Adding Sodium Bonded Mixed Fission Products as Authorized Contents to the NAC-LWT

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ABSTRACT

This paper discusses the necessary analysis and revisions to the NAC-LWT Department of Energy approved Safety Analysis Report in Packaging to support Argonne National Laboratory (ANL) shipping of radioactive material from the Alpha Gamma Hot Cell Facility (AGHCF) to Idaho National Laboratory (INL). The ANL radioactive material is unique in that it is irradiated sodium-bonded nuclear reactor fuel, including derived mixed fission products (FDMFP). As the fuel is sodium-bonded it will be shipped in up to three individual leak-tight, sealed 6CVS containment vessels loaded into the cavity of the NAC-LWT cask. The changes from the previously DOE approved NAC-LWT SARP were limited to those associated with shipping the FDMFP contents in the 6CVS inner containment vessels. Due to the potential for sodium to react with water during both Normal Conditions of Transport (NCT) or Hypothetical Accident Conditions (HAC), the requirements imposed on the transport were more stringent than required for other contents. In order to ensure the safe transport of the contents, two independent, leak-tight boundaries were required.

As part of those changes, this paper also discusses the addition of an alternate size for the O-ring seals employed for the closure of the 6CVS inner containment vessel. This change was necessary to facilitate the helium leak tests to be performed in accordance an approved leaktest method to meet ANSI N14.5 leaktight criteria. The change in the O-ring size would not prevent the 6CVs vessels from performing their intended structural, thermal, containment and nuclear safety functions described in the NAC-LWT SARP. Both O-ring sizes are manufactured of Viton material meeting the same requirements with identical service and performance characteristics and the addition of the flexibility to the helium leak test procedure to permit use of an approved alternate method.

INTRODUCTION AND BACKGROUND

The NAC International Legal Weight Truck spent fuel shipping cask (NAC-LWT) is designed in accordance with the requirements of 10 CFR 71[1] and 49 CFR 173[2] to provide a safe means of transporting various fuel assemblies, fuel elements, and fuel rods.

The NAC-LWT SARP [3], allows Argonne National Laboratory (ANL) to use the NAC-LWT cask for shipping radioactive material from the Alpha Gamma Hot Cell Facility (AGHCF) to Idaho National Laboratory (INL). The ANL irradiated sodium-bonded nuclear reactor fuel derived mixed fission products (FDMFP) is required to be shipped in up to three individual leaktight, sealed 6CVS containment vessels loaded into the cavity of the NAC-LWT cask. As part of supporting the shipment of sodium bonded fuel use of a larger gasket to support use of an approved alternate leakage test method to meet the ANSI N14.5 leaktight criteria for acceptance testing, as well as the annual leakage testing of the 6CVS containment boundary.

GENERAL INFORMATION

The Safety Analysis Report for Packaging for the NAC-LWT Legal Weight Truck Cask System was revised to add the new FDMFP content addition and the engineering drawings revisions related to the ANL 6CVS Transport system the 6CVS containment vessel and basket designs, with an inner leaktight containment used for shipping the ANL sodium bonded contents. Also revised as part of accommodating the use of the NAC-LWT for the sodium bonded fuel is the increase in the gasket size the new 6CVS O-ring size.

The following conditions of approval are applicable to the NAC-LWT shipping cask when using the 6CVS:

- Maximum content weight for one 6CVS containment vessel is 200 lbs.
- Maximum total decay heat load in the NAC-LWT cask cavity is 36 W (≤ 12 W per 6 CVS, three 6CVS maximum per cask)
- Minimum cooling time is >16 years
- Maximum normal operating temperature is ≤200ºF
- 6CVS containment vessel design pressure equals 800 psig

No sodium is permitted external to the 6CVS containment vessel.

Aluminum fuel element (FE) tubes of various diameters may be used to facilitate loading the ANL FDMFP into the 6CVS containment vessel with the tubes are considered dunnage.

For a 6CVS containing sodium-bonded metal FDMFP, the content definition is defined as follows:

- Maximum ^{235}U content is ≤4 kg
- Maximum Pu content is ≤1.5 kg
- Maximum ^{239}Pu fissile gram equivalent is 3,020 g

For a 6CVS containing sodium-bonded metal FDMFP with Bakelite or carbon-based FDMFP, the content definition is defined as follows:

- Maximum volume of Bakelite met mounts per 6CVS is 6000 cm^3
- Maximum ^{235}U content is ≤2 kg
- Maximum Pu content is ≤0.7 kg
- Maximum ^{239}Pu fissile gram equivalent is 2,100 g

Bakelite was modeled as 78 wt % carbon at a density of 1.25 g/cm^3, with the maximum quantity of carbon in the 6CVS is limited to 5,877 grams. For a 6CVS containing sodium-bonded metal

FDMFP with Bakelite, gas generation by radiolysis was defined by a bounding G-Value (conservatively applied as 0.3 molecules/100eV), energy production by Bakelite/epoxy contained FDMFP, and assumed duration between loading and end of transport. To bound any potential ionizing radiation from the non-Bakelite containing components, a 25% value was conservatively applied in the analysis (3W).

A 30-day transport window was assigned to the calculation, resulting in a 15-day transport limit for shipments containing Bakelite.

STRUCTURAL

Use of the 6CVS was considered as a “special design feature” under 10 CFR 71.55(c) which precluded water in-leakage and water contact with the sodium bonded fuel. As previously stated, in-leakage of water could result in an exothermic reaction with the sodium in the FDMFP contents.

The structural evaluation changes submitted in revision consisted mainly of standalone calculations on the 6CVS containment vessels and the accompanying baskets through the NCT and HAC drop scenarios. Thermal stresses were determined using bounding temperature profiles which were combined with stresses from drops and pressures before being compared with allowable stresses for NCT conditions. Proper load combinations were also used in comparing to HAC allowable stresses. Stresses from punctures were not considered because of protection provided by the cask body.

Drop analyses used quasi-static methods in which the inertial load of the 6CVS was simulated by manipulation of the containment vessel material density and the inertial load of contents was represented by a pressure simulating the applied inertial load (25 g for NCT, 61 g for HAC). Dynamic amplification was not considered in the quasi-static analyses. Another non-conservatism noted was that the analyses credit full integration of the vessel rings as part of the containment structure even though they are only attached with seal and intermittent fillet welds. However, given the large margins determined for both NCT and HAC and previous analysis and testing of vessels of similar design in the 9975, 9977 and the T-3[4] shipping packages, no further analysis was deemed necessary.

THERMAL

The thermal analysis included the new transport configuration consisting of the 6CVS containment vessel loaded in the 6CVS basket in the NAC-LWT cask. The transport condition for the NAC-LWT cask was defined to be the NAC-LWT cask in a closed ISO container in which the NAC-LWT cask was backfilled with helium at atmospheric pressure. The contents of a single 6CVS containment vessel generated a 12 W total heat load, which corresponds to a maximum package heat load of 36 W for the NAC-LWT cask.

The maximum total heat load for the contents of a single 6CVS containment vessel was 12 W which corresponded to a maximum package heat load of 36 W for the NAC-LWT cask. The 6CVS and NAC-LWT cask are backfilled to 1 atmosphere with inert gas. For shipments containing Bakelite, a 15-day transport limit was imposed starting at the instant the 6CVS was backfilled with inert gas and sealed.

Chapter 3 was revised to update the safe operating range data from 500 to 1000 hours for Viton® GLT/GLT-S O-rings and the reference to the Parker O-Ring Handbook from year 2001 to 2007.

CONTAINMENT

The containment included the addition of the ANL 6CVS inner containment vessel to the NAC-LWT packaging. Each of the 6CVS vessels provided an independently leaktight vessel to provide a second containment boundary to the NAC-LWT cask. The addition of the 6CVS containment vessel did not change the containment boundary of the NAC-LWT packaging from the previously approved SARP [4].

The Alternate B vent and drain port covers of the NAC-LWT were required for the use of the 6CVS containment vessel in the NAC-LWT cask and were evaluated and accepted as part of the containment boundary of the NAC-LWT cask. These alternate B vent and drain port covers are required as part of the NAC-LWT cask when shipping the ANL contents in the 6CVS containment vessels. Prior to each transport of the 6CVS contents, new metallic seals will be installed on the cask lid and the Alternate B vent and drain port covers before final installation and torqueing. Both the 6CVS containments vessels and the cask containment boundary must be leak tested as required in Chapters 7 and 8 of the SARP [3].

Chapters 4 was revised to specify Viton® GLT/GLT-S for the 6CVS O-rings, rather than a general reference. These changes improved the consistency and specificity of the SARP component requirement.

SHIELDING

The shielding analysis included the addition of the ANL source materials in the 6CVS containment vessels. The shielding analysis focused on the addition of up to three Argonne 6CVS vessels in the NAC-LWT cask. The total computed source was assigned to one 6CVS rather than distributing the source across multiple 6CVS vessels.

Evaluation of the ANL source materials in the 6CVS inner containment vessels has was described adequately and conservatively and was determined to have no impact on the safety performance of NAC-LWT shipping cask. The dose rate requirements of 10 CFR 71[1] for normal conditions of transport and hypothetical accident conditions were satisfied with the Certificate of Compliance limiting the quantities the ANL source material as previously identified. Based on the required shielding, the NAC-LWT with authorized ANL contents was determined to be shippable as non-exclusive use.

CRITICALITY

The criticality evaluations for the NAC-LWT with ANL contents loaded in the 6CVS vessels were performed. The contents were limited to those previously identified assuming an infinite array of NAC-LWT packages in the normal and accident conditions. The 6CVS as considered a “special design feature” under 10 CFR 71.55(c) which precluded water in-leakage and water contact with the sodium bonded fuel. As stated in the revision, in-leakage of water could result in an exothermic reaction with the sodium in the FDMFP contents. Criticality evaluations credited the 6CVS boundary and, therefore, applied a dry vessel interior in all the criticality evaluations.

The Certificate of Compliance limited the quantities of the ANL source material as identified and limited in Chapter 1 of the SARP [3]. The maximum number of 6CVS vessels per shipment was three. Bakelite was modeled as 78 wt % carbon at a density of 1.25 g/cm3, the maximum quantity of carbon in the 6CVS is limited to 5,877 grams. The Criticality Safety Index (CSI) for the NAC-LWT with authorized ANL contents is zero.

PACKAGE OPERATIONS

The NAC-LWT package operations focused on reviewing the operating procedures for loading and unloading ANL contents into the 6CVS containment vessel and the loading and unloading the 6CVS containment vessels and basket modules into the NAC-LWT shipping cask.

The procedural steps for operating the NAC-LWT shipping cask specified in Chapter 7 of the SARP were incorporated in their entirety into the Certificate of Compliance as a condition of package approval. The steps provided the basis for the users/shippers to use to develop formal, site-specific operating procedures for shipping ANL contents in the NAC-LWT shipping cask. In addition, the SARP [3] Section 3.8.4, page 3.8-10, determined a 15-day transport limit for shipments containing Bakelite due to gas generation by radiolysis. Therefore, for a 6CVS containing sodium-bonded metal FDMFP with Bakelite [4, Section 1.2.3.10], the Certificate of Compliance included the 15-day transport limit as a condition of package approval. The 15-day clock begins when the 6CVS is closed (SARP 7.1.14, Step 20) and ends when the consignment is accepted by the Receiver. When shipping a 6CVS containing sodium-bonded metal FDMFP with Bakelite, the shipper must provide the receiver with the date and time the 6CVS was sealed. The shipper is required to verify that the shipment can be completed within the 15-day transport limit.

ACCEPTANCE TESTS AND MAINTENANCE

A revised Chapter 8 included a review of the Acceptance Tests and Maintenance Program for the 6CVS containment vessels and basket assemblies with new the requirements of Sections 8.1 and 8.2 of Chapter 8 of the SARP now inserted into the CoC as a condition of package approval.

Chapter 8 was revised to allow an option to use an approved alternate leakage test method to meet the ANSI N14.5 leaktight criteria for acceptance and annual leakage testing of the 6CVS containment boundary.

QUALITY ASSURANCE

The SARP was revised to describe the quality assurance requirements for ensuring the safety of the NAC-Legal Weight Truck (NAC-LWT) packaging, as applied by Sandia National Laboratories (SNL) for the transport of SNL debris bed experiments (DBE); and by Argonne National Laboratory (ANL) for the transport of Argonne sodium bonded nuclear reactor fuel-derived mixed fission products in sealed 6CVS vessels (6CVS). The revisions to this chapter address the addition of the ANL 6CVS to the SARP.

Appendix 10A was revised to include a description of the NAC International quality assurance requirements for hardware and associated services as applicable to the design, fabrication, procurement, handling, use, and storage of the ANL 6CVS and their transportation in the NAC-LWT cask(s). Appendix 10A, Table 10A-1b (List of ANL Content Related License Drawings) was revised for the revision to Drawing 314-40-154.

Appendix 10B was added to provide a description of the ANL quality assurance requirements for ensuring the safety of the NAC-LWT packaging as applied by ANL for the transportation of mixed fission products derived from irradiated sodium bonded nuclear reactor fuel examination. Appendix 10B was then revised to allow the option to use an approved ANL supplier to perform acceptance tests of the 6CVS.

Overall, ANL and NAC quality assurance program responsibilities, documentation, and approvals were adequately identified and clearly delineated in the SARP revision.

SUMMARY

This paper discussed the key additional analysis and revisions to the NAC-LWT Department of Energy approved SARP to support ANL shipping of radioactive material from INL. As the fuel is sodium-bonded it will be shipped in up to three individual leak-tight, sealed 6CVS containment vessels loaded into the cavity of the NAC-LWT cask. Due to the potential for sodium to react with water during both NCT and HAC, the requirements imposed on the transport were more stringent than required for other contents. In order to ensure the safe transport of the contents, two independent, leak-tight boundaries were required.

As part of those changes, this paper also discusses the addition of an alternate size for the O-ring seals employed for the closure of the 6CVS inner containment vessel.

REFERENCES

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), Packaging and Transportation of Radioactive Materials.

[2] Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), General Requirements for Shipments and Packages.

[3] NAC International, Safety Analysis Report for Packaging for the NAC-LWT Legal Weight Truck Cask System, Revision LWT/DOE-10B, May 2010.

[4] Addendum to the Consolidated Safety Analysis Report for the T-3 Spent Fuel Shipping Cask Demonstrating Compliance to the Requirements of 10CFR71 Sodium-Bonded Fuel, FFTF-30866, Revision 2.