Safety Evaluation Report for the

NAC-LWT Cask and the Sodium Debris Bed Experiments Contained in Welded Transport Canisters

Safety Analysis Report for Packaging
NAC-LWT Legal Weight Truck Cask System
Revision LWT/DOE-07E September 2007

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SUMMARY

By a letter dated September 1, 2006, the Sandia National Laboratories (SNL) submitted an application request to amend the US DOE Certificate of Compliance (CoC) No. 9225 for the Model NAC-Legal Weight Truck (LWT) cask to include SNL Debris Bed Experiments (DBE) contained in welded DBE Transport Canisters as authorized contents. Prior to the submittal of the application request, there were two pre-application meetings held at Argonne National Laboratory in November 2005 and August 2006. The meetings were hosted by the Argonne Safety Analysis Report for Packaging (SARP) Review Group, on behalf of the Packaging Certification Program (PCP) of the Office of Safety Management and Operations (EM-60).

On January 3, 2007 the PCP staff issued sixty (60) Q1 questions on the various chapters in the SARP, Rev. DOE-06D, September 2006. A meeting was held in April 2007 to discuss the Q1s, and the applicant provided written responses to Q1s and proposed changes to the SARP for Chapters 1, 4 through 10 in June, and Chapters 2 and 3 in August, 2007. Because of the importance of weld integrity of the DBE transport canisters, the PCP staff also conducted a source verification of the fabrication (including welding) of the DBE transport canisters at the GE Ionics Plant in May, and witnessed the welding of the canister closure lids at SNL in September 2007. Issues identified during the source verification included the weld size reduction for the closure lid, Code of record, and helium leak testing after welding of the closure lids. All of these issues were resolved, documented, and the relevant chapters in the SARP were revised accordingly.

Based on the statements and representation in the SARP (Revision LWT/DOE-06D, September 2006, as supplemented by Revision LWT/DOE-07E, September 2007) and the staff's confirmatory evaluation and source verification of the fabrication and welding of the DBE transport canisters, the staff concludes that the design and performance of the NAC-LWT cask and the sodium DBE transport canisters are acceptable, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1B are met.

REFERENCE

NAC-LWT Legal Weight Truck Cask System, Safety Analysis Report for Packaging, U.S. DOE-Sandia National Laboratories, Vol. 1 to 3, Revision LWT/DOE-06D, September 2006, as Supplemented by LWT/DOE-07E, September 2007.

1. GENERAL INFORMATION AND DRAWINGS

1.1 Packaging Description

The NAC-LWT packaging, i.e., cask, is a steel-encased, lead-shielded shipping cask. The cask is designed to transport commercial and test reactor assemblies or fuel rods by truck. The NAC-LWT cask is certified by NRC for several contents, and has been certified before by DOE for shipments of the tritium-producing burnable absorber rods (TPBAR) in Lead Test Assemblies (and as irradiated sections in qualified canisters) of the tritium production in commercial light water reactor program.

The overall dimensions of the cask, with impact limiters, are 232 inches long by 65 inches in diameter. The cask body is approximately 200 inches in length and 44 inches in diameter. The cask cavity is approximately 178 inches long and 13.4 inches in diameter.

The cask body consists of a 0.75-inch thick stainless steel inner shell, a 5.75-inch thick lead gamma shield, a 1.2-inch thick stainless steel outer shell, and a 5-inch thick neutron shield tank. The cask lid is 11.3-inch thick stainless steel stepped design, secured to a 14.25-inch-thick ring forging with twelve, 1-inch diameter bolts. The cask lid containment seal is a metallic O-ring. A second Teflon O-ring and a test port are provided to leak test the seal. Other penetrations in the cask cavity include the fill and drain ports, which are sealed with Alternate B port covers and metallic O-rings. A second Viton O-ring and test port are provided on each Alternate B port cover to leak test the metallic seal.

The neutron shield tank is 164-inches long and 5-inches thick and contains an ethylene glycol and water solution that is 1 percent boron by weight. Aluminum honeycomb impact limiters are attached to each end of the cask.

The maximum gross weight of the cask is 52,000 pounds, and the maximum weight of the contents and transport canisters is 4,000 pounds.

DRAWINGS

The drawings that pertain to the NAC-LWT cask and DBE transport canisters are listed in Table 1.1 below:

Table 1.1 List of drawings pertaining to the NAC-LWT cask / DBE canisters

Drawing Title	Drawing No.	Revision
NAC-LWT Cask Body Assembly	315-40-02	21
NAC-LWT Cask Body Assembly	315-40-03	22
NAC-LWT Transport Cask Lid Assembly	315-40-04	11
NAC-LWT Transport Cask Upper Impact Limiter	315-40-05	9
NAC-LWT Transport Cask Lower Impact Limiter	315-40-06	9
NAC-LWT Transport Cask Parts Detail	315-40-08	16
Canister Assembly, SNL Experiment Shipment	315-40-117	3
Details, Canister Weldment, SNL Experiment Shipment	315-40-118	2
Details, Canister Lid, SNL Experiment Shipment	315-40-119	2
Legal weight Truck, Transport Cask Assy, SNL Experiment Transport Configurations	315-40-138	3
Legal Weight Truck, Transport Cask Assy, Spacer	315-40-144	2

1.1.2 Containment Boundary

The primary containment boundary of the NAC-LWT cask consists of the cavity vessel that includes the 0.75-inch-thick inner shell, the 4-inch-thick bottom plate, and a 7.5-inch-thick upper ring forging. The fully welded cavity vessel is closed by an 11.3-inch-thick bolted closure lid secured by 12 high-strength bolts. Two auxiliary access ports are provided in the upper ring forging to allow operational access to the cask cavity with the lid installed to allow draining, evacuation, and backfilling. These two ports are designated as the vent and drain ports and each are provided with a quick-disconnect valved nipple. The valved nipples provide operational access to the cask cavity, but are not considered part of the containment boundary. The containment boundary closure for both the vent and drain ports is provided by a bolted Alternate B port cover and the metallic O-ring seal.

1.1.3 DBE Transport Canisters

The transport canister provides a secondary leak-tight boundary to prevent intrusion and interaction of water with the sodium DBE content. The canisters are made of 304 stainless steel, designed, fabricated, and inspected according to the ASME Code, Section III, Subsection NB, 1995 Edition, to the maximum practical extent. Materials are provided to the ASME Code, Section II, Part A, Part B and part C, 1998 Edition. Based on the code reconciliation performed by the applicant and confirmed by the staff, later code editions up to and including 2004 Edition with 2005 and 2006 Addenda may be used, with specific exceptions or noted alternatives as described in the SARP. The staff has reviewed these exceptions and alternatives in the SARP and found them acceptable.

1.1.4 Serial Number of Casks

NAC-LWT cask Units 6, 7, and 8 will be used for the SNL DBE shipments. These units are equipped with Alternate B port covers and are depicted on NAC License Drawing No. 315-40-02, Revision 21. Cask Units 6 and 8 have been used for TPBAR shipments, whereas Cask Unit 7 has not. Because of the concern of possible tritium contamination [See NuREG-1609, Supplement 2, Standard Review Plan for Transportation Packages for Irradiated Tritium-Producing Burnable Absorber Rods (TPBARs)], cask Units 6 and 8 are allowed for the DBE shipments only after they have been decontaminated of tritium.

1.2 Contents

There are eleven (11) sodium debris bed experiments (DBEs) to be shipped in the NAC-LWT cask. Each DBE consists of a crucible containing UO_2 particles immersed in sodium. (The uranium is 93% enriched in U^{235}.) According to the paper "*In-Pile Experiments and Analysis of the Coolability of UO_2 Debris in Sodium*," G.W. Mitchell et al., Nuclear Safety, Vol. 28, No.1, January-March 1987, these DBE experiments have been conducted in the Sandia Annular Core Reactor between 1977 and 1985. Most DBEs, therefore, have been in storage for over 22 years. A radiation survey of the DBEs was taken in February 2006, and the contact dose rates varied between 0.4 and 1,100 mrem/h. The source term of the radiation is primarily the activated structural and crucible material.

Table 1.2-10 of the SARP lists the gross weight of each of the 11 transport canisters loaded with the DBE experiments, the overall length of each canister, and the weight of uranium, U^{235}, and sodium in each canister. Table 1.2-10 also lists the values of the parameters for a bounding canister case as follows:

Max. DBE weight: 450 lbs
Max. DBE transport canister loaded weight: 1,100 lbs
Max. DBE length (w/o handling adapters): 75 in.
Max. DBE Transport canister length: 90 in.
Max. U^{235} mass: 8 kg
Max. U^{235} enrichment: 94%
Max. activation source term: 15.3 Ci Co^{60}
Max. content heat load of all DBE contents/shipment ≤ 100 W
Min. cooling time: 10 yrs
Max. irradiation time: 80 hrs

The staff has verified that the above parameter values are indeed bounding for the 11 DBEs and canisters, and that these bounding values have been used in the SARP analyses to demonstrate safety and regulatory compliance in the areas of structural, thermal, shielding, and criticality safety.

1.3 Transport Configurations in Exclusive Use Shipment

Up to 3 DBE transport canisters may be loaded into the cavity of a NAC-LWT cask for an exclusive use shipment. The planned canister loading and transport configurations are shown in Drawing No. 315-40-138 and reproduced in Table 1.2 below:

Table 1.2 Planned shipment configurations

Shipment ID	DBE	Canister ID	Required Spacer	Cavity Placement
1	D-10	F	1	Top or bottom
	D-13	F		Top or bottom
2	D-9	E	2	Top
	D-6	B		Middle
	D-2	B		Bottom
3	D-4	F	3	Top
	D-5'	A		Middle
	D-3	B		Bottom
4	D-1	B	None	No preferred order
	D-5	C		
	D-7	D		

Those transport canisters having identical canister IDs in Table 1.2 are interchangeable, i.e., F for F, or B for B between the different Shipment ID groups. The canisters in the same alphabetic group are inter-changeable because they have the same overall length, and because the analyses have used parameter values for the bounding case. The planned loading sequence of the transport canisters may be altered to accommodate the facility requirements in loading and unloading. For Shipment ID 1, 2 and 3 in Table 1.2, a spacer may need to be installed to limit the axial movement of the DBE canisters. Drawing No. 315-40-144, Sheet 1 of the SARP shows the different spacer designs that should be followed for the use of the correct spacers to limit the axial movement of the loaded DBE canisters. Alternate spacers have also been designed to substitute for a DBE transport canister and provide additional operational flexibility. These Alternate spacers are shown in Drawing No. 315-40-144, Sheets 2 & 3 of the SARP.

1.4 Criticality Safety Index

Based on the results of the criticality safety analysis presented in Chapter 6 of the SARP, the staff has confirmed that the Criticality Safety Index (CSI) derived based on the procedure in 10 CFR 71.59(b), is

CSI = 0,

which also satisfies the requirement of 10 CFR 71.59(c) for the exclusive use shipment.

1.5 Conclusion

Based on the statements and representations in Chapter 1 of the SARP and the staff's confirmatory evaluation, the staff concludes that the general information (and drawings) of the NAC-LWT cask and the DBE contents has been adequately described. Evaluation of design and performance of the cask for safety and regulatory compliance in structural, thermal, containment, shielding, operating procedures, acceptance tests and maintenance, and quality assurance are given in the remainder sections of this Safety Evaluation Report (SER).

2. STRUCTURAL

2.1 Discussion

The main focus of the structural evaluation is on the Debris Bed Experiment (DBE) Canister Structural Analysis presented in Section 2.10.16 of the SARP. In addition, the structural evaluation also examined the following three sections in the SARP because they may affect the structural evaluation of the DBE canisters: Section 2.3.1 Mechanical Properties of Materials; Section 2.1.3.2.2 Bolts Closure Lid (Fatigue); and Section 2.10.8 Quarter-Scale Model Drop Test Program for the NAC-LWT Cask.

2.2 Evaluation of Mechanical Properties of Materials

The mechanical properties of the structural materials presented in Section 2.3.1 of the SARP are not always consistent with the values listed in the references. For example, Table 2.3.1-2 of the SARP lists the yield and ultimate strengths for the XM-19 stainless steel at -20ºF as 62.0 and 103.7 ksi, respectively. However, according to ASME Section II, Part D, the corresponding values are 55.0 and 100.0 ksi for the temperature range of -20 to +100ºF. The applicant states that since the yield and ultimate strengths are not used in the structural analysis of the cask for the Normal Condition of Transport, the identified inconsistency does not affect the structural evaluation and no change was made to the SARP.

Another example of inconsistency is related to the mechanical properties of lead. Table 2.3.1-8 of the SARP lists the dynamic mechanical properties of chemical copper lead and references the NUREG/CR-0481 report for the properties. However, the yield strength value of 5,000 psi shown in the table at 70ºF is significantly higher than those (≈ 1,000 psi) shown in Figures 24 and 25 of the NUREG/CR-0481 report. The applicant states that since the finite-element analysis of the cask body was performed using linear elastic properties of the lead, and the quarter-scale model drop test showed no plastic deformation of the lead, no change in the SARP is warranted. For the static mechanical properties of chemical copper lead in Table 2.3.1-7 of the SARP, the Ultimate Strength in the second row of the table has been revised to the correct name Yield Strength.

In summary, the applicant seemed reluctant to revise the SARP to address some of the identified inconsistencies in the materials properties. The staff has not insisted on the SARP revision only because these inconsistencies have been determined not to affect the structural performance of the cask and/or the DBE canisters.

2.3 Determination of Preload in the Cask Closure Bolts

In Section 2.1.3.2.2 of the SARP, the bolt preload force resulting from the top corner drop test is determined by assuming that all 12 bolts would resist the drop load equally. However, since the bolts are located at different distances from the impact point during a corner drop, the bolt that is the farthest from the impact point should receive the largest force. According to the NUREG/CR-6007 report, the largest bolt force is about 1.34 times the average bolt force, regardless of the impact angle. In response to the Q1 question, the applicant performed a finite-element analysis of the NAC-LWT cask during a corner drop and calculated the stress distribution on the closure bolts of the cask. The results showed that the load distribution among the 12 closure bolts is essentially uniform with a variation of ±1.5% from the average, and the maximum bolt load is 23,306 lbs. The recessed construction of the closure lid for the NAC-LWT cask, as opposed to a flat lid construction where a lid sits right on the top of the cask flange as in NUREG/CR-6007, is the reason for the essentially uniform distribution of the loads among the 12 bolts during the corner drop.

Section 2.1.3.2.2 of the SARP employs a coefficient of friction of 0.06 in the calculation of the bolt preload. This value of the coefficient of friction is smaller than the average value of 0.15 in Shigley, Mechanical Engineering Design, 3rd Edition (1977). In response to the Q1 question, the applicant states that a sliding friction coefficient of 0.058 for hard steel on hard steel with graphite lubricant is applicable for the NAC-LWT cask because it uses a graphite-based lubricant. A new reference, Table 3.2.1 in Mark's Standard Handbook for Mechanical Engineers, is provided in the SARP for the sliding coefficient of friction.

Section 2.1.3.2.2 of the SARP conservatively specifies an installed preload of 34,843 pounds. Assuming an uncertainty of ±30% in the installed preload per NUREG/CR-6007, the lowest installed preload would be 24,390 lbs, which is still greater than 23,306 lbs, the maximum bolt load calculated in the finite-element analysis of the cask in the top corner drop test. Furthermore, the use of lubricant would significantly reduce the uncertainty of the preload, as shown in the paper by Blake J.C. and Kurtz H. J., *The Uncertainties of Measuring Fastener Preload*, Machine Design, Vol. 37, Sept. 1965.

In summary, the staff finds the Q1 responses and the corresponding SARP revisions acceptable and that sufficient preload would be installed for the closure bolts in the NAC-LWT cask.

2.4 Dynamic Load Factors

The structural analyses of the NAC-LWT cask and the DBE canisters during drop tests under normal and accident conditions are performed using the ANSYS finite-element code. The results of the quasi-static analyses are compared to the data in the quarter-scale model drop test program described in Section 2.10.8 of the SARP. No justification has been provided in the SARP for not considering the dynamic amplification factor in the analysis. According to the NUREG/CR-3966 report, *Methods for Impact Analysis of Shipping Containers*, if the time required to apply the impact loading (i.e., increase in the load from zero to its maximum value) is less than half the fundamental natural period of the cask, the loading is dynamic and a dynamic amplification factor (≈ 2.0) should be included in the analysis. If the time of the loading is greater than three times the fundamental natural period of the cask, a quasi-static analysis may be used (dynamic amplification factor ≈ 1.0) since the dynamic effects are negligible.

In response to the Q1 question, the applicant evaluated the dynamic response of the cask and the DBE canisters. The time history curves for the 31-foot drops are calculated based on the force-deflection curves shown in Table 2.10.12-18 through Table 2.10.12-20 of the SARP. The fundamental natural periods of the cask and DBE canister are computed and compared to the loading duration. The comparison shows that the loading durations for the end drop and side drop are about one half of the cask fundamental natural periods in each orientation, indicating that the dynamic amplification factors should be applied to the quasi-static stress analysis results of the cask during both the end-drop and the side-drop tests.

For the DBE canisters, the load duration for the end drop test is about half the DBE canister fundamental natural period for axial vibrations; and the load duration for the side drop is about six times the fundamental natural period for bending vibrations. Dynamic amplification factor, therefore, should be applied to the quasi-static stress analysis results for the canister for the end drop test, but not for the side drop test.

The Quarter-Scale Model Drop Program for the NAC-LWT cask resulted in a strain of 560 μin./in. and 2,984 μin./in at the midpoint location of the model during the end drop and side drop tests, respectively. The strains calculated for a full-size cask during the end drop and side drop tests using quasi-static, finite element analysis are, 115 and 2,411 μin./in, respectively. Thus the test strain data of the cask (quarter scale model) is 4.9 times the finite-element analysis result for the end drop and ≈ 1.3 times for the side drop test. Based on these results, the applicant applied a dynamic load factor (DLF) of 5.0 and 2.0 to the quasi-static, finite-element analysis of the DBE canister during the end drop and side drop test, respectively. This is conservative.

2.5 DBE Canister Structural Analysis

The maximum weight of the DBE canisters, for any transport configurations described in the SARP, is 2,110 lbs. This weight is bounded by the maximum weight of 4,000 lbs for the contents in the transport canisters for the NAC-LWT cask. The SARP has conservatively used 4,000 lbs in the DBE canister structural analysis. The maximum shipping weight for the DBE canisters in the NAC-LWT cask is 49,318 lbs, which is bounded by the maximum gross weight of the cask of 52,000 lbs. Therefore, the accelerations (equivalent G load factors) listed in Table 2.6.7-34 of the SARP for the cask with the maximum design weights during the 31-ft drops are considered to be bounding for the DBE canisters.

31-ft Drop Test: As discussed earlier, the DBE canister responds dynamically during the 31-ft end-drop test. The quasi-static analysis calculated a compressive primary membrane stress of 12.7 ksi, based on a maximum weight of 4,000 lbs, instead of 2,110 lbs, for the DBE canisters. Applying a factor of 0.5275 (2,110/4,000) reduces the stress to 6.7 ksi, which is then multiplied by a DLF of 5.0 to obtain a dynamic primary membrane stress of 33.5 ksi. Since the allowable primary membrane stress at the bounding maximum temperature of 430ºF is 44.3 ksi, the margin of safety during the 31-ft end drop for the DBE canisters is 0.32 [= (44.3/33.5) - 1].

For the 31-ft side-drop test, the quasi-static analysis can be used for the DBE canister and the resulting stresses should be multiplied by a DLF of 1.3 to account for the difference between the calculated strains in a full-size cask and the measured strains in the quarter-scale model. Instead, the applicant applied the maximum possible dynamic amplification factor of 2.0 to the stresses calculated for the 31-ft side drop. This gives the margin of safety of 2.6 for the DBE canisters during the 31-ft side drop.

Section 2.10.16 of the SARP has been revised to incorporate the Q1 responses associated with the dynamic load factor; Table 2.10.16-2 has been replaced showing the dynamic stresses and safety margins calculated for the 31-ft end drop and side drop tests with DLF of 5 and 2, respectively. The staff has confirmed the calculations and found the results acceptable.

DBE Canister Orientation for Maximum Damage: In Section 2.10.16.4 of the SARP, structural analysis is performed for the DBE canister during the 31-ft side-drop test. In response to the Q1 question on the drop orientation for maximum damage of the DBE canister, the applicant has performed additional analysis for the DBE canister during a corner or oblique drop of the cask. A conservative method is used to calculate the maximum stresses in the canister during a corner or oblique drop, i.e.,

$$\sigma_{c,ob} = \sigma_{end} (G_{c,ob}/G_{end}) + \sigma_{side} (G_{c,ob}/G_{side})$$

where σ and G are the stress and acceleration, respectively, and the subscripts indicate the drop orientation. The stresses calculated for the end drop and side drop tests are listed in Table 2.10.16-2, and the equivalent G load factors listed in Table 2.6.7-34 of the SARP for lateral (side), longitudinal (end), corner (15.74°), and oblique angles (30°, 45°, 60°) for the 31-ft drops. Table 2.10.16-3 of the SARP shows that the highest stresses in the DBE canister are calculated for the corner drop with a minimum safety margin of 2.0 for the primary membrane stress (14.35 ksi), and 3.2 for the primary membrane plus bending stress (15.33 ksi).

Slap-down of the cask may occur during a corner or oblique drop and causes secondary impact usually at the opposite end of the cask. The impact energy of a slap-down event is generally lower than that of the primary impact and the effect on the DBE canisters should be minor, especially since spacers are employed to limit the axial and radial movement of the canisters inside the cask.

Movement of DBE Canisters: The gap between the DBE canister and the cask wall will affect the impact loads on these components during a drop test. The maximum allowable gap may be determined by ensuring that the impact load is no higher than those assuming no gaps and that the DBE canister will come into contact with the cask lid or wall before the cask bottoms out during the drop test. The applicant estimated the maximum allowable gap sizes to be 7.81 and 7.03 in. for the end drop and the side drop test, respectively. The nominal axial and radial gaps between the DBE canisters and the cask lid and wall are, 0.94 and 0.14 in, respectively. Since these nominal gaps are significantly smaller than the maximum allowable gaps, they should not affect the impact loads on the DBE canister.

DBE Canister Lid Seal Weld: The DBE canister lid seal weld is a partial penetration closure weld. The canister design initially included a 0.25-in. lid seal weld, which was later reduced to 0.125 in. in the final design. The materials for canister and lid are stainless steel and thus do not include a dissimilar metal weld. The weld should not experience stress due to differential thermal expansion between these two components. The lid is supported by the canister top flange, and the lid load is directly transferred to the flange during a drop accident. The main load on the seal weld is due to the pressure inside the canister. According to Section 3.7.4, Normal and Accident System Pressures of the SARP, the bounding DBE canister cask containment pressures are 20 psia for NCT and 24 psia for HAC. The SARP analyzed the lid weld by conservatively assuming that the canister pressure is ≈ 10 times larger, i.e., 250 psi.

The 0.125-in. seal weld resists the 250-psi pressure load by shear deformation. The resulting shear stress is 5,628, whereas the allowable shear stress is 12,000 psi at 250°F, which is the bounding temperature for the canister during NCT. The corresponding margin of safety is 1.132. However, because surface examination (PT) of the seal weld is used according to Drawing No. 315-40-117, Rev. 3 in the SARP, a stress reduction factor of 0.8 should be applied based on the NRC Spent Fuel Office Interim Staff Guidance (ISG)-15, *Materials Evaluation*. The allowable shear stress is therefore 9,600 psi (0.8 x 12,000 psi) and the margin of safety is reduced to 0.905. The actual margin of safety would be considerably higher since the assumed canister pressure is much greater than the bounding pressure for NCT.

Under accident conditions, the pressure load acting on the seal weld is the same but the allowable stress is higher; therefore, the margin of safety is higher. In summary, the integrity of the seal weld will be maintained during the transportation of DBE canisters in the NAC-LWT cask.

2.6 Conclusions

Based on the review of statements and representations in the SARP and the staff's confirmatory evaluation, the staff concludes that the structural design and performance of the DBE transport canisters and the NAC-LWT cask in Chapter 2 of the SARP are acceptable, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 460.1B are met.

3. THERMAL

3.1 Discussion

Analyses are used in the SARP to evaluate packaging temperatures under the normal conditions of transport (NCT) and hypothetical accident conditions (HAC) specified in 10 CFR 71.71(c) and 71.73(c)(4), respectively. The staff evaluation of the SARP thermal analysis focused on the design of the NAC-LWT cask that should provide adequate thermal protection to the containment boundary of the cask and meet the thermal requirements of 10 CFR 71.43(g).

3.2 Material Properties and Temperature Limits

3.2.1 Thermal Properties of Materials

The thermal properties of the materials of all of the packaging components, modeled in the analyses, have been adequately listed in the SARP. The listed property values are in agreement with the values found in the published technical reports, standards, test reports, or handbooks. The references cited for the data are also provided in the SARP. The typographical error on page 3.2-4 of the SARP regarding the exponent 0.278 in the range of evaluation has been corrected. The exponent has been deleted to give the correct range as follows:

$$10^3 < \frac{\mathrm{Pr}^2\, Gr}{1.36 + \mathrm{Pr}} < 10^8$$

According to the SARP (page 3.2-3) the conduction and convection coefficients in the liquid regions of the cask are combined into a single term called the effective thermal conductivity k_e, which depends nonlinearly on the Prandtl number (Pr) and the Grashof number (Gr). Since Gr depends on the temperature difference (ΔT), k_e has a power-law dependence on ΔT, i.e., $k_e \propto (\Delta T)^{0.278}$. The SARP used a single-valued k_e for the neutron shield tank (0.7785 Btu/hr-in-^{0}F) and the expansion tank (0.3573 Btu/hr-in-^{0}F), which are generally more conservative as shown in Fig. 3.1 below: $(\Delta T)^{0.278}$, hence k_e, varies between ≈2 to 3.5, for ΔT across the neutron shield tank (or expansion tank) of 10 to 100^{o}F.

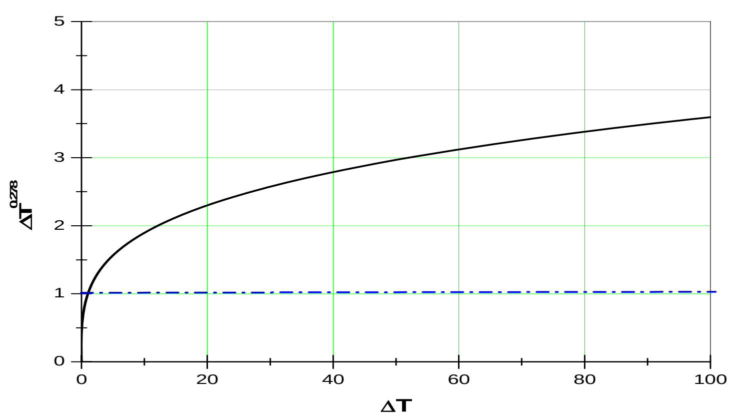


Fig. 3.1 Variation of $(\Delta T)^{0.278}$ versus ΔT

In response to the Q1 question, the applicant has revised the SARP to include results of the thermal test of a cask and compared the data to the results of the ANSYS thermal analysis of the cask for a decay heat load of 1.41 kW shown in Table 3.4-7 of the SARP. The comparison has been used as a justification for using a single-valued k_e that resulted in a conservative ANSYS thermal analysis and the temperatures across the neutron shield tank and the expansion tank.

3.2.2 Operating Temperature Limits for Packaging Components

The components of the NAC-LWT cask that require attention from the perspective of thermal performance include the following:

1) metallic O-rings (for both lid and port cover),
2) TFE and Viton O-rings,
3) lead-gamma shield,
4) aluminum honeycomb impact limiters,
5) liquid neutron shield, and
6) DBE Canisters

The metal O-rings are the inner O-rings used in conjunction with the cask lid and two Alternate B port covers for venting and draining to ensure containment of the contents, including backfilled helium and fission gases, within the NAC-LWT cask. The metallic O-ring for the cask lid is made of stainless steel to the Specification HELICOFLEX U200159, whereas the metallic O-ring for the vent and drain port covers are made of HN-200 silver to the Specification HELICOFLEX #308210 (See Item 35, Dwg. No. 315-40-8 in Section 1.4 of the SARP). The operating temperature ranges are -40^{o}F to 800^{o}F for the metallic O-ring of the lid and -40^{o}F to 600^{o}F for the metallic O-ring of the Alternate B port covers. The SARP (page 3.3-1) has been revised to include both metallic O-rings for the lid and Alternate B port covers with the appropriate safe operating temperature ranges, i.e., -40^{o}F to 800^{o}F and -40^{o}F to 600^{o}F, respectively.

The metallic O-ring (Item 8) for the lid, as specified in Dwg. 315-40-04 (Rev. 10) per specification HELICOFLEX U200159 (for stainless steel 321) has a temperature range from cryogenic to 500^{0}F (see Fig. 4.5-2, pages 4.5-14 and 4.5-22 of the SARP), which is much lower than 800^{0}F. Information provided by the applicant in response to Q1 question (3-2) indicated that HELICOFLEX U200159 is actually a silver plated O-ring made of alloy X-750, not stainless steel as specified in Dwg. 315-40-04 (Rev. 10) per Specification HELICOFLEX U200159. Category information for alloy X-750 identifies acceptable service temperature to 1,100^{0}F and acceptable silver service temperature to 800^{0}F. Dwg. 315-40-04 and Specification HELICOFLEX U200159 have been revised in the SARP to show the correct material for the metallic O-ring for the lid.

Based on the bounding decay heat load of 2.5 kW, the maximum temperatures calculated for the metallic O-rings are 227^{o}F (108^{o}C) for the normal conditions of transport (Table 3.4.5 of the SARP), and 571^{o}F (299^{o}C) for the hypothetical accident conditions (Table 3.5.1 of the SARP). These maximum temperatures should bound those for the 3 DBE transport canisters in the NAC-LWT cask, with a total decay heat load of $\leq$ 0.75 W (0.25 W for each canister). Both types of metallic O-rings are acceptable since the maximum temperatures are significantly lower than the safe operating temperature limits of the metallic O-rings.

As outer O-ring seals, a **tetrafluoroethylene (TFE) resin O-ring** is used for the cask lid, whereas two **Viton O-rings** are used for the vent and drain ports of the Alternate B port cover. Material specifications for the TFE and the Viton O-rings are provided in the drawings #315-40-4 (SHAMBAN S11214-460) and #315-40-8 (PARKER #2-229v0835-75), respectively, in Section 1.4 of the SARP. Test results in the Certified Test Report D9-3362-1, Applied Technical Services Inc., Section 3.3 of the SARP show that the

TFE O-ring is unaffected by temperatures up to 735^{o}F (391^{o}C). Test results in Appendix 4.5.3 of the SARP show that the Viton O-ring maintained its sealing function at 550^{o}F for over 4 hours and at 575^{0}F for a prolonged duration. Both the TFE and Viton O-rings, therefore, are acceptable because the maximum temperatures calculated based on the bounding decay heat load of 2.5 kW are lower than the operating temperature limits of these O-rings. Furthermore, even if the outer Viton O-rings lose their sealing function, the inner metallic O-rings for the Alternate B port covers can still provide the sealing function up to 600^{0}F.

The maximum temperature limit of the **lead gamma shield,** manufactured to Specification ASTM B29, is the solidus temperature of the lead with the chemical copper grade. This temperature is specified as 600^{o}F (316^{o}C) in the SARP, which is slightly lower than the solidus temperature, 618^{0}F (325.5^{0}C), for the lead alloy with 0.04~0.08 Cu in Table 21: "Thermal properties of lead alloys," Lead Industries Association, page 99 of the book entitled "Engineering Properties and Applications of Lead Alloys," Marcel Dekker, Inc., 2000. The maximum temperature calculated for the lead-gamma shield will be discussed later under NCT and HAC.

Two **honeycomb impact limiters**, made of aluminum alloy, are used to absorb the impact force during drop accidents and they are manufactured to specifications of 3500 PSI +5%/-10% dynamic crush strength in radial/axial direction, as stated in Section 1.4 of the SARP. The impact limiters also provide some thermal protection of the lid seals during the hypothetical fire accident. While the melting temperature of the aluminum alloy may be lower than 1,475^{o}F of the HAC fire, the metallic O-rings should retain their sealing functions as discussed previously for HAC.

The safe operating temperature range for the 56% ethylene glycol and water **liquid neutron shield** is -40^{o}F to 350^{0}F (page 3.3-1 of the SARP). This ensures that the neutron shield does not boil and, therefore, provides full neutron shielding capability. An expansion tank is also provided to ensure that the neutron shield remains full at the minimum safe operating temperature of -40^{0}F. The listed temperature range for the liquid neutron shield agrees with that specified in Section 5, Lange's Handbook of Chemistry, 4th ed. McGraw-Hill Inc.

The thermal analysis of the NAC-LWT cask showed that the maximum temperature of the liquid neutron shield is 238^{o}F (Table 3.4-2 of the SARP) for a design basis PWR fuel with a decay heat load of 2.5 kW. This maximum temperature is within the safe operating temperature range of the liquid neutron shield during NCT. The neutron shield is assumed lost during HAC, and, therefore, has not been included in the thermal analysis.

The maximum allowable temperature for the **DBE canisters** is 750^{0}F (page 3.7-3 of the SARP). The DBE canisters are made of 304 stainless steel to the Specification ASME SA312. The maximum allowable temperature agrees with the datum (<800^{0}F) found in the literature "ASME Boiler and Pressure Vessel Code, Section II; Material Properties," page 324, 1998.

3.3 Thermal Analysis for Normal Conditions of Transport (NCT)

3.3.1 SARP Thermal Analysis

The SARP used numerical analyses to evaluate the thermal performance of the NAC-LWT cask during NCT. The thermal model includes the DBE canister with a 10.75-inch outside diameter, the canister supporting rings (1.25-inch for each end and 13.25 inches in the outer diameter), the multi-layered cask body without the neutron shield, and the backfilled helium gas between the canister and the inner shell of the cask. Only one case was analyzed with a canister length of 29.8 inch and a decay heat load of 100 W. The decay heat load was assumed uniformly distributed on the out surface of the canister; solar insolation was taken into account indirectly by using a bounding temperature, i.e. 198^{0}F, of the outer cask shell for a helium backfilled cask in a closed ISO container. The bounding temperature was obtained from previous calculations with a heat-load of 1.26 kW under NCT (see Table 3.4-6 of the SARP).

The effects of ambient temperature, decay heat and solar heating on the packaging temperatures were determined by using the finite element computer code ANSYS. Details of the finite-element model and results are described in Sections 3.4-1 and 3.4-2 (general), and Sections 3.7-1 and 3.7-2 (for the DBE canisters) of the SARP.

3.3.2 Maximum Component Temperatures

The maximum temperatures for the packaging components and their allowable temperature limits are shown in Table 3.1 below. The allowable temperatures for the various components have been evaluated in Section 3.2.2 of this SER and found acceptable. The calculated maximum temperature for each component is well below the corresponding allowable temperature. In addition, the 100 W decay heat load assumed in the analysis is much higher than the total decay heat load of 3 DBE canisters, i.e. 0.25 W x 3 = 0.75 W, that can be loaded into a NAC-LWT cask. Therefore, the maximum component temperatures for a NAC-LWT cask with DBE canisters should be much lower than the calculated maximum temperatures shown in Table 3.1.

Table 3.1 Summary of Calculated Temperatures for NCT

Location	**Max. Comp. Temp. ^{o}F (SARP)**	**Max. Comp. Temp. ^{o}F (Allowable)**
Accessible cask surface	110*	185**
Liquid neutron shield	112	350
Cask outer shell	198	750
Lead gamma shield	206	600
Cask inner shell	207	750
Canister support ring	212	750
Cavity gas/Canister shell	258	750

*Based on 100^{o}F ambient temperature and 100 W decay heat load.
**The temperature limit is based on 10 CFR 71.43(g) for an exclusive use shipment

3.3.3 Minimum Component Temperatures

The minimum temperature of the NAC-LWT cask with no heat load should be -40^{o}C (-40^{o}F) when exposed to an ambient temperature of -40^{o}C (-40^{o}F) in still air and shade. This condition is the coldest environment specified in 10 CFR 71.71(c)(2). The material specifications of the TFE and Viton O-rings presented in Figures 4.5-1 and 4.5-3 in Section 4.5 (Appendices) of the SARP demonstrate that the O-rings would provide a leak tight seal at -40^{o}C (-40^{o}F).

3.3.4 Maximum Internal Pressure

The maximum internal pressure is 20 psia based on the maximum DBE canister shell temperature of 258°F during NCT (page 3.7-3 of the SARP). This pressure is lower than 28.6 psia, - the maximum normal operating pressure for the design-basis PWR spent fuel assembly with 3% failed fuel rods that have been approved previously by NRC.

3.3.5 Maximum Thermal Stresses

For the NAC-LWT cask with the DBE canisters, the maximum temperature for the lead gamma shield is 206°F (97°C) under NCT, with a temperature drop of 9°F (5°C) across the lead thickness of 5.75 in. This translates into a maximum temperature gradient of 1.57°F/in. (21.8°C/m) for the lead gamma shield. The 304 stainless steel DBE canisters also have very small temperature gradient because the canisters have relatively thin wall and high thermal conductivity. These small temperature gradients are unlikely to result in significant thermal stresses [$\approx (\alpha\Delta T)\ E$] in the gamma lead shield and the DBE canisters, where α and E are the corresponding coefficient of thermal expansion and Young's modulus, respectively.

3.3.6 Evaluation of Package Performance for Normal Conditions of Transport

Evaluation of the results of the SARP thermal analyses shows that the maximum temperatures of the components during NCT do not exceed their allowable limits. The analyses assumed a decay heat load of 100 W that is conservative compared to the total decay heat load of 0.75 W for 3 DBE canisters in a NAC-LWT cask.

3.4 Thermal Analysis for Hypothetical Accident Conditions (HAC)

3.4.1 SARP Thermal Analysis

The SARP used an approximate method to evaluate the thermal performance of the NAC-LWT cask during HAC. The maximum temperatures for the DBE canister and its supporting rings are obtained by adding the NCT maximum temperatures of the components to the maximum cask inner shell temperature calculated for the HAC fire event.

The peak temperature of the inner cask shell during a HAC fire has been calculated previously for MTR fuel with a heat load of 1.26 kW. The calculation employed a half-symmetry, cross-sectional model of the cask. The decay heat in the fuel region was simulated using an equivalent, non-uniform heat flux applied to the inner surface of the cask cavity. The liquid neutron shield was not included because the liquid was assumed evaporated completely from the beginning of the fire. These assumptions are conservative because evaporation of the 10-mm-thick liquid takes time, and the effect of latent heat of vaporization was neglected. Furthermore, the decay heat load of 1.26 kW is much higher than the total decay heat load of 0.75W for 3 DBE canisters that can be loaded in a NAC-LWT cask.

3.4.2 Maximum Component Temperatures

The results of the HAC thermal analyses in the SARP are summarized in Table 3.2 of this SER, along with the allowable temperature limits obtained from Section 3.3 of the SARP.

The calculated peak temperatures of the components of the NAC-LWT cask during a HAC fire are lower than the allowable temperatures, except for the Viton O-ring which is used as an outer seal for the Alternate B port covers. (The discussion earlier indicated that the Viton O-ring can maintain its sealing function at 575^0F for a prolonged duration.) The inner metallic O-ring for the Alternate B port covers would survive the HAC fire and maintain the sealing function, and the lead gamma shield should not melt under HAC. With a low decay heat of 100 W, relatively low cavity gas and canister temperatures are expected.

Table 3.2 Summary of Calculated Temperatures for HAC

Location	**Max. Temp., ^{0}F (SARP)**	**Max. Temp., ^{0}F (Allowable)**
Lid O-Ring, TFE: Metal:	558* 571*	735 800
Cask Radial Outer Surface	1460*	-
Cask Outer/Neutron Shell	1435*	-
Radial Lead Shield	578*	600
Cask Inner Shell	334**	750
Canister Supporting Ring	339	750
Cavity gas/Canister Shell	385	750
Alternative B port cover: O-ring seal (Metal) O-ring seal (Vita$^@$)	 547* 565*	 800 550

*The maximum temperatures calculated based on the design basis PWR Fuel, with 2.5 kW heat load.

**The maximum temperatures calculated based on the MTR fuel, with 1.26 kW heat load.

3.4.3 Maximum Internal Pressure

The maximum internal pressure is 24 psia during HAC based on the maximum temperature of 385°F (196°C) for the cavity gas/canister shell. This pressure is lower than 28.6 psia - the maximum normal operating pressure for the design basis PWR spent fuel assembly with 3% failed fuel rods, which has been approved previously by NRC.

3.4.4 Evaluation of Package Performance for Hypothetical Accident Fire Conditions

The evaluation of the results of the SARP thermal analysis shows that maximum temperatures of the components during the HAC fire do not exceed their allowable limits. The evaluation has confirmed that the NAC-LWT cask can provide adequate thermal protection for the HAC fire conditions.

3.5 Conclusion

Based on the statements and representations in the SARP and the staff's confirmatory evaluation, the staff concludes that the thermal design and performance of the NAC-LWT cask in Chapter 3 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 460.1B are met.

4. CONTAINMENT

4.1 Discussion

The containment requirement for the sodium Debris Bed Experiment (DBE) contents is more stringent than that for the other types of contents approved for transport in the NAC-LWT cask. Due to the concern of sodium-water reaction and criticality safety for the highly enriched U^{235}, water must be prevented from entering into the welded DBE transport canisters during NCT and HAC. Two independent, leaktight boundaries have been established for the cask and the DBE transport canisters. Leaktight is defined per ANSI N14.5-1997 to be the leakage rate from the applicable boundaries not to exceed 1×10^{-7} ref cm^3/sec (2×10^{-7} std cm^3/sec helium).

4.2 Containment Boundaries

4.2.1 Primary Containment Boundary of the NAC-LWT Cask

The primary containment boundary of the NAC-LWT cask, shown schematically in Figure 4.5.10-1 of the SARP, consists of the cavity vessel that includes the 0.75-inch-thick internal cavity shell, the 4-inch-thick bottom plate, and a 7.5-inch-thick upper ring forging. The fully welded cavity vessel is closed by an 11.3-inch-thick bolted closure lid secured by 12 high-strength bolts. Two auxiliary access ports are provided in the upper ring forging to allow operational access to the cask cavity with the lid installed to allow draining, evacuation, and backfill. These two ports are designated as the vent and drain ports and each are provided with a quick-disconnect valved nipple. The valved nipples provide operational access to the cask cavity, but are not considered part of the containment boundary. The containment boundary closure for both the vent and drain ports is provided by a bolted Alternate B port cover and the metallic O-ring seal. In the leaktight configuration, all containment seals are metallic face seals capable of limiting leakage into or from the containment to less than 1×10^{-7} ref cm^3/sec per ANSI N14.5-1997.

In response to Q1 question (4-4) on the typical use of the metallic O-rings and potential galvanic reaction between dissimilar metals in the presence of electrolyte, the applicant states that the NAC-LWT cask closure lid utilizes a Helicoflex metallic O-ring, a 3/16-inch diameter, Alloy-X 750 tubing coated with 0.002/0.003-inch-thick silver plating. A new metallic O-ring is installed during annual maintenance and prior to each loaded transport of the NAC-LWT cask. The used metallic seal is left in place for a return empty transport and is removed and replaced during the next cask loading operation. The lid metallic O-ring is in service for a single shipment only. The Alternate B port covers utilize a different type of Helicoflex metallic O-ring, a 5/32-inch diameter, Series 300 stainless steel tubing with a silver jacket. This metallic O-ring is also in service for a single shipment only.

The safe operating temperature ranges of the inner metallic O-rings used for the cask closure lid and the Alternate B port cover are discussed in Section 3.2.2 of this TRR. In response to Q1 question (3-2), the SARP has been revised to incorporate the correct safe operating temperature ranges and the material designation. New drawings [Fig 4.5-2(a) and Fig 4.5-4] and information [Fig 4.5-2(b)]on the Helicoflex metallic O-rings have been included in Chapter 4 of the SARP (p 4.5-22-A, p 4.5-22B, and p 4.5-86-A). [The proprietary information is handled following the guidance in the NRC Regulatory Information Summary (RIS) 2004-01: *Supporting Information Associated with Requests for Withholding Proprietary Information*, June 29, 2004.]

With regard to the proximity of an electrolyte, e.g., borated water/ethylene glycol in the neutron shield tank and expansion tank, to the metallic O-rings for the cask lid and Alternate B Port covers, the applicant states that these tanks are separate pressure vessels surrounding the outer shell of the NAC-LWT cask body. The neutron shield tank is assembled on, and welded to, the 1-1/4-inch-thick XM-19 stainless steel cask outer shell that surrounds the poured-in-place lead gamma shield and the 3/4–inch-thick XM-19 stainless steel cask inner shell. The vent and drain port openings are located at a minimum distance of 10 inches from the exterior top plate of the neutron shield tank, and the port is protected by the installed Alternate B port cover with the test elastomer O-ring and the metallic O-ring isolating the cask containment from the external environment. In addition, each port is provided with a valved Snaptite quick-disconnect male coupling threaded into the cask body. The applicant further states that there is no impact on the local humidity of the area around the Alternate B port covers, as the neutron shield tank fluid is encased in a pressure-retaining vessel isolated from the environment.

In response to Q1 question (4-4) regarding helium leak testing of the NAC-LWT cask, Chapter 7 of the SARP has been revised to include steps for the metallic O-ring seal replacement, seating surface cleaning and inspection. A new paragraph has also been added to Section 4.5.10 of the SARP that makes references to the acceptance criteria as defined in Sections 8.1.3.1 and 8.2.3.3.2, and the appropriate corrective actions may include retorquing the closure bolting, replacement of seals, cleaning of sealing surfaces, etc. until acceptable helium leak test result is achieved.

4.2.2 Secondary Leaktight Boundary of the DBE Transport Canisters

The secondary leaktight boundary, shown schematically in Figure 4.5.10-2 of the SARP for the DBE transport canister, consists of the canister body, bottom weldment, top flange, and the field-installed and welded canister lid with a lifting pintle, valve guard assembly, and a welded port cover. It should be noted that the welded DBE transport canister provides a secondary leaktight boundary to prevent water intrusion into the canister; it is not considered as a containment boundary per 10 CFR 71.

4.2.3 Canister Fabrication and Helium Leak Testing

During fabrication of the DBE transport canisters and except for the final closure lid, the canister is welded with full-penetration welds, and all canister welds are subjected to volumetric examination using radiographic (RT) or ultrasonic (UT) methods in addition to dye penetrant (PT) examinations, as indicated on the appropriate license drawings in the SARP. As part of the final acceptance test, each canister will be helium leak tested using the evacuated envelope method, described in Chapter 8 of the SARP, to demonstrate that the canister is "leaktight," in accordance with the requirements of ANSI N14.5-1997.

Section 4.5.10 of the SARP states that all canister welds will be subjected to volumetric examination using radiographic (RT) or ultrasonic (UT) methods in addition to dye penetrant (PT) examinations, as indicated on the appropriate license drawings. Under the canister valve protector and port cover, even though a confirmed helium tracer gas may be absent, the integrity of the canister valve protector and port cover is confirmed by PT examination, which is the approach taken by the applicant in lieu of helium leak testing based on the NRC Spent Fuel Office Interim Staff Guidance (ISG)-15, *Materials Evaluation*, and ISG-18, *The Design/Qualification of Final Closure Welds on Austenitic Stainless Steel Canisters as Confinement Boundary for Spent Fuel Storage and Containment Boundary for Spent Fuel Transportation*. In Section 7.1.11 of the SARP the description of the procedure for dry loading of the DBE transport canister contents (Step 28, page 7.1-54) has been revised to reflect the use of PT examination in lieu of the helium leak testing for the integrity of the valve protector and port cover welds. Similar revision has also been made in the description of the acceptance testing of the DBE canisters in Section 8.1.4.4.2 (page 8.1-12) of the SARP.

4.3 Conclusion

Based on the statements and representations and staff's confirmatory evaluation, the staff concludes that the containment design and performance of the NAC-LWT cask and the DBE transport canisters in Chapter 4 of the SARP are acceptable, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 460.1B are met.

5. SHIELDING

5.1 Discussion

The sodium debris bed experiments (DBEs) are sealed capsules, and each experiment capsule consists of a crucible containing UO_2 immersed in sodium. The uranium is 93% U^{235} enriched. There are a total of 11 individual DBEs, ten of which were irradiated. One of the experiment capsules (identified as D-5') contains fresh fuel. The characteristics of the 11 DBE capsules are summarized in Table 5.5-1 of the SARP. The measured contact exposure rates of the capsules in February 2006 varied between 0.4 and 1,100 mrem/hr.

In addition to the primary containment boundary provided by the NAC-LWT cask, each DBE capsule is loaded and sealed into a separate leak-tight, welded DBE transport canister. The DBE canister provides a secondary leak-tight boundary to prevent the intrusion and interaction of water with the sodium DBE contents. Up to three DBE canisters may be placed into the NAC-LWT cask cavity for an exclusive use shipment. The DBE transport canister is fabricated of 304 stainless steel 10-inch Schedule 80 piping with a 10.75-inch outside diameter. Six different lengths of canisters ranging from 29.8 inches through 87.3 inches are used to accommodate the transport of 11 DBEs of various lengths. The NAC-LWT cask is transported in a closed ISO container that serves as the personnel barrier.

The staff has issued eight (8) Q1 questions on Chapter 5 Shielding in the SARP that was submitted in September 2006. The applicant has responded to all of the Q1s and revised the SARP accordingly.

5.2 Evaluation of DBE Source Terms

In order to properly envelope the wide range of variables in the 11 DBE experiments, a bounding Design Basis DBE was defined for radiation shielding calculations. Table 5.5-2 and Table 5.5-3 of the SARP list, respectively, the fission product and actinide inventory activities calculated by ORIGEN-S for the bounding case, i.e., the D-10 experiment that contained the highest pre-irradiation fissile mass (6.649 kg U^{235}) with a conservative 80-hour irradiation time. A bounding light-element inventory at discharge is based on the irradiation of 10 kg of Inconel-617 crucible, producing 57 Ci of Co^{60}. The Inconel-617 was modeled at a 12.5 wt% cobalt fraction in the activation analysis. Most other crucibles were made of stainless steel, which had less activation than Inconel-617. The maximum heat load calculated by ORIGEN-S for the design basis DBE is 0.25 W; the Inconel activation contributes 0.23 W to the total heat load, versus 0.02 W contributed by the actinides and fission products. Table 5.5-4 and Table 5.5-5 in the SARP list the neutron and gamma source terms, respectively, assuming a 10-year cooling time since the discharge from the reactor. ORIGEN-S was used to re-bin the neutron and gamma spectra onto the 28- and 22-group structures employed in the evaluation. The last DBE was discharged from the reactor in 1985. The use of 10-year cooling time, therefore, is very conservative for the DBE shielding evaluation. The effect of subcritical neutron multiplication is considered in the SARP. The neutron source rates are scaled by a subcritical multiplication factor of 20, which is included in the tally cards in the MCNP calculations. The staff has evaluated and confirmed that the bounding source terms defined and calculated in the SARP are appropriate for the DBE canisters.

5.3 Shielding Models and Assumptions for Dose Rate Calculations

The MCNP three-dimensional shielding models were constructed for the DBE transport canisters in the NAC-LWT cask as described in the SARP. Details of the DBE canister and the NAC-LWT cask body are explicitly modeled based on the license drawings in the SARP. Three DBE canisters of equivalent length, each containing the bounding source terms are modeled for the dose rate calculations. Within each DBE canister, three source geometrical configuration were considered: (1) a smeared source with an axial length of 144.5 cm (i.e., a source that fills up the cavity of the DBE canister); (2) a compact source with an axial length of 20.3 cm (i.e., a representative cylindrical source region with the same height of the as-built experiments); and (3) a compact source with explicit dimensions of the fuel and the Inconel crucible with a bottom. To reduce the self-shielding effect and for conservatism, the smallest amount of uranium mass (2.14 kg) in the D1 experiment was used for all fuel regions in the shielding model for the dose rate calculations.

The geometrical models for the NAC-LWT cask considered the following in the dose rate calculations::
For Normal Conditions of Transport (NCT)

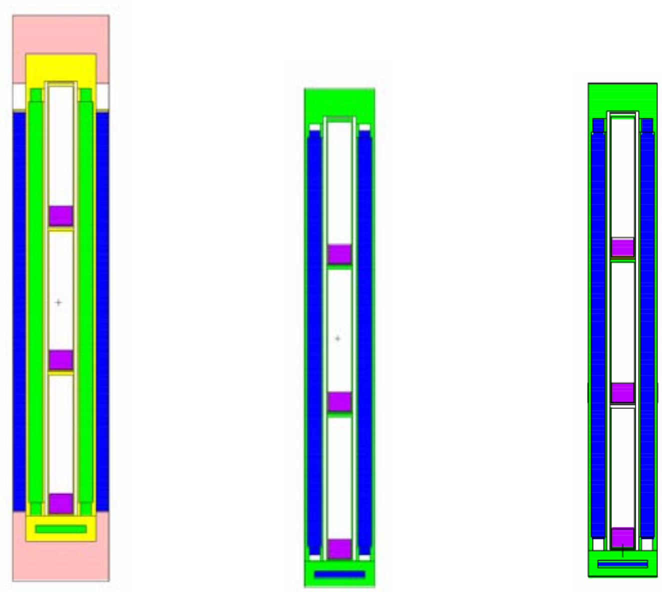
- Radial neutron shield and the shield shell are modeled
- Aluminum impact limiters with 0.5 g/cm^3 density (calculated based on the impact limiter weight and dimensions) and a diameter equal to that of the neutron shield shell

For Hypothetical Accident Conditions (HAC)

- Removal of radial neutron shield and the shield shell
- Loss of upper and lower impact limiters
- Radial and axial lead slump

The radial and axial lead slumps in the HAC models are based on the formation of a gap of 0.1374 cm (due to shrinkage) between the lead outer diameter and the cask outer shell during fabrication.

Figure 5.1 shows the cutaway view of the 3-dimensional MCNP models of the NAC-LWT cask loaded with 3 DBE canisters under NCT, (a), and HAC, (b) and (c).



(a) (b) (c)

Figure 5.1. MCNP models of the NAC/LWT cask loaded with 3 DBE canisters: (a) NCT with impact limiters and neutron shield; (b) HAC without impact limiters and neutron shield and axial lead slump assumed at both ends of the cask; and (c) same as (b) except a larger axial lead slump assumed at only one end of the cask.

The staff has confirmed the dimensions of the shielding models and verified the assumptions used in the SARP for the dose rate calculations. For HAC, the SARP assumed an evenly distributed axial lead slump at both ends of the cask [Fig. 5.1(b)]; the staff assumed a more conservative model with axial lead slump occurring at only one end of the cask [Fig. 5.1(c)]. The staff used MCNP-5 v1.30 to calculate the dose rates at various distances from the side, top and bottom of the NAC-LWT cask for both NCT and HAC. The flux-to-dose rate conversion factors are based on the ANSI/ANS 6.1.1-1977.

5.4 Summary of Dose Rate Calculations and Confirmatory Analysis

Among the three source geometrical models mentioned earlier in this SER, the compact crucible model used in the SARP, and confirmed by the staff, provided the highest calculated dose rates under NCT and HAC. Tables 5.1 and 5.2 below summarize the computed dose rates for the compact crucible model at the tabulated distances (radial and axial) from the cask. The last 3 columns in these tables list the dose rates calculated in the SARP, by the staff, and the applicable 10 CFR 71 limits, respectively. The calculated radial and axial dose rates on the cask surface under NCT are well below the 200 mrem/hr limit for packages transported under the non-exclusive use shipment (and << 1,000 mrem/hr limit for the exclusive use shipment). The maximum dose rate is dominated by the activated Inconel component in the crucible, i.e., ≈ 99% of the calculated maximum dose rate. For HAC, the calculated radial and axial dose rates at 1-meter from the cask are well below the 1,000 mrem/hr limit. Therefore, there are significant margins for the dose rates from the 10 CFR 71 limits. Figures 5.2 to 5.6 show the profiles of the calculated dose rates at various locations under NCT and HAC. The agreements of results for NCT are excellent between the SARP and staff calculations. For HAC the staff analyses assuming lead slump at only one end of the cask resulted in larger calculated dose rates due to a wider “gap” in the bottom (or top) of the cask for radiation streaming. However, the calculated dose rates at 1-m from the cask surface are still well below the 10 CFR 71 limit of 1,000 mrem/hr.

Table 5.1 Maximum Radial Dose Rates (mrem/hr) - Compact Crucible Model for DBE

	Dose Location	SARP				Staff Total	10 CFR 71 Limit
		Fissile Material		Inconel	SARP Total		
		Neutron	Gamma	Gamma			
NCT	Surface	0.00	0.00	1.72	1.72	1.71	200
	1 m	0.00	0.00	0.20	0.20	0.20	10
HAC	1 m	0.00	0.54	63.38	63.92	163.00	1000

Table 5.2 Maximum Axial Dose Rates (mrem/hr) - Compact Crucible Model for DBE

	Dose Location*	SARP				Staff Total	10 CFR 71 Limit
		Fissile Material		Inconel	SARP Total		
		Neutron	Gamma	Gamma			
NCT	Surface – T	0.00	0.00	< 0.01	< 0.01	0.005	200
	Surface – B	0.00	0.00	0.08	0.08	0.078	200
	1 m – T	0.00	0.00	-	-	0.0005	10
	1 m – B	0.00	0.00	-	-	0.015	10
HAC	1 m – T	0.00	0.00	<0.01	<0.01	0.002	1000
	1 m – B	0.00	0.00	3.31	3.31	8.82	1000

*T – top end; B – bottom end.

5.5 Conclusion

Based on the review of the statements and representations and the staff's confirmatory evaluation, the staff concludes that the shielding design and performance of the NAC-LWT cask in Chapter 5 of the SARP are acceptable, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 460.1B are met.

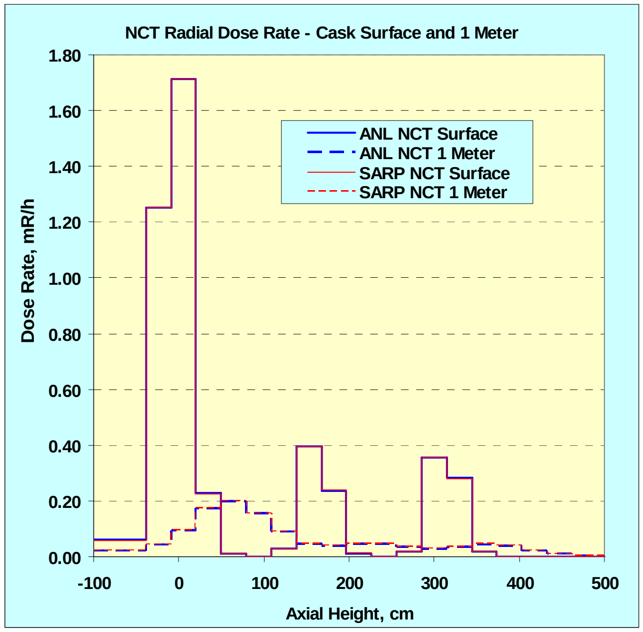


Figure 5.2. Calculated radial dose rates on the cask surface and at 1-m from the surface (NCT).

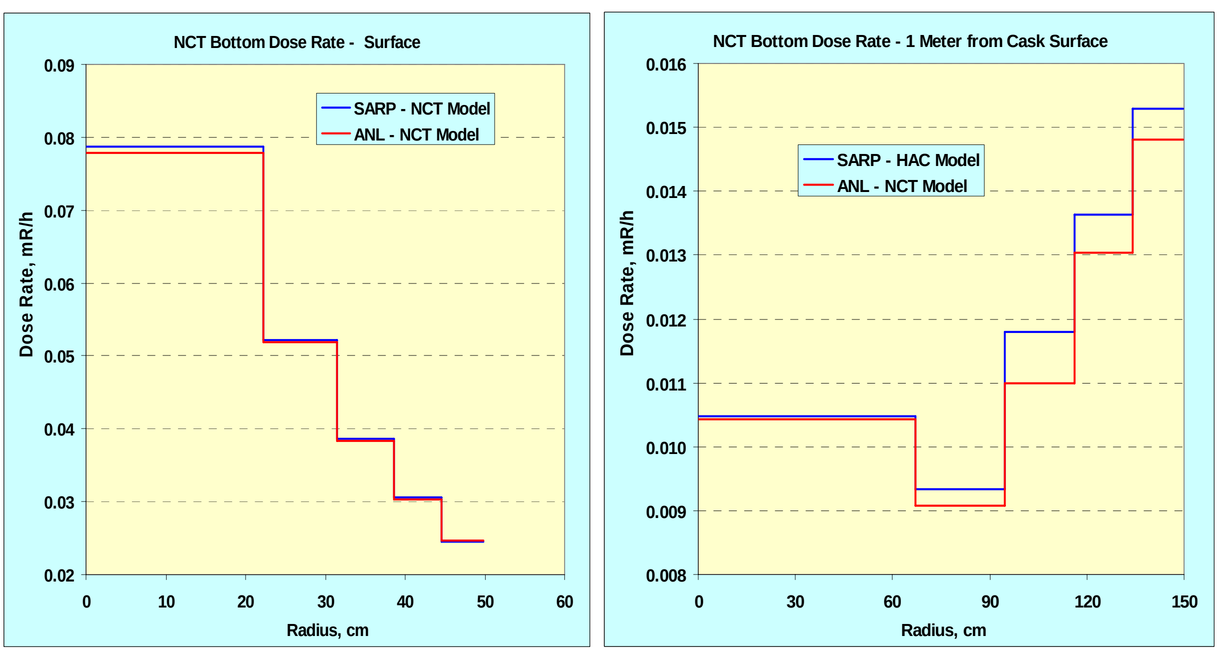
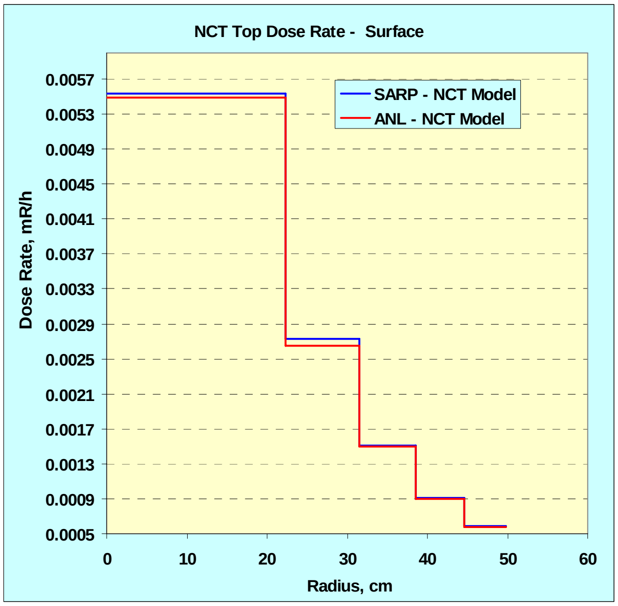


Figure 5.3. Calculated axial dose rates on the cask bottom surface and at 1-m from the surface (NCT).



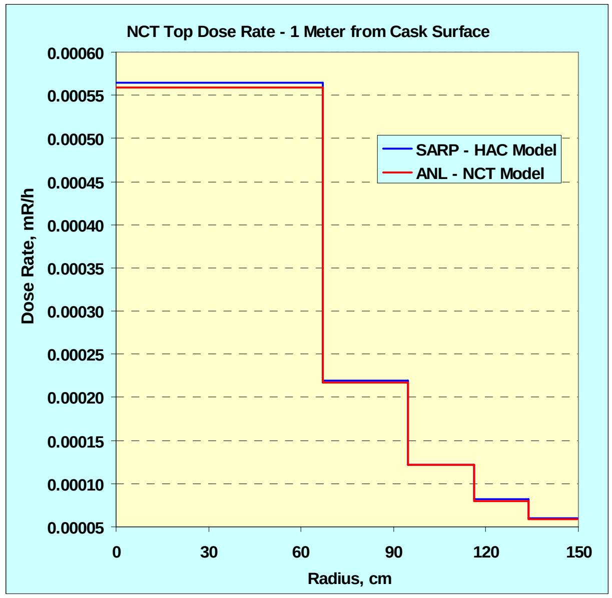


Figure 5.4. Calculated axial dose rates on the cask top surface and at 1-m from the surface (NCT)

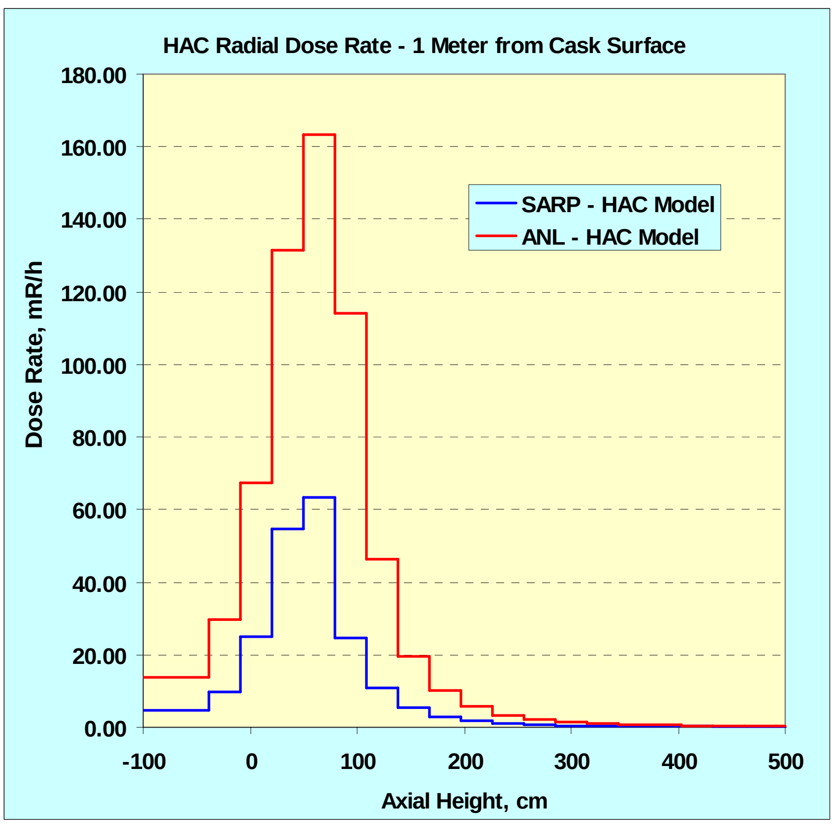


Figure 5.5. Calculated radial dose rates at 1-m from the cask surface (HAC). The staff results are ≈ 3 times higher than the SARP results due to the use of a conservative model for lead slump.

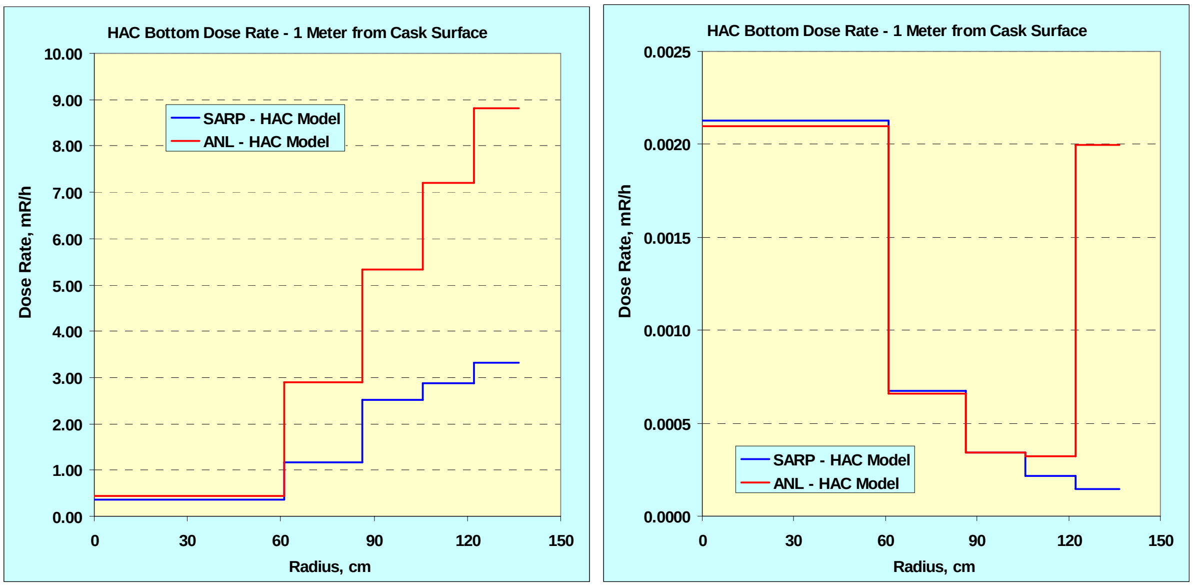


Figure 5.6. Calculated axial dose rates at 1-m from the cask surface (HAC). The staff results are ≈ 3 times higher than the SARP results due to the use of a conservative model for lead slump.

6. CRITICALITY

6.1 Discussion

The sodium debris bed experiments (DBEs) are sealed capsules, and each experiment capsule consists of a crucible containing UO_2 immersed in sodium. The uranium is 93% U^{235} enriched. There are a total of 11 DBEs, ten of which were irradiated. One of the experiment capsules (identified as D-5') contains fresh fuel. Table 6.7-1 of the SARP lists the mass values of sodium, uranium, and U^{235} for each DBE; the mass of uranium contents ranges between 2.14 and 7.16 kg. The SARP assumed a uranium mass of 8 kg and a U^{235} enrichment of 94% for each DBE capsule, which is conservative for the criticality safety analysis.

In addition to the primary containment boundary provided by the NAC-LWT cask, each DBE capsule is loaded and sealed into a separate leak-tight, welded DBE transport canister. The DBE canister provides a secondary leaktight boundary to prevent the introduction and interaction of water with the sodium DBE contents, which is also important to criticality safety because of the highly enriched U^{235}. The DBE transport canister is fabricated of 304 stainless steel 10-inch Schedule 80 piping with a 10.75-inch outside diameter. Six different lengths of canisters ranging from 29.8 inches through 87.3 inches are used to accommodate the transport of 11 DBEs of various lengths. Up to three DBE canisters may be loaded into the NAC-LWT cask for an exclusive use shipment. The SARP used the shortest canister with a length of 29.8 inches as the bounding case for criticality safety calculations; this is also conservative because of the reduced distances of U^{235} between the adjacent DBE canisters in the NAC-LWT cask.

The staff has issued eight (8) Q1 questions on Chapter 6 Criticality in the SARP that was submitted in September 2006. The applicant has responded to all of the Q1s and revised the SARP accordingly.

6.2 Evaluation of Criticality Models and Assumptions

The MCNP three-dimensional criticality models were constructed for the DBE canisters in the NAC-LWT cask as described in the SARP. The DBE canister is constructed using stainless steel, and the NAC-LWT cask is constructed using stainless steel and lead surrounded by a liquid (glycol) neutron shield and neutron shield shell. The neutron shield external expansion tank (45-inch height with 0.13-inch wall) is not modeled. Reflecting boundary conditions are imposed on the exterior surfaces of the cask model to produce an equivalent "infinite" array configuration. A bounding uranium mass of 8 kg per DBE canister is assumed with a bounding enrichment of 94% U^{235} and a sodium mass of up to 5.1 kg. Structural materials in the DBE capsules were not modeled, which is conservative because they are parasitic neutron absorbers. Figures 6.7-2 and 6.7-3 of the SARP show the MCNP-generated cask models for NCT and HAC, respectively. Two types of DBE transport canisters, Type A and Type B, were modeled. The Type A canisters are shorter and thus reduce the spacing of UO_2 in the adjacent canisters. The Type A canisters configuration is the bounding configuration for criticality calculations, even though there is only one DBE canister of the Type A length. (See SARP and Table 1.2 of this TRR.) Figures 6.7-5 and Figure 6.7-6 of the SARP show the cross-sectional sketches of the cask model (with dimensions). The differences between the cask models for NCT and HAC are the removal of the neutron shield, including the shield shell, and the impact limiters in the HAC calculations.

In order to determine the maximum system reactivity, the distribution of fissile material within the DBE canister must be considered, as are the distributions of moderator inside and outside the NAC-LWT cask. Based on a leak-tight primary containment boundary provided by the NAC-LWT cask, and a secondary leak-tight boundary provided by the welded DBE transport canister, the moderator density variation is considered only to regions outside the cask body under NCT. For HAC, the moderator density is varied in the gap between the DBE canisters and the cask assuming moderator intrusion into the cask cavity, but not into the DBE transport canisters. The moderator intrusion into the gap is a conservative assumption for criticality calculation, since the structural evaluation has shown that the primary containment boundary of the NAC-LWT cask would remain intact during HAC.

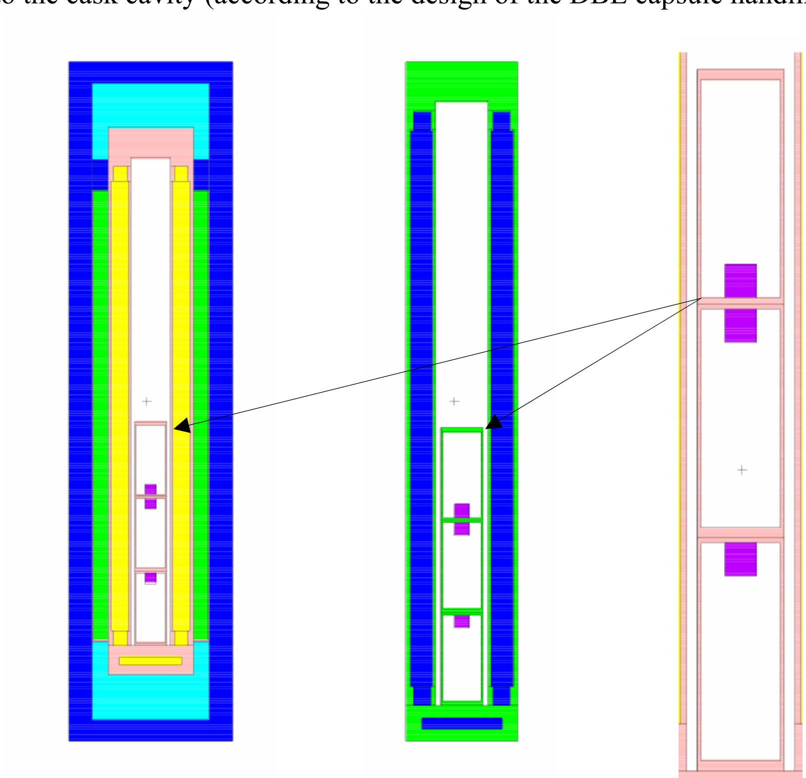
To establish the reactivity trends due to neutronic coupling between canisters and casks in the array, three fuel configurations were evaluated: (a) fuel restricted to the crucible space in the DBE capsule; (b) a cylindrical distribution occupying the radial cross-section of the canister, but extending only 50% of the canister height; and (c) a distribution throughout the canister cavity. The evaluations also considered a canister "flipped" configuration, i.e., a model where canisters are modeled as upside down with two canister bottoms touching. This “flipped” configuration allows a significantly closer fissile material approach than the 3.5-inch high lid structure. An illustration of the flipped configuration is shown in Figure 6.7-3 of the SARP. The results from these SARP evaluations indicate that the maximum system reactivity may be obtained from: (1) a flipped configuration of a condensed fuel mixture, (2) a less than full density moderator in the canister-to-cask gap, (3) ignoring sodium in the fuel-mixture model since the presence of sodium causes a small decrease in system reactivity, and (4) a dry cask exterior since a full-density moderator reduces system reactivity by restricting neutronic interaction between fissile materials in the cask array.

Figure 6.7-10 through Figure 6.7-16 of the SARP show the results obtained for varying fissile material distributions inside the DBE canister as a percentage of the canister radius, canister height, and a simultaneous variation of canister radius and height, and as a function of the moderator density in the gap between the canister and the cask. These results clearly indicated that a compacted fuel mixture, in combination with a low-density moderator in the canister-to-cask gap, produced the maximum system reactivity.

Sections 6.7.4.2, 6.7.4.3, and 6.7.4.4 in the SARP include additional detailed calculations for cases that involved a low leakage, minimum fissile material volume with a void canister-to-cask gap and a void cask exterior, a mixture of sodium and fissile material, and variations of tolerances (maximum and minimum) of components. Figure 6.7-21 of the SARP shows the results of the calculations, and Table 6.7-2(a) lists the calculated effective neutron multiplication factors (k_{eff}) and the standard deviations (σ) for various fissile material, canister, and cask configurations under HAC and NCT. In all cases considered, the highest $k_{eff} + 2\sigma$ of 0.56156 is obtained under HAC for an infinite array of the NAC-LWT casks, each containing 3 Type-A DBE canisters (one flipped) with a dry canister-to-cask gap and a dry exterior. As shown in Table 6.7-2(a) , the corresponding neutron lethargy causing fission (ALF) for the maximum reactivity is 0.21 MeV. This lethargy is within the range (0.00003 to 0.843 MeV) of the MCNP benchmarks for fast fission of uranium. The maximum reactivity is well below the Upper Subcriticality Limit (USL) of 0.9371, which is based on the 64 critical benchmarks listed in Table 6.7-3 of the SARP.

6.3 Summary of Criticality Calculations and Confirmatory Analyses

The staff evaluated the criticality analyses in the SARP and confirmed the maximum reactivity for the NAC-LWT cask containing the DBE canisters under HAC. The most reactive configuration, shown in Fig.6.1 below, is composed of: (1) three short Type-A canisters stack up inside NAC/LWT cask cavity, each containing a maximum of 8 kg U (maximum 94 wt% U^{235}) in a compact right cylindrical geometry for minimum neutron leakage, (2) dry cask cavity and cask exterior (cask under hypothetical accident condition with loss of neutron shield), (3) a hypothetical "flip" scenario in which a canister may be loaded upside down into the cask cavity (according to the design of the DBE capsule handling device, such a



(a) (b) (c)

Figure 6.1. MCNP Models of the NAC-LWT cask loaded with 3 DBE canisters: (a) NCT with impact limiters and neutron shield; (b) HAC models without impact limiters and neutron shield; and (c) enlarged view of the DBE canisters showing no gaps between the canisters in the model used in the staff confirmatory evaluation.

configuration can never be achieved in practice), and (4) neglect sodium and assume minimum axial tolerances in canister design for conservatism. In order to satisfy the 10 CFR 71.55 and 10 CFR 71.59 requirements, normal condition infinite array cask models (with impact limiter and neutron shield in place) are also evaluated with 3 Type-A "flipped' canisters, as well as a single cask containing 3 Type-A "flipped' canisters with the containment boundary fully reflected by water.

It should be noted that the MCNP models used in the staff's confirmatory calculations are slightly more conservative than those used in the SARP because the staff models eliminated the axial gaps between the canisters that are present in the SARP models. This brings the fissile material in the canisters even closer and hence more reactive. Table 6.1 of this SER summarizes the results from the SARP and the staff confirmatory evaluation; the calculated values of $k_{eff} + 2\sigma$ generally agree to the second decimal point after round-off. The maximum reactivity under NCT and HAC are all well below the USL of 0.9371, with substantial safety margins.

Table 6.1 Maximum Reactivity for the NAC-LWT cask / DBE canisters

Package Condition		HAC		NCT		NCT	
Model	Canister Type	A		A		A	
	Fuel Geometry	Compact		Compact		Compact	
	Top Canister	Flipped		Flipped		Flipped	
Cask	Configuration	Infinite Array		Infinite Array		Single	
Moderator	Canister Interior	Dry		Dry		Dry	
	Cask-to-Can. Gap	Dry		Dry		Dry	
	Cask Exterior	Dry		Dry		Wet	
	Canister Tolerance	Min		Min		Min	
Results		SARP	Staff	SARP	Staff	SARP	Staff
Maximum Reactivity	k_{eff}	0.55830	0.56111	0.45758	0.46230	0.45737	0.46454
	σ	0.00163	0.00158	0.00112	0.00121	0.00117	0.00115
	$k_{eff} + 2\sigma$	0.56156	0.56427	0.45982	0.46472	0.45971	0.46684
Safe Limit	USL	0.9371		0.9371		0.9371	

The results in Table 6.1 demonstrate that the NAC-LWT cask containing DBE transport canisters meets the fissile material criticality safety requirements of 10 CFR 71.55 and 71.59 under NCT and HAC.

The Criticality Safety Index (CSI), based on the most reactive infinite array of the NAC-LWT casks containing DBE canisters, is 0 per 10 CFR 59(b), which also meets the requirement in 10 CFR 59(c) for an exclusive use shipment.

6.4 Conclusion

Based on review of the statements and representations and the staff's confirmatory evaluation, the staff concludes that the criticality safety design and performance of the NAC-LWT cask in Chapter 6 of the SARP are acceptable, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 460.1B are met.

7. OPERATING PROCEDURES

7.1 Discussion

Chapter 7 of the SARP describes the requirements and the general operating procedures for loading, unloading, and preparing the NAC-LWT cask for transport the Debris Bed Experiments (DBE) caspsles in the welded DBE transport canisters. These general operating requirements shall be implemented by site-specific procedures to ensure that the cask is used in accordance with the Certificate of Compliance for the NAC-LWT cask. Oversight organizations, such as Quality Assurance or Quality Control, may participate in certain cask handling operations.

7.2 Cask Loading

Section 7.1.11 of the SARP describes the requirements for the preparation, loading, closure, and testing of the DBE canisters, followed by the dry loading of up to three (3) DBE canisters into an NAC-LWT cask in an external (i.e., open air) dry loading work station. Appropriate radiological controls and procedures, which address the control of radioactive material releases and ALARA principles during the canister loading and closure, and canister loading into the NAC-LWT cask shall be implemented by the user.

7.2.1 Preparation for Loading

The requirements for the preparation for loading include: (1) having a proper Certificate of Compliance for the NAC-LWT cask with the DBE contents, (2) checks for cask serviceability, (3) conduct of radiation surveys, and (4) having approved site operating procedures prepared according to the requirements enumerated in Chapter 7 of the SARP. The serviceability of the cask is determined based on the criteria given in the maintenance program in Section 8.2 of the SARP. Steps 1 through 13 of Section 7.1.11 of the SARP address the requirements for the preparation for loading the cask. Radiation survey requirements are addressed in Steps 1, 3, and 6. The user will verify that cask Units 6, 7 and 8 are decontaminated of tritium. (See discussion in Section 1.1.4 of this SER.)

7.2.2 Loading of Contents

7.2.2.1 Loading of the DBE Canister

The fuel/sodium region in each DBE is contained within an individually sealed capsule, and each capsule is loaded into a separate DBE transport canister. Steps 14 through 32 of Section 7.1.11 of the SARP describe the loading of a sealed DBE capsule into a DBE transport canister.

Steps 14 through 18 describe the placement of the sealed DBE capsule into a DBE canister.

Steps 19 through 22 describe this welding and inspection of the DBE canister lid to DBE canister top flange. The DBE canister lid is put in place in the DBE canisters top flange and welded with a root pass. The root pass weld is then liquid penetrant (PT) inspected. The welding of the DBE canister lid is completed and again PT inspected.

Steps 23 through 27 describe the evacuation, helium filling, port cover welding, and dye penetrant inspection. The DBE canister is then evacuated to a vacuum of < 3 torr. and backfilled with 99.9 % pure helium to -1 to +2 psia. The vacuum and helium equipment is disconnected from the DBE canister port quick disconnect valve nipple. The valve guard port cover is welded in place and liquid penetrant inspected.

Steps 28 through 32 describe this leak testing of the welded DBE transport canister. A helium leak test fixture is placed over the top lid and flange assembly to envelope all lid closure welds. A mass spectrometer leak detector (MSLD) is connected to the helium leak test fixture. The helium leak test fixture is evacuated to approximately 1-2 torr. The MSLD is operated to verify that there is no indication of a helium leak exceeding 2×10^{-7} cm^3/sec at a minimum test sensitivity of 1×10^{-7} cm^3/sec helium. Following a successful helium leak test the DBE canister is ready for loading into a NAC-LWT cask.

As stated above, the final closure seal welds for the canister lid to body, canister valve protector and port cover, and pintle to lid, are helium leak tested. The seal welds for the canister lid to body and pintle to lid are leak tested in accordance with ANSI N14.5-1997. Due to the absence of a confirmed helium tracer gas under the canister valve protector and port cover, the integrity of the canister valve protector and port cover is confirmed by PT examination. PT examination is allowed in lieu of helium leak testing by the NRC Interim Staff Guidance (ISG)-15 *Materials Evaluation*, and ISG-18 *The Design/Qualification of Final Closure Welds on Austenitic Stainless Steel Canisters as Confinement Boundary for Spent Fuel Storage and Containment Boundary for Spent Fuel Transportation*. The SARP has been revised to reflect the use of a PT examination in lieu of the helium leak testing.

7.2.2.2 Loading of the NAC-LWT Cask

Steps 33 through 42 of Section 7.1.11 of the SARP describe the loading of the DBE canisters into the NAC-LWT cask. Up to three (3) DBE canisters, and in certain configurations a spacer, or an alternate spacer may be loaded into the NAC-LWT cask to limit the axial movement of the canisters within the cask. A lid and gasket is installed with 12 closure bolts, which are tightened to 260 ± 20 ft-lbs in three passes in the sequence indicated on the lid. A helium leak test is performed on the cask lid in accordance with the requirements of Section 8.1.3.1, Steps 3 through 10 of the SARP. Alternate B port covers are used on the vent and drain openings. These covers are installed and helium leak tested in accordance with the requirements of Section 8.1.3.3.2 of the SARP. The cask is then surveyed for radiation dose rates and removable contamination levels, and decontaminated if necessary. Radiation dose rates and contamination levels shall comply with 49 CFR 173.441 and 49 CFR 173.443, respectively.

7.2.3 Preparation for Transport

Steps 43 through 48 of Section 7.1.11 of the SARP describe preparation for transport. Steps 43 through 46 describe the placement of the loaded cask onto the transport vehicle, installation of the tie-down strap and impact limiters, and the transport vehicle appurtances. Step 47 requires a health physics survey and compliance with 10 CFR 71.87(i) and 10 CFR 71.47. Step 48 covers the shipping documentation, any required carrier instructions, and the application of the appropriate placards and labels.

7.3 Cask Unloading

The cask unloading is described in Steps 1 through 26 of Section 7.1.12 of the SARP. The removal of the cask from the transport vehicle is essentially the same as described in Section 7.1.11 of the SARP. A receiving radiation survey is performed. After the cask is surveyed and removed from the transport vehicle, the cask atmosphere is sampled for radioactivity using the vent quick disconnect valves. Step 13 requires measurement of cask cavity gas pressure and cask cavity radioactivity. Cask cavity sampling discharge is to an off-gas system or atmosphere, depending on the radioactivity level and the site requirements. If activity levels are acceptable, the cask lid is removed. The DBE canisters are removed from the NAC-LWT cask and placed in a site transfer cask for transfer to a storage location. The lid and port covers are reinstalled and the NAC-LWT cask is available for return empty transport.

7.4 Preparation of Empty Cask for Transport

The preparation of the NAC-LWT cask for return empty transport is done in accordance with the general procedure described in Section 7.3 of the SARP. Section 7.3 has been previously approved by NRC and DOE.

7.5 Conclusion

Based on the statements and representations in the SARP and the staff's confirmatory evaluation, the staff concludes that the operating procedure requirements presented in Chapter 7 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, DOE Order 460.1B have been met.

8. ACCEPTANCE TESTS AND MAINTENANCE

8.1 Discussion

The requirements for acceptance tests to be performed for each NAC-LWT cask prior to initial use are presented in Section 8.1 of the SARP. These tests include visual inspections, structural and pressure tests, leak tests, component tests, test for shielding integrity, thermal acceptance tests and neutron absorber tests. The maintenance program used to ensure continued performance of the cask components is described in Section 8.2 of the SARP. Certain procedures are used for the fabrication acceptance, maintenance, and periodic tests. The tests applicable to the use of the NAC-LWT cask for the debris bed experiments (DBE) are discussed below. The acceptance and use of the DBE canisters are described in Section 8.1.4.4 of the SARP. The results of the staff's evaluation of the acceptance tests and maintenance program for the DBE transport canisters are described below:

8.2 Closure Lid Leakage Rate Test (Section 8.1.3.1, SARP)

With the cask lid installed and torqued to 260 ± 20 ft-lbs per the cask loading procedure in 7.1.11 of the SARP, the cask cavity is evacuated and filled with helium via the cask cavity vent or drain ports. The evacuation and filling is done twice to ensure a helium concentration of approximately 98%. A mass spectrometer leak detector (MSLD) is connected to the cask lid test port and started to check the helium concentration between the cask lid O-ring seals for leakage. The test is acceptable if the indicated leakage is $\leq 2 \times 10^{-7}$ cm^3/sec of helium, i.e., leak-tight per ANSI N14.5 - 1997.

8.3 Alternate B Port Cover Leakage Rate Tests (Section 8.1.3.3.2, SARP)

A maintenance leakage rate test procedure is performed on the Alternate B port cover after metallic O-ring replacement during each cask loading operation. The Alternate B port cover with the replaced metallic seal is inserted into a plastic test bag. The test bag is then sealed to the cask body around the port opening with suitable tape. The test bag is then evacuated and filled with 99.9% pure helium. The test bag is again evacuated and filled with helium a second time to one atmosphere absolute. Without breaking the seal of the plastic bag the Alternate B port cover is installed and the bolts tightened hand tight. This traps helium under the port cover. The plastic bag is then removed and the bolts torqued to 280 ± 10 in-lbs. The test port plug is removed from the Alternate B port cover. A helium mass spectrometer is attached to the Alternate B test port, the volume between the seals is then evacuated and tested. The test is acceptable, if the indicated leakage is $\leq 2 \times 10^{-7}$ cm^3/sec of helium, i.e., leaktight per ANSI N14.5 - 1997. The procedure is then repeated for the second Alternate B port cover.

8.4 Maintenance program

No new or specific maintenance procedures from those previously approved by NRC and DOE are required for the use of the NAC-LWT cask with the DBE canisters.

8.5 Fabrication and Acceptance Testing of DBE Canisters (Section 8.1.4.4, SARP)

The DBE canister secondary leak-tight boundary is defined as the canister body, canister lid, top flange, bottom weldment, valve guard and port cover. As described in Section 8.1.4.4.1 of the SARP, the DBE canister secondary leak-tight boundary is designed, fabricated, examined, and tested in accordance with the requirements of Section III, Subsection NB of the ASME Code.

The ASME Code references for the fabrication, inspection and acceptance testing of the DBE canisters shall be in compliance with the 2004 Edition, including the 2005 and 2006 Addenda. Applicable revisions of other codes and standards are specified and included in Chapter 9, Section 9.1 of the SARP. Materials of construction for the DBE canisters shall be procured with certification and supporting documentation as required by Section II of the ASME Code, and Section III, Subsection NB of the ASME Code when applicable, and as modified by the code exclusion and alternates described in Section 1.2.3.9 of the SARP.

Materials and components shall be receipt inspected for visual and dimensional acceptability, material conformance to the applicable code specification, and traceability markings as applicable. Materials for the DBE canister secondary leak-tight boundary shall also be inspected per the requirements of Section III, Subsection NB-2500 of the ASME Code.

The DBE canister secondary leak-tight boundary shall be fabricated and inspected per the requirements of Section III, Subsection of the ASME Code, except for the partial penetration closure welds of the canister lid to canister body as discussed in Section 1.2.3.9 of the SARP. The welding shall be performed using welders and weld procedures qualified to Section IX of the ASME Code.

The inspections shall include visual, dye penetrant (PT), radiographic (RT), and ultrasonic (UT) examinations in accordance with the ASME Code, and as detailed in Section 8.1.4.4.1 of the SARP. The final closure welds following loading of the DBE capsule into the DBE canister shall be dye penetrant (PT) examined at the root and final surface in accordance with Section V of the ASME code.
The DBE canister weldment, including the canister body, bottom and top flange shall be leak tested using the evacuated envelope method as described in Section V, Article 10 of the ASME Code, and ANSI N14.5-1997. The DBE canister weldment will be closed for the leak test using a test lid installed on top of the flange. The canister cavity will be evacuated to a vacuum of two (2) torr or less. A test envelope is placed around the DBE canister weldment enclosing all the canister welds. The test envelope is then evacuated and filled with to between ½ to 1 atmosphere with pure helium. A mass spectrometer leak detector (MSLD) is attached to the test lid and samples are taken from the evacuated DBE canister cavity volume for helium. The minimum sensitivity of the helium MSLD, and the overall test sensitivity, is $\leq 1 \times 10^{-7}$ cm^3/sec of helium, which is ½ of the allowable leakage criteria for leaktight acceptance per ANSI N14.5 - 1997.

Following closure welding of each DBE canister, the closure welds of the canister lid are PT inspected and helium leak tested per Section 8.1.4.4.2 of the SARP, and as summarized in Section 7.1.2.1 of this report.

8.6 Conclusion

Based on the statements and representations in the SARP and the staff's confirmatory evaluation, the staff concludes that the acceptance tests and maintenance program requirements presented in Chapter 8 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 460.1B have been met.

9. REFERENCES

Section 9.1 of the SARP lists the documents, papers and reports that are referenced in the SARP for the sodium DBE transport canisters in the NAC-LWT cask. The list includes those references added in response to the Q1 questions and the source verification.

10. QUALITY ASSURANCE

10.1 Discussion

The requirements for a Quality Assurance (QA) Program presented in Chapter 10 of the SARP have been reviewed and found to satisfy the QA requirements of 10 CFR Part 71, Subpart H. These QA requirements provide sufficient control over all items and quality-affecting activities that are important-to-safety as applied to the design, fabrication, assembly, inspection, testing, operation, maintenance, modification, and repair of the NAC-LWT Cask for the Sodium Debris Bed Experiments (DBE) contained in the DBE transport canisters. The QA requirements are based on a graded approach as described in 10 CFR 71.101. The graded approach in the QA Chapter includes an important-to-safety Q-list for each significant item and activity and is graded based on the design function of the item relative to the safety and performance requirements for the complete shipping cask. The quality assurance categories for each component are listed in Table 10A-3a of the SARP. The Q-list uses three QA categories with associated definitions for each. The QA level of each important-to-safety item is based on specific criteria. The QA requirements assure that the packaging is designed, fabricated, tested, and operated in accordance with the drawings identified in the SARP. In addition, the QA Chapter requires the user to invoke the same level of QA requirements for the use, maintenance, and repair of the packaging, as is required for the procurement, fabrication, and acceptance testing of the original packaging. The QA categories for important-to-safety items and activities are based on the following definitions:

1. Category A (Critical) - Category A items and activities shall be ones whose single failure or malfunction will result in an unacceptable condition of containment, shielding, and subcriticality based upon federal regulations.

2. Category B (Major) - Category B items and activities shall be ones whose single failure or malfunction could indirectly result in an unacceptable condition of containment, shielding, and subcriticality. An unsafe condition could result only if the failure of a Category B item occurred in conjunction with the failure of another Category B item.

3. Category C (Minor) - Category C items and activities shall be ones whose single failure or malfunction would not reduce packaging effectiveness and would not result in an unacceptable condition of containment, shielding, and subcriticality regardless of other failures or malfunctions of items in the same QA category.

After determining the applicable QA category, the appropriate level of QA effort for design, procurement, fabrication, testing, operations, maintenance, modification, and repair activities is determined from the 18

QA requirements identified in 10 CFR Part 71, Subpart H. Specific QA requirements from Subpart H of 10 CFR 71 relative to packaging activities are categorized in Table 10A-2 of the SARP. The 18 requirements identified in the SARP are as follows: organization; quality assurance program; design control; procurement document control; instructions, procedures, and drawings; document control; control of purchased material, equipment, and services; identification and control of material, parts, and components; control of special processes; inspection control; test control; control of measuring and test equipment; handling, shipping, and storage control; inspection, test, and operating status; control of nonconforming materials, parts, or components; corrective action; QA records and QA audits. Table 10A-4 of the SARP specifies which documents are considered to be lifetime records e.g., the Certificate of Compliance (CoC), QA Manual, and final test reports. The record retention program specifies that the licensee shall retain records for 3 years beyond the date when the licensee last engaged in a particular activity that is documented by the prescribed records.

The QA Chapter of the SARP includes independent verification of fabrication, operational and maintenance activities considered to be critical in satisfying the regulatory requirements as identified in 10 CFR Part 71. Verification of critical activities is contained in Section 10A.3.2 of the SARP which includes procurement activities, assembly operations, welding requirements, leakage criteria, maintenance activities, cask use, cask loading, and empty cask shipment.

The Sandia National Laboratories (SNL) QA Program Plan, QAPP, AS-PT-PD-04, Revision 0, adequately addresses the 18 requirements in Subpart H of 10 CFR 71. Table 10.3-1 of the QA Chapter provides a cross reference between each of the 18 QA requirements in Subpart H of 10 CFR Part 71 and the SNL QA program. NAC's QA Program description has been approved by the NRC as complying with Subpart H of 10 CFR Part 71.

The staff conducted two (2) source verifications during fabrication of the DBE transport canisters. The purpose of the source verification is to provide oversight of select critical activities to assure that the requirements in Chapters 7, 8 and 10 of the SARP are being implemented. The staff planned and observed fabrication welding and nondestructive examination at critical points. The first source verification was performed at Canonsburg, PA., on May 24-25, 2007, to observe the following activities:

- Welding of a typical canister bottom flange
- Welding of a typical canister upper flange
- Final liquid penetrant and ultrasonic examination of the above welds

The staff determined that all processes, procedures and qualification records for welding and nondestructive examination were appropriately implemented and documented, with two observations for future improvement. The staff noted that the welding procedure for the Gas Tungsten Arc Weld of the root pass for the bottom assembly weld requires a full penetration, one-side weld. The welding procedure specifies the gas flow rate, but not the gas backing composition. The staff determined that the welder has taken the necessary precautions to ensure the proper gas flow rate, and the record review showed that the gas composition used was appropriate. The plant management agreed to revise the welding procedure to specify the backing gas composition for future use.

The second observation involved the establishment of the ASME Code of Record. The staff determined that although Chapter 9 of the SARP specified the material should comply with the 1998 edition of the ASME B&PV Code, the material that was used to fabricate the canisters was certified to the 2004 Edition of the Code with 2005 and 2006 Addenda. In response to the staff's inquiry, the applicant performed an evaluation and determined that the material purchased for the canisters was in compliance with the 1998 Edition of the Code. The staff has verified the applicant's determination. Section 1.2.3.9 of the SARP was revised to describe the ASME Code of record for the DBE transport canisters.

The staff conducted the second source verification at the Sandia National Laboratories, Albuquerque, NM, on September 6, 2007, to observe the various stages of the final weld closure of six DBE transport canisters including liquid penetrant examinations. The stages included fit-up, tack, partial root pass, final pass, and liquid penetrant examination. The staff determined that all processes, procedures and qualification records for welding and nondestructive examination were appropriately implemented and documented.

10.2 Conclusion

Based on the statements and representations in the SARP and the staff's confirmatory evaluation and source verification, the staff concludes that the Quality Assurance plan and requirements in Chapter 10 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 460.1B are met.