeable material.

(4) The containment boundary is the container of the WVMP.

(5) Besides the container of the WVMP, there are multiple barriers between the radioactive contents and the environment that minimize the potential releases of the radioactive contents, such as:

a. The annulus between the outside shell of the WVMP and the melter was filled with LDCC, with some of the LDCC entering the melter. The LDCC binds any loose contents on the outside of the melter, and minimizes the likelihood of escape, providing another barrier to the release of surface contamination previously fixed with PBS, thus minimizing its escape.

b. The LDCC external to the melter encases the melter shell within the container, which minimizes the dispersible contents from the glass that might otherwise be created, serving as another barrier to dispersal of radioactive contents in the event of a breach in the containment boundary.

c. Bartlett's PBS has an approximate life of around 20 years and is a strong fixative and further captures any surface contamination.

Periodic and pre-shipment leak test criteria are not applicable as a measure of containment integrity, since the WVMP is not leaktight. Instead, it is shown that for NCT the maximum permitted leak rate in 10 CFR 71.51(a)(1) will not be exceeded based on negligible damage to the LDCC and the glass, and multiple barriers minimizing release. (reference 4-2) For HAC, it is shown the maximum permitted leak rate in 10 CFR 71.51(a)(2) cannot be exceeded because the combination of perimeter seal and face seal displacement occurring at the WVMP door joint are favorable (i.e., clear open gaps, with the largest displacements being transient at impact and recoverable) such that minimal content is releasable, and the multiple barriers with their torturous leak path must be overcome to result in release of radioactive content.

The package contains no explosive mixtures.

4.1 Description of the Containment System

Figure 4-2 shows the container before the melter was loaded into it.

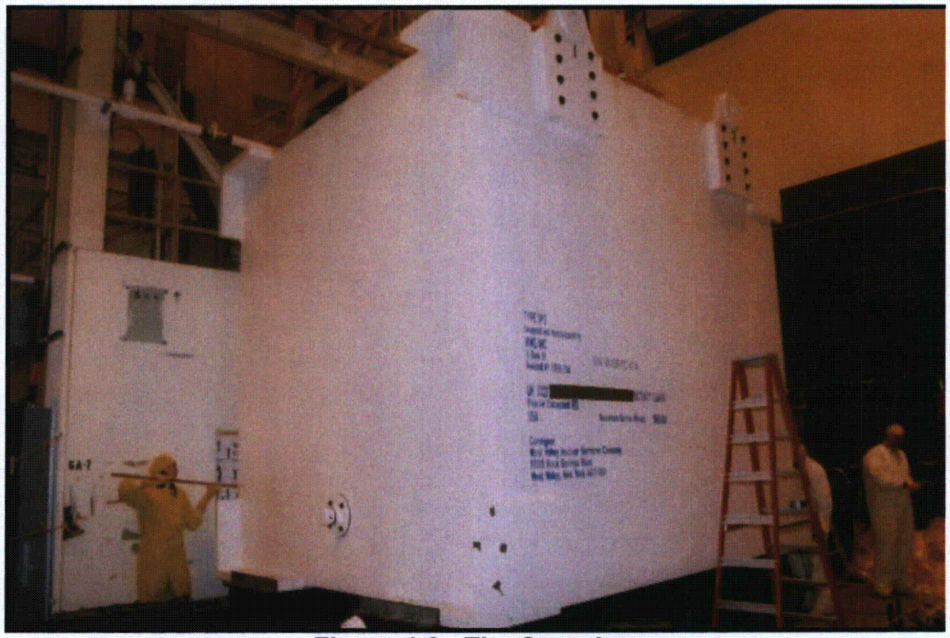

Figure 4-2. The Container

4.1.1 Containment Boundary

The container shown in Figure 4-2 forms the containment boundary for the WVMP. It serves as the outside container for the melter and the LDCC.

Engineering drawings used in fabrication of the container appear in Chapter 1. These drawings identify the dimensions, the materials of construction, and the types of welds used in the design.

The container is fabricated with ASTM SA-516, Grade 70 carbon steel for the package top, bottom, sides, end cover, and temporary attachments. The WVMP is approximately 15'9" long by 12'7" wide by 12'6.5" high with the dimensions of the container itself being 13'5" long by 12'4" wide by 12'4" high. The sides of the container are 6" thick and the top and bottom are 4" thick. Five sides are welded in place with the bolted side door on the sixth side. The empty container weighed approximately 208,000 lbs.

The container was designed, constructed, and procured under a NQA-1 program (reference 4-3) to provide containment under NCT. The Chapter 2 structural analysis concludes the package will undergo localized damage to the LDCC external to the melter and that the deformations to the bolted door do not result in any clear open gaps, even under HAC.

Figure 4-3, does not include the Impact Limiter, and illustrates the Containment System.

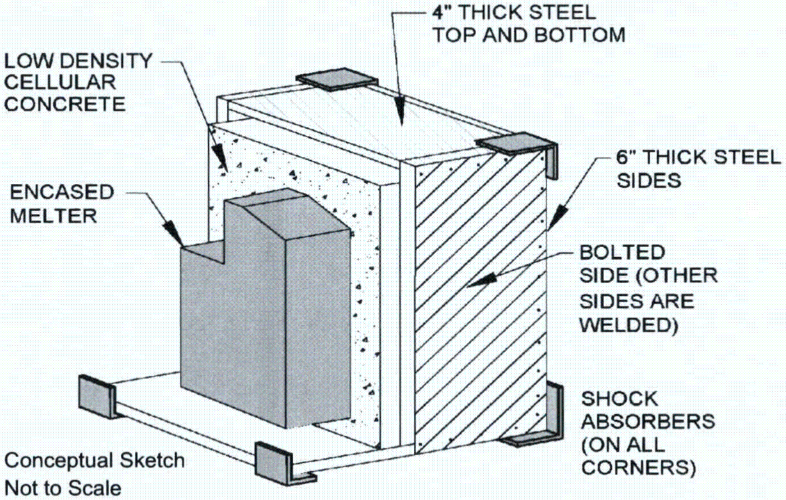

Figure 4-3 Containment System

4.1.2 Containment Penetrations

There are two types of containment penetrations associated with the WVMP. The first includes the five gasketed ports. These penetrations are 4.5" in diameter, stepped to 6.5" diameter for the outer half of the plate thickness, and are sealed with similarly step-sized steel plugs bolted in place. The other penetration consists of the bolted side door recessed into the package secured with 32 ASTM A193-B7 1½"-diameter bolts. Although the bolted side door is sealed with a single piece of flat neoprene gasket compressed to ¼" thick by 4" wide on the face seal and the perimeter joint (1/4" by 6" width) is sealed with RTV, the gasket is not credited in the containment analyses.

The package is not vented.

4.1.3 Special Requirements for Plutonium

Not applicable to the WVMP.

4.1.4 General Considerations

The requirements for Type A packages are not applicable to the WVMP.

The contents of the WVMP package contain approximately 3,554 curies of radioactivity, with less than 1E-1 A_2s conservatively calculated to be released under potential HAC as shown in Appendix 4.6.2. Most of the radioactive content is contained within the borosilicate glass matrix and adhered to the inside of the melter, with only a small quantity of surface contamination on the outside of the melter. The original surface contamination on the outside of the melter contained approximately 2 A_2s.

Subsequently, the surface contamination (2.32 A_2s) was coated with PBS. This material has an approximate life of around 20 years (reference 4-4), and is a strong fixative (reference 4-5). As part of preparing the WVMP for shipping, the melter was placed within the container and encased in LDCC.

In sections 4.2 and 4.3 below, it is shown that the rugged construction of the WVMP, the multiple layers of protection, and immobilization added by the LDCC added to the internals of the melter and to the container, as well as the physical characteristics of the glass, the PBS and the LDCC preclude leakage of dispersible materials from containment during both NCT and HAC.

Although the WVMP was not designed to be leaktight and cannot be leak tested, Appendix 4.6.2 shows that it will perform its intended safety function under the tests and conditions specified in 10 CFR 71. For hydrogen generation, the content can be assumed to have a G (H_2) value of approximately 0 [molecules H_2/100 ev] (reference 4-6).

4.2 Containment under Normal Conditions of Transport (Type B Packages)

The maximum permitted leakage rate under NCT cannot be exceeded during transport of the WVMP. 10 CFR 71.51(a)(1) *states that the containment requirements for NCT are:*

> ". . . there would be no loss or dispersal of radioactive contents--as demonstrated to a sensitivity of 10^{-6} A_2 per hour, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging . . ."

The analyses described in Appendix 4.6.2 used NCT Damage Ratios (DR) for borosilicate glass as 0.001. With Chapter 2 estimating the NCT to have little effect on the LDCC, the impact to external LDCC is assumed to be 0.01 and internal LDCC damage ratio as 0.002. Based on testing (references 4-7 and 4-8) an Airborne Release Fraction (ARF) of 1E-6 was applied to the borosilicate glass and an ARF of 1E-5 to the LDCC. Considering the NTC temperature and pressure increase calculated in chapter 3, an additional release mechanism at less than 25 psig, using an ARF of 5E-3 and an Respirable Fraction (RF) of 0.4 was applied to the LDCC both inside and external to the melter. As the Chapter 3 maximum temperature and pressure are bounding, this condition includes any chimney type effect.

As discussed in Section 4.1.1, the WVMP containment is welded on five sides, with the sixth side being the bolted side door. Containment is shown in Chapter 2 of this application to remain intact during NCT, precluding release of the radioactive contents. Conservatively, in the analysis the WVMP was credited for a Leak Path Factor (LPF) of 0.1 (reference 4-9), except for the LDCC contributions based on reference 4-7 because the test results were already reported in a combined ARF x LPF term. Since Chapter 2 did not show any impact to the melter, an LPF of 0.1 was also applied to a release of glass and LDCC contributions when the calculated release was not based on reference 4-7.

In summary the NCT release is calculated to be less than 1E-7 A_2/hr. The WVMP package therefore satisfies the containment requirements of 10 CFR 71.51 under NCT.

4.3 Containment under Hypothetical Accident Conditions

In this section it is shown that the maximum permitted leakage rate under HAC cannot be exceeded during transport of the WVMP. 10 CFR 71.51(a)(2) states that the containment requirements for HAC are:

> ". . . there would be no escape of krypton-85 exceeding 10 A_2 in 1 week, no escape of other radioactive material exceeding a total amount A_2 in 1 week, and no external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in) from the external surface of the package."

The bulk of the radioactive content is contained within the borosilicate glass with the melter, as discussed previously.

Because of the properties associated with the glass – $(DR \times ARF)_{HAC}$= 0.01 x 3E-4 – most of the release is associated with the LDCC external to the melter with an assumed non-aerosol release of the LDCC external to the melter being the largest contributor, DR x ARF x LPF = 1 x 0.35 x 1 (refer to Appendix 4.6.2). Because of the small amount of dispersible radioactive materials, the structural strength of the WVMP, and the multiple barriers that protect the contents, dispersal of contents greater than the maximum permitted in 10 CFR 71.51(a)(2) will not occur.

As discussed at the beginning of this chapter, features of the WVMP that serve as barriers to excessive dispersal of the radioactive contents for the purposes of containment considerations include:

- The borosilicate glass is contained within the melter, with LDCC sealing the three side penetrations into the melter (a combined LPF up to exiting the melter equal to 0.1) ;
- Testing has shown that the borosilicate glass has an extremely low dispersability (DR x ARF = 0.01 x 3E-4);
- Surface contamination on the melter has been fixed in place with three layers of Bartlett's PBS, which is impermeable and hard to remove
- The melter has been encased in LDCC (The LDCC external to the melter represents an additional barrier not numerically credited in Appendix 4.6.2); and
- The WVMP is welded on five of the six sides with the Chapter 2 structural analysis concluding that the container never has both a perimeter and face seal displacement (i.e.,

never any clear open gaps) under HAC (an additional barrier not numerically credited in Appendix 4.6.2.).

The analysis of the WVMP in Chapter 2 has shown that the 30-foot-drop HAC would result in localized damage to the LDCC along with small quantified levels of face seal displacement and/or perimeter seal displacement, but never a combination that results in any permanent clear open gaps.

Based on information in Appendix 4.6.2, the HAC-DR for borosilicate glass is 0.01, the external LDCC damage ratio is 0.35 and the internal LDCC damage ratio is 0.10. The corresponding HAC ARF values are 5E-5 for the contained LDCC and 7.5E-3 for the uncontained LDCC. A leak path factor of 1 is applied to the WVMP during HAC since the modeling results of Chapter 2 show minor face seal displacement would occur under HAC (i.e., no credit applied). Since Chapter 2 did not show any impact to the melter under HAC, a leak path factor of 0.1 is also applied to the melter (reference 4-9).

Considering the maximum HAC temperature and pressure as discussed in Chapter 2, an additional release mechanism for pressures >25 psig, using an ARF of 5E-3 and an RF of 1 was applied to the LDCC both inside and external to the melter. As these temperatures and pressures are bounding for HAC, this contribution accounts for any chimney effect.

As shown in Appendix 4.6.2, almost all of the release can be attributed from the external LDCC, with the A_2 contribution from non-airborne LDCC solids leaking out of the WVMP being much greater than the A_2 contribution from external LDCC from pressurization, being much greater than external LDCC airborne solids from drop, being much greater than the A_2 contribution from LDCC airborne solids inside the melter. In addition, each of the contributions from the LDCC was significantly greater than that from each of the borosilicate glass contributions. For detailed ratios of all factors associated with release contribution, refer to Appendix 4.6.2.

In summary, HAC could result in localized damage to the LDCC. However, the amount of radioactive material released would be limited by the multiple barriers to dispersal, and the amount that could pass through small breaches in the LDCC and containment. With the conservative HAC assumptions, less than 1E-1 A_2s are released. This is less than the limit of 10 times an A_2 quantity per week for Kr-85 and 1 A_2 per week for all other isotopes, as specified in 10 CFR 71.51(a)(2), and the package therefore meets the release limits specified by 10 CFR 71.

4.4 Leakage Rate Tests for Type B Packages

Not applicable. The WVMP was not designed to be leaktight and cannot be leak tested.

4.5 Conclusion

The WVMP is not leaktight. Analysis shows the releases under NCT and HAC will meet the release limits specified in 10 CFR 71.51 and the package can be deemed acceptable for equivalent safety.

4.6 Appendix

This appendix contains the following information:

4.6.1 List of references

4.6.2 E. T. Ketusky, *A_2s Released from West Valley Melter Package (WVMP) during Normal Conditions of Transport (NCT) and during Hypothetical Accident Conditions (HAC)*, X-CLC-G-00121, Rev. 0, Savannah River Site, August 25, 2014. (appended to reference section of the SAR)

APPENDIX 4.6.1 – REFERENCES

4-1 10 CFR Part 71, *Packaging and Transportation of Radioactive Material.*

4-2 *Structural Evaluation of WVMP to Specific Requirements of 10 CFR 71.71*, M-CLC-A-00497, Savannah River National Laboratory, Aiken, SC, October 2014. (see Chapter 2)

4-3 *Quality Assurance Requirements for Nuclear Facility Applications*, NQA-1, American Society for Mechanical Engineers, New York, New York, 2004.

4-4 *Stabilization of Residue Plutonium in L-9 Hood in Product Removal Room of PUREX With Polymeric Barrier System*, WHC-SD-SQA-CSA-508, Rev. 0, Chiao, T., Westinghouse Hanford Company, Richland, Washington. (provided)

4-5 *Decontamination Using Remote-Deployed Nitrocision Technology*, Chilson L. and L. B. Winkler, WM2011 Conference, February 27 – March 3, 2011, Phoenix, Arizona. (provided)

4-6 *Hydrogen Generation in TRU Waste Transportation Packages*, NUREG /CR-6673, Lawrence Livermore National Laboratory, Livermore, California, May 2000.

4-7 Experiments to Quantify Airborne Release from Packages with Dispersible Radioactive Materials Under Accident Conditions, Martens R., F. Lange, W. Koch, and O. Nolte, EuroSafe Forum, IEAE-32625, February 3, 2005. (provided)

4-8 *Impact Testing of Vitreous Simulated High-Level Waste in Canisters*, IBNWL-1903 UC-70, Pacific Northwest National Laboratory, Richland Washington, May 1975. (provided)

4-9 *Leak Path Factors for Radionuclide Releases from Breached Confinement Barriers and Confinement Areas*, 000-00c-MGRO-01500-000-00A, Bechtel SAIC Company, LLC, Las Vegas, Nevada, 2007. (provided)

5.0 SHIELDING EVALUATION

This chapter describes the radiation shielding design of the West Valley Melter Package (WVMP) and provides an evaluation of that design. The WVMP is comprised of (1) the Grouted Melter Package (GMP), consisting of the melter and Low Density Cellular Concrete (LDCC) inside the steel container; and (2) the Impact Limiter (IL). Figure 5-1 shows the different components of the WVMP.

This shielding evaluation demonstrates compliance with the performance requirements specified in 10 CFR 71.47 (reference 5-1), 10 CFR 71.51 (reference 5-1), and 49 CFR 173.441 (reference 5-2). The requirements of 10 CFR 71 for radiation dose rate limits are met for both Exclusive Use transport and Hypothetical Accident Conditions (HAC).

The Transport Index (TI) to be included on the WVMP Class 7 (Radioactive) label is to be determined by radiation measurement at the time of transport.

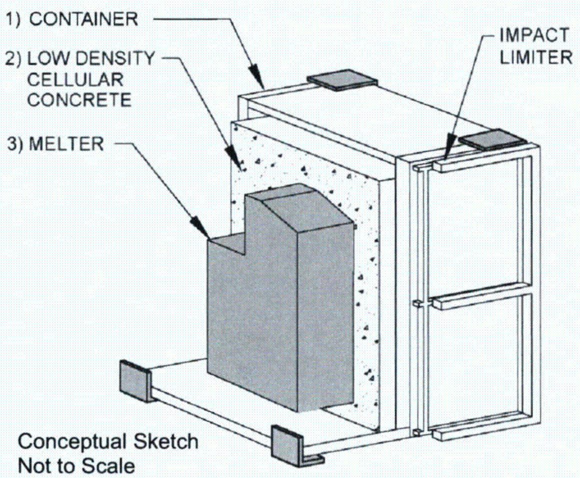

Figure 5-1. West Valley Melter Package Components

Key Terms and Acronyms in this Chapter	
GMP	Grouted Melter Package (consisting of the melter, LDCC inside the container, and the container itself)
IL	Impact Limiter
LDCC	Low Density Cellular Concrete
WVMP	West Valley Melter Package (consisting of the GMP with the IL installed)

5.1 Description of Shielding Design

5.1.1 Design Features

Figure 5-2 illustrates the GMP. The container was fabricated with ASTM SA516, Grade 70 carbon steel (4" thick top and bottom; 6" thick sides) and is approximately 14'11" long by 12'6" wide by 12'6" high as shown on detailed engineering drawing provided in Chapter 1. The density of the steel is 7.98 g/cm^3.[1]

The vitrification melter inside the container is encased with LDCC, which also entered the interior of the melter. The density of the LDCC is 1.12 g/cm^3.

Figure 5-3 illustrates the West Valley melter. The melter outer shell is made

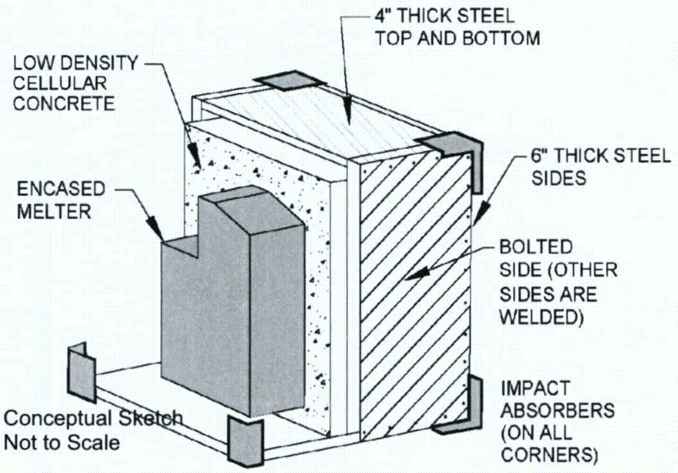

Figure 5-2. Grouted Melter Package

[1]Material properties used in the analyses, including densities, are listed in Table 5-7 below along with the sources of the values used.

of stainless steel. A cooling water jacket covers the sides and bottom of the outer shell. The shell interior is lined with refractory brick, which is a combination of Monofrax™ K-3 and Zirmul™. The density of this refractory material is 3.89 and 3.14 g/cm^3, respectively. The maximum envelope dimensions of the melter are 11'10" long, by 10'9¾" wide by 10'5½" high.

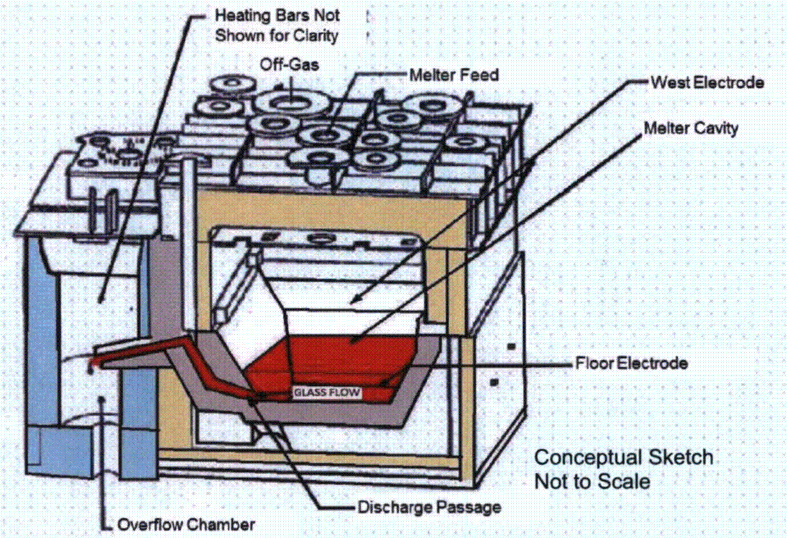

Figure 5-3. West Valley Melter

5.1.2 Summary Table of Maximum Radiation Levels

Shielding analyses were performed for the content as described in Section 1.2.2.

The Normal Conditions of Transport (NCT) shielding model includes all components of the package with geometric simplifications that result in a conservative analysis. The HAC shielding model assumes that the LDCC is consumed by HAC events; consequently, the calculated HAC dose rates result in a conservative analysis. The dose rates from gamma radiation were calculated using the QADS Point Kernel Module of the SCALE Code System (reference 5-3) with its built-in attenuation and buildup coefficients. Table 5-1 summarizes the NCT and HAC maximum calculated dose rates and compares the results against the regulatory limits for shipment in commerce.

Table 5-1. Radiation Dose Rates for the Package

Location	NCT			HAC
	Surface	1 m	2 m	1 m
	Maximum Dose Rate (mr/hr)			
North Side	0.056	0.052	0.037	0.52
South Side	0.043	0.019	0.011	0.84
East Side	0.013	0.012	0.009	0.43
West Side	0.016	0.014	0.011	0.51
Bottom	80.40	16.73	7.50	201.63
Top	2.43	1.18	0.689	429.03
10 CFR 71 Limits	200	N/A[1]	10	1000

NOTE: (1) 1 m dose limit (TI≤10) does not apply since package is being shipped as Exclusive Use meeting dose limits of 10 CFR 71.47(b).

5.2 Source Specification

There are four source terms of radioactive material in the WVMP: the melter heel, the plugged discharge spout, the refractory material, and surface contamination on the exterior of the melter. Table 5-2 shows the gamma source content evaluated.

5.2.1 Gamma Source

Table 5-2. Source Content

Isotope	Heel (9/20/2002)	Spout (11/26/2001)	Refractory (7/18/2002)	Surface Contamination (4/20/2004)
	Mass (grams)			
H-3				2.00E-09
C-14	7.75E-04	4.96E-04		8.44E-04
K-40	2.12E+03	1.22E+03		
Mn-54	3.00E-06	2.02E-06		
Fe-55				6.64E-06
Co-60	1.34E-05	2.59E-05	5.80E-05	1.16E-06
Ni-59				6.35E-03
Ni-63	2.92E-03	1.90E-03		2.75E-04
Sr-90	3.01E-01	6.23E-01	1.04E+00	2.06E-02
Zr-95	2.01E-04	1.23E-04		
Tc-99	1.19E-01	9.30E-01	3.09E+00	6.16E-02
I-129				2.24E+00
Cs-137	8.21E+00	1.32E+01	3.24E+00	7.40E-02
Pm-147				7.42E-05
Eu-154	7.88E-04	1.08E-03	5.44E-03	1.09E-04
Th-228	1.06E-05	6.78E-06	2.78E-06	5.56E-08
Th-230	2.93E-03	1.88E-03	7.38E-04	1.48E-05
Th-232	6.15E+02	3.96E+02	3.81E+02	7.62E+00
U-232	3.73E-04	2.40E-04	2.25E-05	4.62E-05
U-233	3.48E-01	2.24E-01	6.07E-02	2.44E-03
U-234	2.57E-01	1.66E-01	4.49E-02	1.34E-03
U-235	2.85E+01	1.83E+01	3.20E+01	6.39E-01
U-236	2.88E+00	1.86E+00	3.26E+00	6.49E-02
U-238	1.11E+03	7.17E+02	3.45E+02	1.82E+01
Np-237	1.49E+00	1.00E+00	1.20E+00	2.40E-02
Pu-238	6.66E-03	7.36E-03	9.05E-03	2.21E-04
Pu-239	4.21E-01	4.85E-01	6.00E-01	1.59E-02
Pu-240	8.81E-02	1.01E-01	1.25E-01	3.01E-03
Pu-241	5.15E-03	3.31E-03	3.59E-03	7.17E-05
Am-241	1.45E-01	1.12E-01	2.50E-01	1.00E-02
Am-243	2.99E-02	2.28E-02	3.37E-02	6.71E-04
Cm-242	1.08E-05	1.31E-06	2.07E-06	4.14E-08
Cm-243	5.81E-05	5.08E-05	8.20E-05	1.64E-06
Cm-244	9.14E-04	8.17E-04	1.33E-03	2.64E-05

The contributing mechanisms for photon (gamma) production include: (1) nuclide decay, (2) decay of daughter products, (3) fission product decay, and (4) spontaneous fission. Table 5-3 shows the source spectrum and total source strength (photons/sec).

Table 5-3. Photon Source Spectra

Group	Energy Boundary (MeV)		Source Strength (p/s)			
	Lower	Upper	Heel	Spout	Refractory	Surface
1	8.00E+00	1.00E+01	3.87E+00	3.37E+00	5.56E+00	1.20E-01
2	6.50E+00	8.00E+00	1.82E+01	1.59E+01	2.62E+01	5.65E-01
3	5.00E+00	6.50E+00	9.31E+01	8.11E+01	1.34E+02	2.89E+00
4	4.00E+00	5.00E+00	2.32E+02	2.02E+02	3.34E+02	7.21E+00
5	3.00E+00	4.00E+00	6.93E+02	6.03E+02	9.92E+02	2.14E+01
6	2.50E+00	3.00E+00	9.50E+07	5.99E+07	5.96E+06	1.17E+07
7	2.00E+00	2.50E+00	3.97E+06	8.05E+06	1.36E+07	2.76E+05
8	1.66E+00	2.00E+00	7.79E+07	1.57E+08	2.65E+08	5.45E+06
9	1.33E+00	1.66E+00	6.61E+08	1.15E+09	2.48E+09	5.41E+07
10	1.00E+00	1.33E+00	4.06E+09	6.98E+09	1.94E+10	4.28E+08
11	8.00E-01	1.00E+00	4.83E+09	9.08E+09	1.93E+10	4.10E+08
12	6.00E-01	8.00E-01	1.61E+13	2.55E+13	6.38E+12	1.51E+11
13	4.00E-01	6.00E-01	2.27E+10	4.46E+10	7.09E+10	1.46E+09
14	3.00E-01	4.00E-01	3.78E+10	7.31E+10	1.05E+11	2.14E+09
15	2.00E-01	3.00E-01	6.47E+10	1.20E+11	1.50E+11	3.10E+09
16	1.00E-01	2.00E-01	2.55E+11	4.59E+11	4.82E+11	9.99E+09
17	5.00E-02	1.00E-01	4.80E+11	8.33E+11	7.34E+11	1.55E+10
18	1.00E-02	5.00E-02	3.15E+12	5.20E+12	2.79E+12	6.04E+10
		Total	2.02E+13	3.23E+13	1.08E+13	2.45E+11

The ORIGEN-S code (reference 5-4) was used to calculate the energy-dependent decay source terms in the SCALE eighteen group structure. The initial material compositions for the heel, spout, refractory, and surface contamination (Table 5-2) were decayed from the date listed until September 2014 to determine the buildup of daughter isotopes. The source spectrum was input into QADS for each source region.

5.2.2 Neutron Source

There are no significant neutron sources in the melter glass.

5.3 Shielding Model

Figures 5-2 and 5-3 respectively depict the GMP and melter schematically. Geometric models for QADS were developed using the information in Table 5-4 and Table 5-5. Figure 5-4 and Figure 5-5 show the NCT model. Figure 5-6 shows the HAC model developed from the NCT model by replacing the LDCC with void. There were no NCT or HAC tests for the WVMP. The NCT analysis

showed no damage significant to the shielding and the HAC damage by analysis was conservatively bounded by the removal of the LDCC.

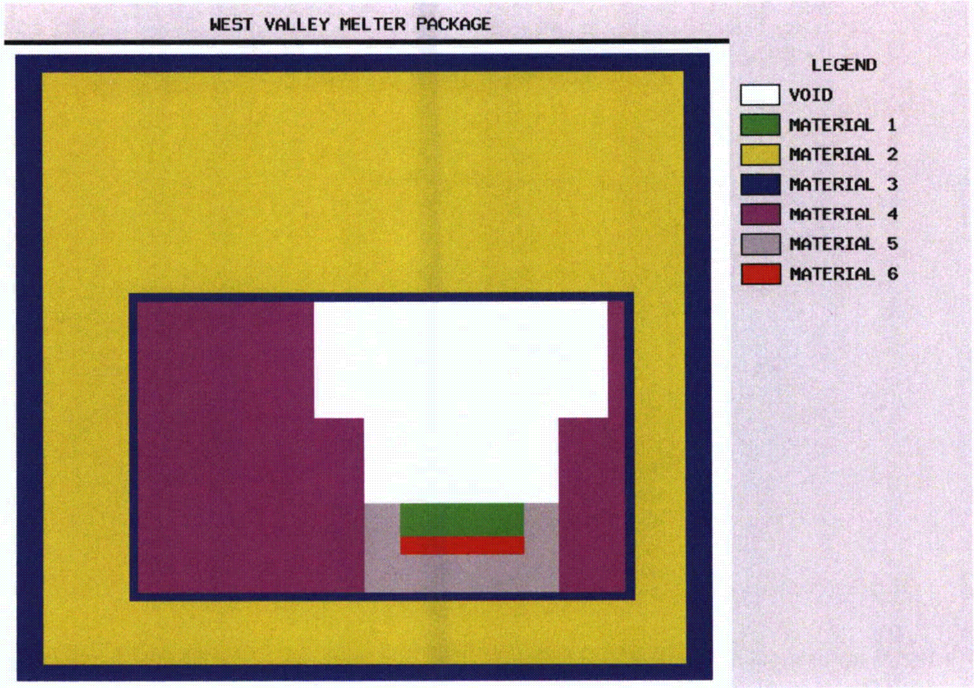

Figure 5-4. NCT Package Model Elevation View at Center of Melter

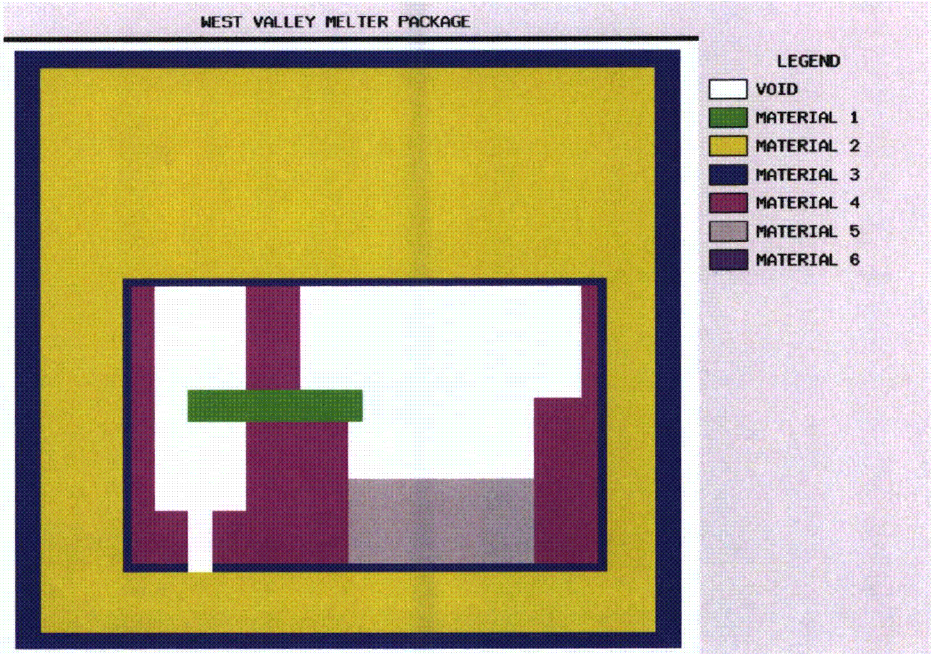

Figure 5-5. NCT Package Model Elevation View at Center of Plugged Spout

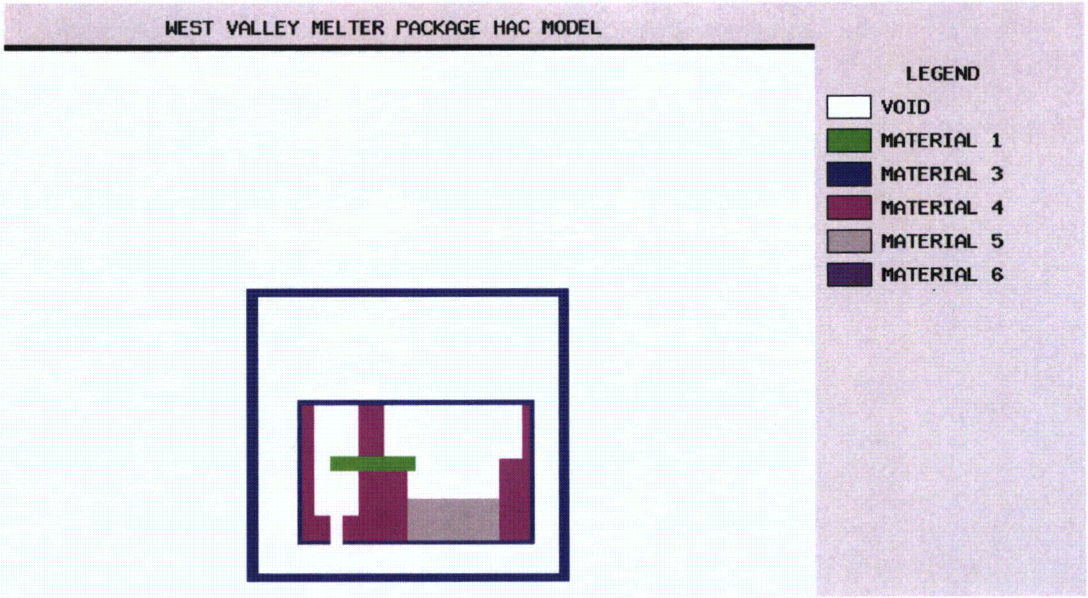

Figure 5-6. HAC Package Model

5.3.1 Configuration of Source and Shielding

Ten source configurations are modeled for the WVMP (see Engineering Calculation in Appendix 5.5.2):

- Uniformly distributed in the glass in melter heel,
- Uniformly distributed in the glass in the melter spout (modeled as a rectangular source),
- Glass in refractory brick above the melter heel modeled as uniform sources on each of the four vertical surfaces of the region above the melter heel,
- Surface contamination on the outside of the melter modeled as uniform sources on each of the four vertical surfaces of the steel surrounding the melter, and
- The source distribution in the melter spout modeled as a rectangle with the cross section equal to that of the cylinder.

Point detectors were modeled adjacent to the package and at two meters from the surface of the package for NCT cases. Point detectors were modeled at one meter from the surface of the damaged package for HAC cases. Table 5-6 lists the detector locations.

Table 5-4. Melter Geometry

Region	Parameter	English (inches)	Metric (cm)
Heel	Length	28.71	72.91
	Width	27.50	69.85
	Height	8.00	20.32
Middle	Length	45.41	115.34
	Width	68.00	172.72
	Height	20.00	50.80
Rectangular space above melter	Length	68.50	173.99
	Width	86.00	218.44
	Height	22.75	57.78
Melter Box Bottom	Length	118.00	299.72
	Width	99.00	251.46
	Height	73.00	185.42
	Thickness (1)	2.13	5.40
Melter Box Hat	Length	86.63	220.03
	Width	99.00	251.46
	Height	15.50	39.37
	Thickness (1)	2.13	5.40
Discharge Piping	Length	42.50	107.95
	Radius (2)	4.00	10.16

NOTES: (1) The thickness was conservatively modeled as 2.125".
(2) Radius inferred from lengths and mass of plug.

Table 5-5. Grouted Melter Package Model Dimensions(1)

Parameter	English (inches)	Metric (cm)
Length	144.00	365.76
Width	144.00	365.76
Height	156.00	396.24
Side Thickness	6.00	15.24
Top/Bottom Thickness	4.00	10.16

NOTE: (1) Conservative dimensions modeled.

Table 5-6. Detector Location for Surface of WVMP

Pt.	Location	Surface of Package Coordinate (cm)			1 m from Surface of Package Coordinate (cm)			2 m from Surface of Package Coordinate (cm)		
		x	z	y	x	z	y	x	z	y
1	North Side	148.2725	-25.4000	0.0000	248.2725	-25.4000	0.0000	348.2725	-25.4000	0.0000
2		148.2725	30.4800	-59.7694	248.2725	30.4800	-59.7694	348.2725	30.4800	-59.7694
3		148.2725	10.1600	0.0000	248.2725	10.1600	0.0000	348.2725	10.1600	0.0000
4		148.2725	18.4150	0.0000	248.2725	18.4150	0.0000	348.2725	18.4150	0.0000
5	South Side	-263.2075	-25.4000	0.0000	-363.2075	-25.4000	0.0000	-463.2075	-25.4000	0.0000
6		-263.2075	30.4800	-59.7694	-363.2075	30.4800	-59.7694	-463.2075	30.4800	-59.7694
7		-263.2075	10.1600	0.0000	-363.2075	10.1600	0.0000	-463.2075	10.1600	0.0000
8		-263.2075	18.4150	0.0000	-363.2075	18.4150	0.0000	-463.2075	18.4150	0.0000
9	East Side	0.0000	-25.4000	187.9600	0.0000	-25.4000	287.9600	0.0000	-25.4000	387.9600
10		-156.5275	30.4800	187.9600	-156.5275	30.4800	287.9600	-156.5275	30.4800	387.9600
11		-48.5775	30.4800	187.9600	-48.5775	30.4800	287.9600	-48.5775	30.4800	387.9600
12		0.0000	10.1600	187.9600	0.0000	10.1600	287.9600	0.0000	10.1600	387.9600
13		0.0000	18.4150	187.9600	0.0000	18.4150	287.9600	0.0000	18.4150	387.9600
14	West Side	0.0000	-25.4000	-187.9600	0.0000	-25.4000	-287.9600	0.0000	-25.4000	-387.9600
15		-156.5275	30.4800	-187.9600	-156.5275	30.4800	-287.9600	-156.5275	30.4800	-387.9600
16		-48.5775	30.4800	-187.9600	-48.5775	30.4800	-287.9600	-48.5775	30.4800	-387.9600
17		0.0000	10.1600	-187.9600	0.0000	10.1600	-287.9600	0.0000	10.1600	-387.9600
18		0.0000	18.4150	-187.9600	0.0000	18.4150	-287.9600	0.0000	18.4150	-387.9600
19	Bottom	0.0000	-121.9200	0.0000	0.0000	-221.9200	0.0000	0.0000	-321.9200	0.0000
20		-156.5275	-121.9200	-59.7694	-156.5275	-221.9200	-59.7694	-156.5275	-321.9200	-59.7694
21		-48.5775	-121.9200	-59.7694	-48.5775	-221.9200	-59.7694	-48.5775	-321.9200	-59.7694
22		0.0000	-121.9200	0.0000	0.0000	-221.9200	0.0000	0.0000	-321.9200	0.0000
23		0.0000	-121.9200	0.0000	0.0000	-221.9200	0.0000	0.0000	-321.9200	0.0000
24		-149.2250	-121.9200	-58.8169	-149.2250	-221.9200	-58.8169	-149.2250	-321.9200	-58.8169
25	Top	0.0000	254.0000	0.0000	0.0000	354.0000	0.0000	0.0000	454.0000	0.0000
26		-156.5275	254.0000	-59.7694	-156.5275	354.0000	-59.7694	-156.5275	454.0000	-59.7694
27		-48.5775	254.0000	-59.7694	-48.5775	354.0000	-59.7694	-48.5775	454.0000	-59.7694
28		0.0000	254.0000	0.0000	0.0000	354.0000	0.0000	0.0000	454.0000	0.0000
29		0.0000	254.0000	0.0000	0.0000	354.0000	0.0000	0.0000	454.0000	0.0000

5.3.2 Material Properties

Six materials are considered in the shielding models: borosilicate glass, steel, LDCC concrete, Monofrax™, Zirmul™, and Inconel. Table 5-7 lists the shield material densities and compositions.

Table 5-7. Material Compositions

	Glass [1]	LDCC [2]	Steel [3]	Monofrax™[4]	Zirmul™ [5]	Inconel [6]
Density (g/cc)	2.6	1.12	7.98	3.89	3.14	8.3
Element	**Weight Fraction**					
H		0.0100				
Li	0.0181					
B	0.0423					
C			0.0031			
O	0.4554	0.5320		0.4093	0.4064	
Na	0.0631	0.0290				
Mg	0.0058	0.0340		0.0362		
Al	0.0335			0.3070	0.2470	
Si	0.2031	0.3370	0.0023	0.0093	0.0821	0.025
P			0.0004			
S			0.0004			
K	0.0438					
Ca		0.0440				
Ti						0.025
Cr				0.1916		0.15
Mn			0.0103			
Fe	0.0892	0.0140	0.9837	0.0466	0.0009	0.07
Ni						0.73
Zr	0.0104				0.2636	
Th	0.0354					

NOTES:
(1) Derived from West Valley Nuclear Services Company Processing Equipment Characterization Results WMG Report 4005-RE-024, Revision 4 (reference 5-5).
(2) Concrete Regular, from Chapter 5 of SRNS-IM-2009-00035 (reference 5-6) with density corresponding to 70 lbs/ft^3.
(3) Grade SA516 Grade 70 from Mechanical and Physical Properties of Steels for Nuclear Applications
(4) Derived from the oxide compositions for MONOFRAX K-3 at http://www.rhi-ag.com/internet_en/products_solutions_en/glass2_en/glass_prod_en/glass_prod_fc_en/glass_prod_fc_monofrax_en/
(5) Derived from the chemical composition for Zircon Mullite at http://www.cumi-murugappa.com/emd/datasheet/ZIRMUL_DataSheet.pdf
(6) Chapter 5 of SRNS-IM-2009-00035 (reference 5-6).

5.4 Shielding Evaluation

5.4.1 Methods

Gamma dose rates from the source material are determined by using the point kernel code QADS. The shielding analysis is formally documented in Engineering Calculation N-CLC-G-00153 (Appendix 5.5.2). The appendix includes all details pertinent to the analyses.

5.4.2 Input and Output Data

The input and output files are listed in Appendix 5.5.3 and provided separately on a disk.

5.4.3 Flux-to-Dose-Rate Conversion

Photon dose conversion factors were obtained from the American National Standards Institute standard, ANSI/ANS-6.1.1-1977 (reference 5-7). The values from the 1977 version of the standard were used rather than those from the 1991 version of the standard because the photon dose conversion factors in the 1977 version more closely correspond to the response measured by instrumentation.

5.4.4 External Radiation Levels

The package external radiation levels for NCT and HAC conditions are tabulated in Table 5-1. The contents are analyzed with the compositions given in Table 5-2.

5.4.5 Summary and Conclusions

The shielding evaluation for the package results in radiation dose rates that meet the requirements of 10 CFR 71 for limits for NCT and HAC.

5.5 Appendix

This appendix contains the following information:

5.5.1 List of References

5.5.2 Engineering Calculation N-CLC-G-00153, *Dose Rates Outside West Valley Melter Package* (calculation withheld under 10 CFR 2.390, *Public Inspections, Exemptions, Requests for Withholding*)

5.5.3 Input/output Computer Files (provided)

APPENDIX 5.5.1 – REFERENCES

5-1 10 CFR Part 71, *Packaging and Transportation of Radioactive Material,* Washington, D.C., January 2012.

5-2 49 CFR 173, *Shippers - General Requirements for Shipments and Packagings*, Washington, D.C., October 2010.

5-3 *QADS: A Multidimensional Point-Kernel Analysis Module*, Volume 1, Book 3, Section S5, ORNL/TM-2005/39, Revision 5, Broadhead, B.L. and Emmett, M.B., Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 2005.

5-4 *ORIGEN-S: Scale System Module to Calculate Fuel Depletion, Actinide Transmutation, Fission Product Buildup and Decay, and Associated Radiation Source Terms*, Volume 2, Section F7, ORNL/TM-2005/39, Revision 5, Hermann, O.W., and Westfall, R.M., Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 2005.

5-5 *West Valley Nuclear Services Company Processing Equipment Characterization Results*, WMG Report 4005-RE-024, Revision 4, WMG, Inc., Peekskill, NY, August 2013. (provided)

5-6 *Savannah River Nuclear Solutions Criticality Safety Methods Manual*, Chapter 5, Standard Material Compositions for Nuclear Criticality Safety Calculations, SRNS-IM-2009-00035, Revision 3, Savannah River Nuclear Solutions, Aiken, South Carolina, January 2014. (provided)

5-7 *Neutron and Gamma-Ray Flux-to-Dose-Rate Factors*, ANSI/ANS-6.1.1-1977, American Nuclear Society, LaGrange Park, Illinois, March 1977.

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6.0 CRITICALITY EVALUATION

This chapter describes the criticality evaluation for the West Valley Melter Package (WVMP). The total quantity of fissile material associated with the WVMP is 81.56 grams consisting of the following fissile material radionuclides: Pu-239, Pu-241, U-233, and U-235. In the WVMP, approximately 99.2 percent (80.9 grams) of the fissile material is contained within the glass matrix. The approximate weight of the residual vitrified glass is 467 kilograms. The consistency of the compositions throughout the glass in the melter with no measurable stratification of actinides or noble metals is supported by sampling and studies (reference 6-1). The remaining quantity of fissile material, 0.8 percent (0.66 grams), is conservatively distributed on the exterior surface of the Melter body.

In performing the Criticality Evaluation for the WVMP, each of the four source terms was analyzed independently. For the residual glass source terms, the analysis uses the mass of the vitrified glass only. The 0.66 grams of fissile material of surface contamination is conservatively distributed on the exterior stainless steel surface of the Melter. Each of the independent glass source terms meet the Fissile Exempt criteria as identified in:

§71.15(c) (1) Low concentrations of solid fissile material commingled with solid nonfissile material, provided that:

(i) There is at least 2000 grams of solid nonfissile material for every gram of fissile material, and

(ii) There is no more than 180 grams of fissile material distributed within 360 kg of contiguous nonfissile material.

(2) Lead, beryllium, graphite, and hydrogenous material enriched in deuterium may be present in the package but must not be included in determining the required mass of solid nonfissile material.

The WVMP meets the requirement of 10 CFR Part 71.15 (reference 6-2). The WVMP is exempt from the fissile material criteria of 10 CFR 71.55 and 71.59, and a criticality evaluation is not applicable.

The package is fissile exempt.

6.1 Appendix

This chapter contain as single appendix – the list of references.

References

6-1 *Characterization of DWPF Melter One Glasses,* WSRC-TR-2003-00477, Rev 0, A.D. Cozzi and J.M. Pareizs, Westinghouse Savannah River Company, Aiken, South Carolina, October 2003. (provided)

6-2 10 CFR Part 71, *Packaging and Transportation of Radioactive Material.*

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7.0 PACKAGE OPERATIONS

This chapter describes the operations (1) previously completed to load and stabilize the melter inside the Grouted Melter Package (GMP), (2) to attach the Impact Limiter (IL) to the GMP, and (3) to prepare the West Valley Melter Package (WVMP) for transport and unloading at the disposal site.

Key Terms and Acronyms in this Chapter	
GMP	Grouted Melter Package (consisting of the melter, LDCC inside the container, and the container itself)
IL	Impact Limiter
LDCC	Low Density Cellular Concrete
RTV	room temperature vulcanizing
WVDP	West Valley Demonstration Project
WVMP	West Valley Melter Package (consisting of the GMP with the IL installed)

The design and fabrication of the one-time, exclusive use container were completed in 2004. The melter was loaded into the package in 2004 and the Low Density Cellular Concrete (LDCC) was added in 2013. The GMP components were procured, constructed, and loaded under a Quality Assurance (QA) program meeting the requirements of NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications* (reference 7-1).

Upon receipt of NRC Special Authorization, the IL will be procured and installed under the West Valley NQA-1 QA program that meets the requirements of 10 CFR 71, Subpart H (reference 7-2).

The completed operations described in this chapter were performed in accordance with detailed written procedures and work instruction packages approved under the site contractor's[1] QA Program, which complied with 10 CFR 71, Subpart H, *Quality Assurance*, including the applicable record keeping, inspections, reporting, and advance notification requirements addressed in 10 CFR 71.91 (records), §71.93 (inspection and tests), and §71.95 (reports).

Upcoming package operations at the site will be accomplished to these same requirements. All operations will continue to be conducted in a manner consistent with the evaluations described in Chapters 2 through 6 while maintaining occupational radiation exposures as low as reasonably achievable (ALARA) as required by the *Standards for Protection Against Radiation* in 10 CFR 20.1101(b) (reference 7-3) and the equivalent DOE ALARA requirements such as those in 10 CFR 835, *Occupational Radiation Protection* (reference 7-4).

7.1 Package Loading

This section describes previously conducted activities associated with preparing the container for loading the melter. The activities included loading the melter into the container, securing the container bolted side door, filling the container with LDCC through ports located on top of the container, and securing the ports after completion of LDCC emplacement. The container with the melter and the LDCC comprises the GMP.

This section also describes future activities associated with the installation of the IL to the exterior of the GMP and preparing the WVMP for transportation. These activities ensure the WVMP is not damaged and radiation and surface contamination levels are within allowable regulatory limits.

[1]Since August 2011, CH2M HILL B&W West Valley, LLC (CHBWV) has been the site contractor. West Valley Environmental Services (WVES) was the previous site contractor. In 2004, when the melter was placed in its container, the West Valley Nuclear Services Company (WVNSCO) was the site contractor.

7.1.1 Preparation for Loading

The operations for preparing the container so the melter could be loaded into it are discussed herein. These operations specify the container is loaded and closed in accordance with detailed written procedures. No moderator or neutron absorber is required.

Preparation of the Melter

The melter was used from 1996 through 2002 to heat the high-level waste mixture and glass formers to turn them into homogenized molten glass. In September 2002, after completion of vitrification operations, the melter was used to process low-activity decontamination solutions. Prior to shutdown of the melter, the final diluted heel was removed to the extent practical using a vacuum extraction system developed by DOE. The melter was then shut down.

To prepare the melter for removal from the West Valley Demonstration Project (WVDP) Vitrification Facility and placement into a shielded transfer container, electrodes were cut and shield plugs installed. The exterior surface of the melter was coated with Bartlett Polymeric Barrier System (PBS) to ensure surface contamination was fixed. The PBS-coated melter was then pulled on rails into a shielded transfer container to facilitate its movement through a portion of the WVDP main process plant.

Preparation of the Container

The container was manufactured and delivered to the WVDP in 2004. Figure 7-1 shows the container when it arrived in 2004 with its bolted side door removed. Acceptance tests and inspections associated with the container are discussed in Chapter 8.

Upon receipt at the WVDP, the empty container was lifted off the incoming transport vehicle using a gantry crane and the lifting lugs installed by the manufacturer.

Figure 7-1. The Container upon Arrival at the Site

7.1.2 Loading of Contents

This subsection describes how the melter was placed in the container and how the LDCC was emplaced.

Loading of Melter into the Container

In 2004, using integral container transfer rails, the melter was moved into its container through the open side door. The bolted side door was then secured per manufacturer's instructions (reference 7-5) by:

- Cleaning the bolted side door plate gasket seating area and inspecting the interface surfaces of the neoprene gasket,
- Aligning and installing the gasketed side door plate to the container by aligning the side door lift tabs to the slots in the container's top skirt to guide it into position,
- Applying anti-galling lubricant to the threads of each of the 328" long by 1.5" diameter bolts and installing them with their washers through the bolted side door into the container, and
- Tightening the bolts to the manufacturer-specified final torque value of 500 lb-ft.

To secure the melter (sitting on rails) within the container during onsite movement, a horizontal securement device provided by the container manufacturer was then installed through a penetration port in the container. Additionally, vertical securement devices were installed through two penetration ports in the top of the container. The container was then lifted onto a heavy-load transport vehicle and moved to the interim storage area at the WVDP, placed on dunnage, and covered with a tarp to await placement of the LDCC.

Placement of the LDCC

The three securement devices (rods) installed in 2004 to support the movement of the container to the interim storage area were removed prior to placement of the LDCC. A final penetration cover was then installed where the horizontal securement device was removed (reference 7-6) by:

- Cleaning the penetration gasket seating areas and inspecting the interface surfaces of the neoprene gaskets,
- Installing and securing the gaskets on the 6" deep penetrations,
- Applying anti-galling lubricant to the threads of each of the 3¾" long by 5/16" diameter socket head cap screws,
- Positioning the gasketed plug into recessed area of the penetration, and
- Installing the socket head cap screws and tightening them to the manufacturer-specified final torque value of 35 lb-ft.

To identify a LDCC recipe that would provide a minimum 28-day compressive strength of 1,000 psi inside the container, a series of recipe development mock-ups were tested offsite in 2013 by a subcontractor knowledgeable of LDCC (reference 7-7). These studies indicated that if the wet density of the LDCC realized in the field after addition of a foam additive and prior to transfer to the container was between 68 and 72 lbs per cubic foot, the LDCC would achieve a minimum compressive strength of 1,000 psi after 28 days inside the container.

Upon the removal of the two vertical securement devices on top of the container, the same two top 5" diameter penetrations were used for emplacing the LDCC. One of the two penetrations was

used for the LDCC fill pipe and the other for a ventilation hose and a bullet camera (and then switched between lift one and lift two).

The LDCC fill pipe was initially lowered into the annulus between the melter and the container to approximately three feet above the bottom of the container and then raised as the LDCC level in the annulus increased. In addition to filling the annulus between the melter and the container, during the LDCC placement process LDCC passively entered the melter cavity through three openings in the melter. Figure 7-2 shows the grouting taking place.

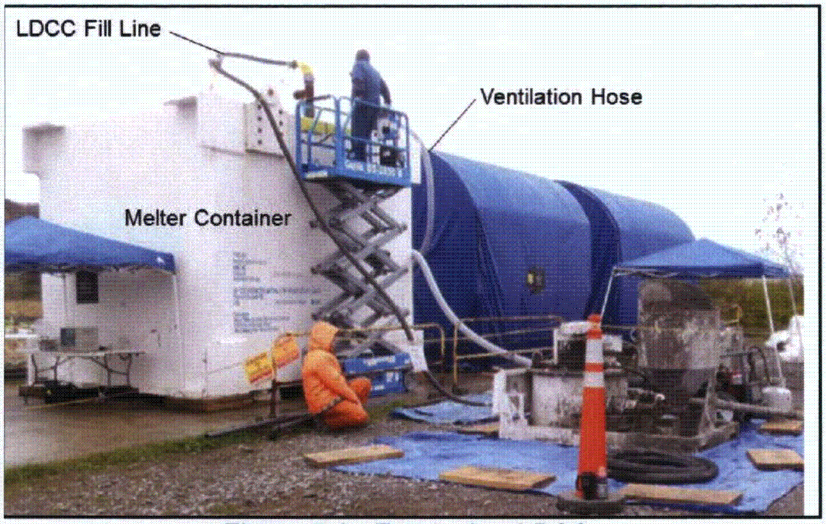

Figure 7-2. Emplacing LDCC

Two openings (open plenum/glass thermowell ports, each approximately 5" in diameter) are located on the top of the melter. A third opening is a non-plugged pour spout (approximately 6" in diameter) located in the bottom half of the melter side. During the grouting process, the level of the LDCC in the annulus was monitored using the bullet camera and by measuring dose rates on the outside of the container, which decreased as the LDCC level rose. As the LDCC level rose to the height of the pour spout, the annulus fill rate was significantly reduced indicating the entry of LDCC into the melter cavity as expected.

Similarly, when the LDCC rose to above the upper lip of the melter, the annulus fill rate also lagged, indicating additional filling of the melter cavity via the upper two melter openings. To manage the risk associated with LDCC entering and exiting the ports on top of the container (considering that LDCC placement was being conducted in open air), LDCC placement continued until the melter was completely encased in LDCC leaving the annulus approximately 93 percent full of LDCC with an air gap at the top of the GMP.

After LDCC placement activities were completed, the associated equipment was removed and the two ports on top of the GMP were closed (reference 7-8) by:

- Cleaning the penetration gasket seating areas and inspecting the interface surfaces of the neoprene gaskets,
- Installing and securing the neoprene gaskets onto the 4" deep plugs,
- Applying anti-galling lubricant to the threads of each of the 2¾" long by 5/16" diameter socket head cap screws,
- Positioning the gasketed plugs into the recessed area of the container penetrations, and

- Installing the socket head cap screws and tightening them to the manufacturer specified final torque value of 35 lb-ft.

The GMP was then reweighed and RTV applied to the gap between the bolted side door and the container.

7.1.3 Preparation for Transport

This subsection describes installation of the IL and the other preparations for shipment of the WVMP.

Installation of Impact Limiter

The IL will be installed on the bolted side door of the GMP. The IL will be fabricated and installed following receipt of NRC Special Authorization and prior to loading of the package onto the offsite transport vehicle.

Upon arrival at the WVDP site, the IL will be receipt inspected by CHBWV, verifying that no damage occurred to the structure during shipment and it complies with the procurement specification documentation. Installation will be performed in accordance with the CHBWV QA program and approved detailed written work instructions (reference 7-9). The installation process will include the following steps:

(1) The IL will be rigged to a mobile crane, boomed fork lift truck, or similar lifting device and transitioned from horizontal to vertical orientation.

(2) The IL will be positioned within the confines of the GMP shock absorbers snug against the lid and clamping devices will be installed to temporarily secure it in place.

(3) Fitment of the IL to the GMP will be inspected to verify that correct tolerances have been maintained.

(5) The IL retaining pin locations will be laid out and suitably marked.

(6) The IL main frame and the current GMP shock absorbers will be match drilled and reamed to required tolerances.

(7) The retaining pins will be installed.

(8) The clamping devices will be removed.

Other Preparations for Transport

Prior to the WVMP leaving the WVDP, the following steps will be performed in accordance with approved CHBWV procedures.

(1) The package will be marked per 10 CFR 71.85 (c), which states that *"The licensee shall conspicuously and durably mark the packaging with its model number, serial number, gross weight, and a package identification number assigned by NRC..."*

(2) Package tamper-indicating devices will be applied to bolted closures of the WVMP.

(3) Radiation surveys of the package (on contact and at one meter from the surface) and non-fixed (removable) contamination surveys will be performed per CHBWV's radiological program within 60 days of loading. The WVMP's exterior surface is expected to be free

of removable contamination, and package exterior radiation levels will not exceed the limits specified in 10 CFR 71.47 at any time during transportation.

(4) WVMP will be marked and labeled in accordance with 49 CFR 172.300 and 172.400 respectively and the transport vehicle will be placarded in accordance with 49 CFR 172.500 (reference 7-10).

(5) Measurement of the WVMP surface temperature will be required prior to offsite transport.

Loading and Securement

The WVMP will be loaded and secured onto a heavy-haul trailer. The WVMP will be moved to a railcar at the transload facility and prepared for transport to the Waste Control Specialists (WCS) low-level waste disposal facility. These activities will be performed during the movement:

(1) Using a 350-ton minimum capacity gantry crane to move the WVMP to the heavy-haul trailer,

(2) Securing the WVMP to the heavy-haul trailer,

(3) Using the gantry crane to move the WVMP to the railcar, and

(4) Securing the WVMP to the railcar for transport.

The bolted-on lifting lugs shown on sheet 7 of Drawing 4005-DW-001 (see Chapter 1) will be utilized in lifting the WVMP. Securement lugs will be attached to the heavy-haul trailer and railcars to tie-down the WVMP. The tie-down systems are not a structural part of the package and are therefore not subject to 10 CFR 71 requirements.

The lifting hardware utilized during initial loading and subsequent transloading evolutions will accompany the shipment so that it can be utilized by WCS in handling of the WVMP.

7.2 Package Unloading

This subsection describes how the WVMP will be handled at the disposal facility.

7.2.1 Receipt of Package from Carrier

WCS personnel will perform radiation and contamination surveys of the WVMP upon its arrival at the WCS facility in accordance with WCS written policies and procedures. The WCS Onsite Transportation and Lift Plan for the WVMP will delineate detailed steps associated with tasks such as the following:

(1) Move the railcar so the WVMP is positioned under a 500-ton minimum capacity gantry system.

(2) Check the package tamper-indicating devices on bolted closures of the WVMP to ensure they remain intact.

(3) Remove equipment used to secure the WVMP to the railcar.

(4) Install the four lifting lugs to the WVMP.

(5) Install a suitable lifting assembly to connect the gantry crane to the WVMP.

(6) Using a 500-ton capacity gantry crane and this lifting assembly, lift the WVMP from the railcar, move it sideways toward the WCS Goldhofer transporter, position it on the deck of the transporter, and remove the rigging from the WVMP lifting lugs.

(7) Move the WVMP to a temporary staging area.

(8) Using the vertical lift capability of the Goldhofer, temporarily stage the WVMP on steel pipe stands.

(9) While the WVMP is being staged, dissemble the gantry system and transport it into the disposal cell to be reassembled.

(10) Transport the WVMP using the Goldhofer from the staging area down into the disposal cell via the current access ramp and into position it underneath the gantry crane.

(11) Rig and lift the WVMP package using the hydraulic gantry system.

(12) Lower the WVMP on WCS-provided saddles.

7.2.2 Removal of Contents

This subsection is not applicable. The WVMP is a one-time use package. The entire WVMP will be disposed of at WCS. The WVMP will not be opened at the WCS.

7.3 Preparation of Empty Package for Transport

This section is not applicable. The WVMP will be disposed of at WCS. Therefore, empty package transport requirements are not applicable for the WVMP.

7.4 Other Operations

The WVMP surface temperature must be above 3°F at West Valley prior to shipment and during packaging operations at WCS. The weather forecasts along the route shall predict ambient temperatures above 3°F.

Other weather restrictions normally associated with the utilization of cranes to perform lifts such as loading and unloading the WVMP (e.g., wind speed) also apply.

7.5 Appendix

This chapter includes a single appendix: 7.5.1 – List of references

APPENDIX 7.5.1 – REFERENCES

7-1 NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications*, American Society for Mechanical Engineers, New York, New York, 2008.

7-2 10 CFR Part 71, *Packaging and Transportation of Radioactive Material.*

7-3 10 CFR Part 20.1101(b), *Standards for Protection Against Radiation.*

7-4 10 CFR Part 835, *Occupational Radiation Protection.*

7-5 *Remove Melter from Vitrification Facility*, WVNSCO work instruction package VFS-112008-WIP, West Valley Nuclear Services Company, West Valley, December 2004. (provided)

7-6 *Weigh and Prepare Melter Container TC 474 for Grouting at the Rail Packaging and Staging Area*, CHBWV work instruction package W1303663, CH2M Hill-B&W West Valley, LLC, West Valley, New York, completed October 2013. (provided)

7-7 *Melter Waste Package Grouting Implementation/QA Plan*, Revision 2. CH2M Hill-B&W West Valley, LLC, West Valley, New York, October 23, 2013. (provided)

7-8 *Grout Melter Container TC-474 at the Rail Packaging and Staging Area*, CHBWV work instruction package W1303694, CH2M Hill-B&W West Valley, LLC, West Valley, New York, completed November 2013. (provided)

7-9 *Administration of Work Instruction Packages*, EP-5-002, Revision 37, CH2M Hill-B&W West Valley, LLC, West Valley, New York, March 19, 2014. (provided)

7-10 49 CFR Part 172, *Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, and Training Requirements.*

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter describes the completed acceptance tests for the West Valley Melter Package (WVMP), including those for the container and the Low Density Cellular Concrete (LDCC) used to fill the container and the melter, and those to be accomplished on the Impact Limiter (IL) to be installed on the bolted side door of the Grouted Melter Package (GMP). The design and fabrication of the one-time, exclusive use container were completed in 2004, the melter was loaded into the container in 2004, the LDCC added in 2013, and the new IL is to be installed before shipment to Waste Control Specialists (WCS) for disposal.

No maintenance program is required for the one-time use package.

8.1 Acceptance Tests

Key Terms and Acronyms in this Chapter	
GMP	Grouted Melter Package (consisting of the melter, LDCC inside the container, and the container itself)
IL	Impact Limiter
LDCC	Low Density Cellular Concrete
WVDP	West Valley Demonstration Project
WVMP	West Valley Melter Package (consisting of the GMP with the IL installed)

The acceptance tests and inspections that were performed on the container were accomplished under the West Valley Demonstration Project (WVDP) Quality Assurance (QA) program in accordance with written procedures, as were the acceptance tests and inspections of the LDCC used to fill the melter and container void spaces (reference 8-1). These tests and inspections confirmed the container was fabricated in accordance with the drawings identified in Chapter 1 and the LDCC meets the comprehensive strength requirements established by the designer of the GMP. The acceptance tests and inspections for the IL will be accomplished to the same requirements.

8.1.1 Visual Inspections and Measurements

This subsection summarizes visual inspections and measurements that were completed on the container and the LDCC used to fill it and the melter void spaces and those inspections and measurements to be performed on the IL.

The Container

The container was fabricated at American Tank and Fabricating Company of Cleveland, Ohio to NQA-1 (reference 8-2) requirements and the design drawings provided in Chapter 1. Upon receipt at the WVDP in 2004, in accordance with the site QA program and receipt inspection requirements identified in site procedures, visual inspections and measurements (reference 8-3) confirmed that the container:

- Did not show any visible shipping damage;
- Met specifications on the purchase order, including gaskets; and
- That no suspect or counterfeit parts were used.

The acceptance criteria for these inspections included compliance with the specified requirements.

The process for taking action on nonconformances involved identifying unacceptable items with a QA hold tag and segregating them. An issue report would then be generated to document and address the nonconformance. Nonconforming items would be dispositioned based on their condition as "use-as-is", "rework", "repair," "scrap," or "return to vendor". The QA hold tag would only be removed by a QA representative after approval of the resolution and completion of the necessary action.

Low Density Cellular Concrete

The level of the LDCC in the annulus was visually monitored as the mixture was being poured using the bullet camera. LDCC placement continued until the melter was completely encased. The following day, after the LDCC placement equipment was removed from the top ports of the GMP, personnel visually re-confirmed that the melter was completely encased in LDCC. The GMP is approximately 93 percent full[1].

The tests confirm the LDCC meets the minimum compressive strength requirements as discussed in Section 8.1.5 below.

Impact Limiter

Upon arrival at the WVDP site, the IL will be receipt inspected by CHBWV, verifying the following conditions:

- It does not show any shipping damage,
- Meets specifications on the purchase order, and
- No suspect or counterfeit parts were used.

Acceptance criteria for these IL inspections includes compliance with the specified engineering and procurement requirements to include key dimensions and associated tolerances, proper fit to the GMP component, and receipt of proper documentation of material certification. Any nonconforming characteristics will be reviewed in accordance with the WVDP QA Program and recommended dispositions proposed and approved. Items that deviate from design requirements whose disposition is "use-as-is" or "repair" will be subject to design control measures commensurate with those applied to the original design. Any such dispositions and corrective actions will be formally documented, with technical justification provided.

8.1.2 Weld Examinations

This section describes welding examinations used to verify fabrication of the container in accordance with the specified drawings, codes, and standards and those welding examinations to be performed on the IL.

[1]The 93 percent value corresponds to a void space of approximately 10 inches at the top of the container. This space resulted from concerns to avoid LDCC overflow and spreading radioactive contamination given that LDCC was being poured outdoors in the open air. The void space was considered in the modeling described in Chapter 2 and Chapter 4.

Container

The container was fabricated at American Tank and Fabricating to NQA-1 requirements and the design drawings identified in Chapter 1. Welding was performed in accordance with American Welding Society Structural Code D1.1, *Structural Welding Code – Steel* (reference 8-4). In compliance with 10 CFR 71.119, welds were visually examined and magnetic particle inspected in accordance with this code (reference 8-5).

As shown in Appendix 8.3.2, the applicable requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section EIII, Article ND-5300, *Acceptance Standards* (reference 8-6) were implemented by the WVDP and its container subcontractor in connection with fabrication of the container.

Impact Limiter

Prior to installation onto the GMP, visual examinations and magnetic particle examinations will be performed on the IL welds. The acceptance criteria shall be those specified in the ASME Boiler and Pressure Vessel Code, Section III, Subsection NF, Article NF-5300, *Acceptance Standards* (reference 8-6).

During the installation of the IL, the retaining pins will be secured in place with a bevel weld performed by certified welders using WVDP qualified procedures (reference 8-7).

8.1.3 Structural and Pressure Tests

Chapter 2 documents the analyses that demonstrate the WVMP structural integrity. Based on analysis showing an appropriate safety factor, no pressure test was performed.

The analysis confirms the WVMP integrity under Normal Conditions of Transport provides assurance the radioactive materials will remain contained in the package. Therefore, the package meets the requirements of 10 CFR 71 (reference 8-8) under Normal Conditions of Transport. In the event of a breach of containment under Hypothetical Accident Conditions, the released radioactivity levels would be within the limits of 10 CFR 71 as discussed in Chapter 4.

8.1.4 Leakage Tests

Leakage tests are not applicable to the WVMP because there is no pressure vessel or other leak-testable boundary associated with the package.

8.1.5 Component and Material Tests

This subsection describes component and material tests that have been performed on the container and the LDCC and those to be performed on the IL.

Container

Component and material tests were performed on components of the container that affect package performance. Certified material test reports confirmed the components and materials meet the

acceptance criteria (reference 8-9). The West Valley receipt inspection confirmed that the gaskets meet the requirements of the purchase order (reference 8-3).

Low Density Cellular Concrete

During the LDCC placement process in 2013, one sample from each of the LDCC truck loads was taken to confirm that the 68 to 72 pounds per cubic foot wet density criteria was met (reference 8-10). Test cylinders cast from each truck load were tested after 28 days and confirmed the LDCC had acceptable compressive strength. The 28-day compressive strengths for all the cylinders exceeded 1,000 psi (reference 8-11).

Impact Limiter

All plate material shall be provided with certified material and chemical test reports. These tests shall include determination of the nil-ductility transition temperature for materials three inches thick and over. All base metals and filler materials utilized will be qualified for notch toughness. All welding will be performed in accordance with approved procedures.

8.1.6 Shielding Tests

Shielding tests are not applicable for the WVMP. The WVMP is a single use package shipping a unique content that has already been loaded and sealed. The packaging design does not include any features specifically credited with shielding. The calculated dose rates are based upon a bounding estimate of the contents and the package built to the certified design using certified materials. The calculated dose rates bound the measured dose rates and are within the regulatory limits.

8.1.7 Thermal Tests

Thermal acceptance tests are not applicable. The packaging design does not incorporate active heat transfer features nor are passive heat transfer mechanisms particularly sensitive to normal variations in the materials of construction or fabrication methods. The WVMP materials are capable of withstanding temperatures within its design envelope as shown in Chapter 3.

8.1.8 Miscellaneous Tests

No additional tests prior to use of the package are applicable. No tests other than those described above are necessary for the WVMP (either the GMP or the IL).

NOTE

> Appendix 8.3.2 includes a series of tables that show how the WVMP complies with ASME requirements on materials, design, fabrication, examination, and welding.

8.2 Maintenance Program

No maintenance program is applicable for the WVMP for the following reasons:

- The WVMP is a single-shipment package used for transportation and disposal of the melter.
- The WVMP is a sealed enclosure with no instrumentation or operating control devices that are relied upon for maintaining and monitoring its integrity during the shipment.
- The initial acceptance tests and inspections as described herein and the pre-shipment routine determinations to be performed in accordance with 10 CFR 71.87 criteria.

8.2.1 Structural and Pressure Tests

Not applicable. A maintenance program and associated tests are not required for this package.

8.2.2 Leakage Tests

Not applicable. A maintenance program and associated tests are not required for this package.

8.2.3 Component and Material Tests

Not applicable. A maintenance program and associated tests are not required for this package.

8.2.4 Thermal Tests

Not applicable. A maintenance program and associated tests are not required for this package.

8.2.5 Miscellaneous Tests

Not applicable. A maintenance program and associated tests are not required for this package.

8.3 Appendix

This chapter contains two appendices:

8.3.1 List of References

8.3.2 ASME Requirement Comparison Tables

APPENDIX 8.3.1 – REFERENCES

8-1 *Receipt Inspection*, Quality Assurance Procedure QP 10-2, Revision 15, CH2M Hill-B&W West Valley, LLC, West Valley, New York, October 22, 2013. (provided)

8-2 *Quality Assurance Requirements for Nuclear Facility Applications*, NQA-1, American Society for Mechanical Engineers, New York, New York, 2004.

8-3 Material Receiving Inspection and Release (MRIR) report #04-1152, West Valley Nuclear Services Company, West Valley, New York, October 15, 2004. (provided)

8-4 *Structural Welding Code – Steel*, AWS D1.1, American Welding Society, Miami, Florida, 2004.

8-5 Nondestructive Test Reports MT-110-04, VT-35-04, X-R-I Testing Division of X-Ray Industries, Inc., Troy, Michigan, October 13, 2004. (provided)

8-6 *ASME Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, New York, New York, 2004.

8-7 *WVDP Site Welding Manual*, WVDP-352, Revision 5, CH2M Hill-B&W West Valley, LLC, West Valley, New York, July 11, 2012. (provided)

8-8 10 CFR Part 71, *Packaging and Transportation of Radioactive Material.*

8-9 Certified Test Reports 2004, various reports Including: Receiving Inspection and Material Validation – Steel Plate; Steel Warehouse, Certificate of Analysis and Tests; United States Steel Corporation Metallurgical Test Reports; Bethlehem Steel Test Certificates; Report of Tests and Analysis; Fastenal Certificate of Compliance; Cardinal Fastener Test Certification; Wrought Washer Mfg. Certificate of Compliance; Steel Dynamics Chemical/Physical Certification; Nova Machine Products Corporation Material Test Report; Dyson Corp. Certified Test Report; Technical Stamping Material Certification; and Sabre Steel Inc. Certificate of Conformance. (provided)

8-10 Supplier Surveillance Reports SR-13-078 (10/31/2013) and SR-13-085 (11/06/2013), CH2M Hill-B&W West Valley, LLC, West Valley, New York, 2013. (provided)

8-11 Grout Compressive Strength Test Reports, ASTM C-1019, Ticket Numbers 522, 523, 524, 526, 544, 546, and 547, Quality Inspection Services, Inc., Buffalo, New York, December 9, 2013. (provided)

APPENDIX 8.3.2 – ASME REQUIREMENT COMPARISON TABLES

Table 1. Material Requirements ASME/WVMP Compliance

ASME Sect. III, Div. 1, Subsection ND		WVMP Compliance
Section	**Requirements**	**Compliance Method**
ND-2121	Materials shall be restricted to those listed in Tables 1A, 1B and 3.	The WVMP is compliant. SA516-70 and SA-36 are listed in Table 1A and within the permitted thickness.
ND-2221	Coupon and specimen location shall be as required by the material specification. Note that the ASME/ASTM material specification (Sect. II Part A Specification SA 20/A 20M-89, Section 11.2 states; the longitudinal axis of the tension test specimens shall be transverse to the final rolling direction of the plate).	The WVMP is compliant. Per the Certified Material Test Reports (CMTRs), coupons were taken in accordance with ASTM A516.
ND-2128	Bolting material to be listed in Table 3.	The WVMP is compliant. ASTM 193-B7 is in Table 3.
ND-2130	Material CMTRs to be supplied.	The WVMP is compliant. CMTRs for SA-516, SA-36, and Bolts were supplied.
ND-2311	Pressure retaining material shall be impact tested, unless LST is set above Table ND-2311-1 values.	The WVMP is compliant. Table ND-2311-1 exempts impact testing for LST > -10°F for SA-516-70 up to 2½ inches. Appendix 2.2.12 analysis justifies LST = 3°F for 6 inch thick.
ND-2410	All welding material used in construction and repair of components shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX.	The WVMP demonstrates equivalent safety. Lowest Service Temperature of 3°F and NQA-1 program for purchase QA of weld rods.

Table 2. Design Requirements ASME/WVMP Compliance

ASME Sect. III, Div. 1, Subsection ND		WVMP Compliance
Section	**Requirements**	**Compliance Method**
ND-3100	Loading and Design Criteria are specified.	The WVMP is compliant. The loads are per the CFR and consistent with ND-3100. Design Criteria are per ND-3100.
ND-3300	Design Requirements are specified.	The WVMP is compliant. Stress Limits used in Chapter 2 structural analysis are in compliance with RG 7.6 and consistent with ND-3300.
ND-3350	Weld Joint requirements: The walls of the rectangular GMP are fabricated of single slabs. The only structural welds are on the corner joints. ND-3350 is targeted to circular vessels constructed of pieced plates. The best match to the corner joint is ND-3350, Category D.	The WVMP is compliant. The corner joints feature partial groove welds on both inside and outside edges with reinforcing fillets on the inside. ND-3350 permits partial groove welds.

Table 3. Fabrication Requirements ASME/WWMP Compliance

ASME Sect. III, Div. 1, Subsection ND		WVMP Compliance
Section	**Requirements**	**Compliance Method**
ND-4100	Material control requirements are specified.	The WVMP is compliant. CMTRs were supplied and maintained on record for the structural components of the GMP.
ND-4200	Forming, fitting, and aligning requirements are specified.	The WVMP is compliant. These requirements are focused on circular vessels. There are no features of the GMP sensitive to tolerance or fit-up beyond those already controlled by material specifications and construction drawings. Weld joint requirements are already discussed in ND-3350.
ND-4300 and ND-4400	Welding Qualifications are specified.	The WVMP is compliant. AWS D1.1 welding was used and is consistent with ND-4300.
ND-4600	Preheat, interpass and post-weld heat treatment are specified.	The WVMP demonstrates Equivalent Safety. AWS D1.1 pre-qualified weld procedures were used and provide equivalent safety.

Table 4. Examination Requirements ASME/WVMP Compliance

ASME Sect. III, Div. 1, Subsection ND-5200		WVMP Compliance
Section	**Requirements**	**Compliance Method**
ND-5230	Radiography is not required when the weld joint is not a butt-weld.	The WVMP is compliant. All welded joints are liquid penetration and magnetic particle tested, per AWS D1.1 requirements,
ND-5280	Based on Storage Tanks to WVMP similarity. Bottom-to Sidewall, Roof to sidewall joints shall be examined visually. Alternatively, MT and PT may be substituted.	The WVMP is compliant. *All welded joints are liquid penetration and* magnetic particle tested, per AWS D1.1 requirements.
ND-5340 and ND-5350	Acceptance standards for MT and PT are specified.	The WVMP is compliant. Both ND and AWS D1.1 disallow any crack indications. AWS D1.1 Table 6.1 limit weld undersize, *undercut and porosity to levels* compliant with ND-5000

Table 5. Welding Requirements NUREG & AWS/West Valley Compliance

NUREG/CR-3019 – Containment Related Welds, Category II; ASME Section III, Sub. ND	Fabrication Code – AWS D1.1, 2004 Edition	WVMP Compliance Method
Base Materials – *ND-2000 (except ND-2300 and ND-4100)*	Base Materials – A36, A572 grade 50/60 (sub. A633 E/C), A516 grade 70 – Thickness (1/8" 1/2", 1", 2", 4" 6")	The WVMP demonstrates equivalent safety. Base materials approved by ASME and AWS, same SA (ASME specification designation) and ASTM specifications as applicable. Base materials prior to welding receive a visual examination based on AWS and an NDE (UT) in accordance with ASME Section III, Subsection NB. LST set to 3°F to exempt fracture toughness testing.
Welding Materials – *ND-2400* NUREG/CR-3019 and ASME Subsection ND require addressing fracture toughness. ASME Section III, Subsection ND requires filler material testing for tensile and chemistry.	Welding Materials Used – E71T-1 (spec. A5.20), ER70S-3 (spec. A5.18), E81T1-A1M (spec. A5.29), E7018 (spec. A5.1), and EA1 (spec. A5.23)	The WVMP demonstrates equivalent safety. Welding filler materials meet ASME SFA5.X specifications and AWS A5.X specifications. Storage and handling of welding materials are met.
Joint Preparation – *ND-4200* ASME Section III, Subsection ND specifies weld requirements based on weld type.	Weld Joint/Welds - Complete/partial joint penetration v-groove, fillet and plug welds.	The WVMP demonstrates equivalent safety. Weld joint preparation, groove type, weld type, and welding profiles used in the fabrication. The corner joints feature partial groove welds on both inside and outside edges with reinforcing fillets on the inside. ND-3350 permits partial groove welds.
Welding – *ND-4400*	Welding Processes – FCAW, GTAW, SMAW, and SAW	The WVMP is compliant.
Heat Treatment – *ND-4600*	AWS only requires heat treatment when specified contractually.	The WVMP demonstrates equivalent safety. Weld procedures and specifications used are prequalified for heat treatment if required.
Qualification Procedure/Personnel – *ND-4300*	Welding Procedure Specifications – Prequalified and qualified Welder Performance Qualifications – Performed in accordance with ASME Section IX	The WVMP is compliant.

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