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Obtaining a Special Administrative License Exemption to Ship the West Valley Melter Box - 16327

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ABSTRACT

In order to ship the West Valley Melter Package (WVMP) package to support its disposal, the U.S. Department of Energy (DOE) requested a one-time shipment license exemption from the U.S. Nuclear Regulatory Commission (NRC). Based on content, the previously constructed WVMP, containing residual borosilicate glass and Low Density Cellular Concrete was shown to require a Type B Package. Therefore, Title 10 of the United States Code of Federal Regulations, Part 71 (10 CFR 71) required that radioactive releases under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) would remain less than 1E-7 A_2/hour and 1E-1 A_2/week, respectively.

Although the NRC normal method for demonstrating conformance to the 10CFR71 requirement is through performance of leak rate testing per American National Standards Institute (ANSI) standard N14.5, the WVMP does not contain a pressure vessel; therefore, performance of leak rate testing was not applicable/possible. Instead, an alternate method, adapted from DOE Handbook 3010 was used to show that the maximum allowed 10 CFR 71 radionuclide release rates for NCT and HAC would not be exceeded. Summarizing the effort, this paper provides the technical synopsis for requesting the exemption.

INTRODUCTION

Containment requirements for packages used to transport radioactive materials ensure that any release of radioisotopes during NCT or HAC conditions will fall within the regulatory specified limits. Although transportation packages are designed to contain the radioactivity and to maintain their structural integrity under severe conditions, leak testing ensures that packages are manufactured and assembled correctly and that no unacceptable leak paths have developed with subsequent use or over time. American National Standards Institute (ANSI) standard N14.5 presents the approved NRC methodology used for determining the acceptance criteria for leakage testing of radionuclide shipping packages. The content of the ANSI standard has been accepted by the Nuclear Regulatory Commission (NRC) staff as an acceptable method for meeting the leakage requirements presented in 10 CFR 71. The ANSI N14.5 standard specifies: 1) the package containment requirements; 2) methods of relating package containment requirements to measured release and leakage rates; and, 3) the minimum requirements for release and leakage rate measurement procedures.

The container was constructed in 2004 using welded steel plate, with one side being a door secured with multiple bolts and a neoprene gasket. Each corner of the WVMP contains a shock absorber. The melter consists of a stainless steel box structure approximately 3 meters on each side lined with refractory material. The melter weighs approximately 49,000 kilograms. The Characterization Report [1] shows that the residual radioactivity in the melter amounts to approximately 1.3 E+15 Bq, with over 99.8 percent from cesium 137 and strontium 90 and their daughters, with approximately 82 grams of fissile material within the melter. The melter contains radioactive material immobilized in borosilicate glass, accounting for more than 99 percent of the total residual radioactivity associated with the WVMP. The LDCC filled most of the annulus between the WVMP and melter, with a small fraction entering the melter. The LDCC was poured into the WVMP in 2013. From 1996 through 2002, the melter produced homogenized mixtures of high-level waste and borosilicate glass. During use, the primary pour spout plugged with hardened glass, so the secondary pour spout was used to complete the waste vitrification campaign. Upon completion, low-activity flush solutions were used to reduce the radioactive concentration contained within the melter cavity.

Flushing was deemed completed; only after it was confirmed that as much as practical of the radioactive material within the melter cavity was removed. Based on the Characterization Report [1] the melter currently contains approximately 467 kilograms of hardened glass, with approximately 99 kilograms contained within the plugged primary pour spout. Aspects of the WVMP that help ensure that the NCT and HAC radioactive release limits will not be exceeded include:

Total radioactive content consists of approximate 200 A_2s, with approximately 98% of the A_2s are contained within the residual borosilicate glass matrix adhered to the inside of the melter [1].
Based on the Structural Analysis [2] performed to support the exemption, the melter remains intact even after HAC, thus minimizing impact to the borosilicate glass in addition to the LDCC located inside the melter.
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 [3].
The "containment boundary" is considered the WVMP shell, and includes the door gasket. Neither are credited in ST release analyses (i.e., No credit is applied for the WVMP, including no credit applied for the door gasket (i.e., Leak Path Factor (LPF) refers to the fraction of radionuclides that becomes airborne and escape, with a fraction of 1 is conservatively assumed for the WVMP shell and gasket).
Besides the "containment boundary" or shell of the WVMP, there are internal

barriers between the radioactive contents and the environment that minimize potential releases. They include:

The annulus between the outside shell of the WVMP and the melter is predominately filled by LDCC (i.e., external LDCC), with some LDCC inside the melter (i.e., internal LDCC). The external LDCC binds loose contents on the outside of the melter, providing a type of barrier to the release of surface contamination previously fixed with PBS.

LDCC external to the melter encases the melter shell, minimizing dispersible glass that might otherwise be released from inside the melter.

CALCULATIONS

The NCT and HAC radionuclide releases were calculated using methodology adapted from DOE-HDBK-3010 [4], commonly called the five-factor formula, where the complete formula to calculate an airborne inhalation release is written as in Equation 1:

$$ST = MAR \times DR \times ARF \times RF \times LPF \qquad \text{(Eq.1)}$$

Where:

Source Term (ST) refers to each of the calculated potential NCT and HAC radionuclide release contributions, and as part of the conclusion of this effort is shown to be less than the NCT and HAC radionuclide release rate limits.

Material at Risk (MAR), is the material which would be impacted and subject to escape. It is determined from the Characterization Report [1]. Note: For simplification herein, only the A_2s values for the material at risk will be provided based on using RadCalc 4.1®, without showing the actual spreadsheet used for converting each isotope's curie content to an A_2 conversion value based on 10 CFR 51 Appendix A [5].

Damage Ratio (DR) represents the fraction of the MAR that is impacted. For LDCC, it was determined from the Structural Analysis [2], while for the borosilicate glass, the DR is determined from the Historic Glass Testing Report [6].

Leak Path Factor (LPF) refers to the fraction of material that becomes airborne and escapes. Conservatively the WVMP shell is assumed to have an LPF = one, therefore, requiring no further analyses of gap sizes, penetrations, or testing/replacement of the existing neoprene gasket. For the melter, which has been shown to survive under both the NCT and HAC, the gap size allowing leakage and maximum pressure will be estimated, enabling a corresponding LPF to be determined [7].

Airborne Release Fraction (ARF) refers to the fraction that is aerosolized. Respirable Fraction (RF) is the fraction of airborne radionuclides as particles that can be transported through air and inhaled into the human respiratory system. The RF is commonly assumed to include particles 10-μm Aerodynamic Equivalent Diameter (AED) and less [4]. For both internal and external LDCC, there are potential ARF and RF values corresponding to the following:

Impact
Maximum temperature and pressure resulting in the release of existing fines
Maximum temperature, potentially resulting in the decomposition of LDCC, with the ARF x RF values to be taken from DOE Handbook 3010 [4], as applicable

For borosilicate glass, a combined ARF x RF term calculated using the DR and the glass testing which measure the wt% of the total borosilicate glass broken to less to a particle size of less than 20-µms (20-microns), with the difference between 10-µms (i.e., normally considered the mean particle size of an aerosol) is considered negligible [6]. Based on a review of the Characterization Data [1], the Thermal Analysis [8] and Structural Analysis [2], the applicable potential phenomena resulting in ST contributions under NCT and HAC potentially include:
Impact/drop type release from spout glass
Impact/drop type release from heel glass
Impact/drop type release from refractory glass
Impact/drop type release from internal LDCC
Impact drop type release from external LDCC
Maximum temperature/ pressure, resulting in release of existing fines, from internal LDCC
Maximum temperature/ pressure, resulting in release of existing fines, from external LDCC
Decomposition of LDCC/dewatering release from internal LDCC
Decomposition of LDCC/dewatering release from external LDCC
Non-inhalation contributions for HAC only

Resulting in the following:
Total NCT ST release in terms of A_2 (i.e., NCT roll-up)
Total HAC ST release in terms of A_2 (i.e., HAC roll-up)

Since the ST equation in DOE Handbook 3010 (i.e., the five factor formula) only accounts for the dose from inhalation, other pathways that are applicable to longer exposures associated with transportation accidents [9], were also considered, resulting in an additional ST contribution from non-inhalation contribution under HAC conditions.

INPUTS AND RESULTS

The Characterization Report [1] data for the radionuclide distributions associated with the WVMP are summarized in terms of A_2s. Refer to Table 1. Note: The actual calculation provide to the NRC included a spreadsheet showing all isotopes listed, corresponding A_2 values for 10 CFR 71 Appendix A, and bases for A_2 conversion values, with a RadCalc 4.1 A_2 values provided as an additional check of the calculated A_2 values.

TABLE I. Summary of Characterization Report Data

Source	**Characterized Content (A_2s)**
Glass radionuclides in melter spout	82.45
Glass radionuclides in melter heel	63.81
Glass radionuclides in melter refractory	67.15
Surface contamination on outside of melter	2.14

Based on the Characterization Report [1] data, five different contributions (i.e., material at risk) are considered to be potentially released during an accident. They are:

1) Glass in melter spout = 82.45 A_2s
2) Glass in melter heel = 63.81 A_2s
3) Glass in melter refractory = 67.15 A_2s
4) LDCC inside the melter = 1.03E-1 A_2s, where radioactive content from the glass heel (63.81 A_2s from Table 1) is assumed to have leached into LDCC, with a leach ratio (LR = 1.6E-3) applied based on Glass Leaching Studies [10]
5) LDCC external to melter = 2.14E-2 A_2s, where the radioactive surface contamination (2.14 A_2s from Table 1) is assumed to have leached through the Bartlett's Polymeric Barrier System (PBS)® and into the LDCC, with the leach ratio (LR=1E-2) conservatively estimated based on PBS being impermeable [3]

Using the Thermal Analysis [8] constructed as part of the WVMP request for exemption, the maximum NCT and HAC temperatures for the borosilicate glass and LDCC internal and external to the melter were identified, and are shown in Table 2.

TABLE II. Maximum Temperatures and Pressure Increases
from Thermal Analyses

Accident Condition	**Maximum Temperature**	**Corresponding Change in Pressure**
NCT	Glass = 63.5°C	13790 Pa
	External LDCC = 84.2°C	20684 Pa
	Internal LDCC = 63.5°C	13790 Pa
HAC	Glass = 63.7°C	13790 Pa
	External LDCC = 367.6°C	503317 Pa
	Internal LDCC = 63.7°C	13790 Pa

With Table 2 showing little change in pressure from NCT conditions, a release of existing internal LDCC fines from the maximum temperature, corresponding ST from a pressure increase was negligible. With a maximum necessary decomposition temperature of 100°C not reached for the LDCC under NCT condition, the ST contributions associated with maximum temperature and pressures resulting in the release of existing fines, as well as LDCC decomposition were deemed to have a negligible impact on ST.

The Structural Analysis [2] identified the DR for the internal and external LDCC impacts under NCT conditions as 0.006% and 0.06%, respectively, and DRs for the internal and external LDCC under HAC conditions as 35% and 3.5%. Historic Glass Testing Report [6] provided the fraction of glass broken at 7.62 meters/second and 13.7 meters/second, representing NCT and HAC conditions, as 5E-5 and 3E-4, respectively. For decomposition of the LDCC for NCT conditions, the DR is conservatively assumed as 5%, while for HAC conditions, at the NRC request, the DR is conservatively assumed one. Since the Structural Analysis showed no impact to the melter [2], only the external LDCC is considered to have a non-inhalation component. To account for potential decomposition of the LDCC, a DR of 100% for external LDCC was applied when calculating the non-inhalation ST from external LDCC.

Airborne Release Fraction (ARF) refers to the aerosolized fraction, while the Respirable Fraction (RF) refers to the fraction of airborne radionuclides, as particles, that can be transported through air and inhaled into the human respiratory system. As previously stated, the RF is commonly assumed to include particles 10-μm Aerodynamic Equivalent Diameter (AED) and less [4] For LDCC, the ARF x RF values originated from DOE-HDBK-3010 [4] and summarized in Table 3 below. For the borosilicate glass, the ARF x RF values were based on the Historic Glass Testing Report [6] at 7.62 meters/second under NCT resulting in a combined ARF x RF value of 2E-4, and at 13.7 meters/second under HAC, a combined ARF x RF value of 1E-3.

Table 3. DOE-HDBK-3010 Applicable ARF and RF Values for LDCC

Condition	Impact		Maximum Temperature and Pressure (Resulting in the Release of Existing Fines)		Decomposition	
	ARF	RF	ARF	RF	ARF	RF
NCT	1E-3	1E-1	5E-3	4E-1	6E-3	1E-2
HAC	1E-3	1E-1	1E-1	7E-1	6E-3	1E-2

As can be seen from Table 3, only the LDCC ARF x RF values associated with maximum temperature and pressure, the release of existing fines is pressure dependent and varies based on if under NCT or HAC, since the ARF x RF values for decomposition of LDCC is based on test results from unreactive powders from the DOE-HDBK-3010 [4].

Based on a review of the Characterization Report [1] data, the Thermal Analysis [8] and Structural Analysis [2] as well as the applicable potential phenomena resulting in ST contributions under NCT and HAC are as follows:

Impact/drop type release from spout glass
Impact/drop type release from heel glass
Impact/drop type release from refractory glass
Impact/drop type release from internal LDCC
Impact drop type release from external (to melter) LDCC
Maximum temperature/ pressure release of existing fines from external LDCC
Decomposition of LDCC/dewatering release from external LDCC
Non-inhalation contributions for HAC only

The corresponding source terms for NCT in terms of A_2s were calculated to be the following:

NCT ST from spout glass, impact = 8.32E-8 A_2s
NCT ST from heel glass, impact = 6.37E-8 A_2s
NCT ST from refractory glass, impact = 6.74E-8 A_2s
NCT ST from internal LDCC, impact = 6.12E-11 A_2s
NCT ST from external LDCC, impact =1.29E-9 A_2s
NCT ST from external LDCC, maximum temperature/pressure, release of existing fines = 2.57E-8 A_2s
NCT ST from external LDCC, decomposition/de-watering of LDCC = 6.43E-8 A_2s.

The result was a calculated total A_2 release under NCT conditions (i.e., NCT roll-up) of 2.22E-7 A_2s.

The corresponding source terms for HAC in terms of A_2s were calculated to be the following:
HAC ST from spout glass, impact = 3.33E-6 A_2s
HAC ST from heel glass, impact = 2.55E-6 A_2s
HAC ST from refractory glass, impact = 2.69E-6 A_2s
HAC ST from internal LDCC, impact = 3.57E-8 A_2s
HAC ST from external LDCC, impact = 7.50E-7 A_2s
HAC ST from external LDCC, maximum temperature/pressure, release of existing fines = 5.25E-4 A_2s
HAC ST from external LDCC, decomposition/de-watering of LDCC = 1.29E-6 A_2s
HAC non-inhalation ST =2.14E-2 A_2s

The result was a calculated total A2 release under HAC conditions (i.e., HAC roll-up) of 2.20E-2 A_2s.

RESULTS

After rounding, the NCT radionuclide release was conservatively approximated as less than 3E-7 A_2s, with most of the ST contribution evenly distributed from the potential sources, with the lowest contribution being from internal LDCC, after impact. Again, after some rounding to slightly overestimate the radionuclide ST release, the HAC radionuclide release was conservatively approximated as less than 1E-1 A_2s, with almost all of the contribution noticeably from the non-inhalation ST.

CONCLUSIONS

The 10 CFR 71.51 maximum allowed radionuclide release rate under HAC conditions is one A_2 in one week. Conservatively assuming the limit as “instantaneously released,” it is clearly demonstrated that a radionuclide release rate of 1E-1 A_2s/week will not exceeded.

The 10 CFR 71.51 maximum allowed radionuclide release rate under NCT conditions is 1E-6 A_2s/hr. Conservatively assuming the limit as an “instantaneously released,” it is clearly demonstrated that the limit of < 1E-7 A_2s/hr, also will not be exceeded.

REFERENCES

C. Brandjes and T. Pieczyniski, *West Valley Demonstration Project Waste Characterization of Vitrified Melter*, Ameriphysics Report, Oak Ridge TN, September 2014.
2. Charles McKeel, Structural *Evaluation of WVMP to Specific Requirements of 10 CFR71.71, M-CLC-A-00497*, Rev. 1, Savannah River Site, Aiken, SC, May 5, 2015**.**
3. Chilson L. and L. B. Winkler, *Decontamination Using Remote-Deployed Nitrocision Technology*, WM2011 Conference, February 27 – March 3, 2011, Phoenix, Arizona.
4. DOE-HANDBOOK*, Airborne Release Fractions/Rates and Respirable Fractions for Non-Reactor Facilities,* Volume 1 DOE-HDBK-3010-94, December 1994.
5. *U.S. Code of Federal Regulation 10 CFR 71*.
6 *Impact Testing of Vitreous Simulated High-Level Waste in Canisters*, IBNWL-1903 UC-70, Pacific Northwest National Laboratory, Richland Washington, May 1975.
7. *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.
8. James Laurinat, *Thermal Analysis for West Valley Melter Package*, M-CLC-A-00498, Rev. 0, Savannah River Site, Aiken, SC, November 19, 2014.
9. Jonathan G. Teague, *Consequence of Nuclear Material Container Spills-Worker Risk*, LA-UR-14—23726, Institute of Nuclear Materials Management, 2014-07-23, Los Alamos National Laboratory.
10. John R. Wiley, *Leach Rates of High Activity Waste for Borosilicate Glass,* DP-MS-77-80, Savannah River Site, Aiken, SC, 1977.