Safety Evaluation Report for the Justification for Shipment of Sodium-Bonded Carbide Fuel Pins in the T-3 Cask

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OVERVIEW

This report documents the review of the Fluor Submittal (hereafter, the Submittal), prepared by Savannah River Packaging Technology (SRPT) of Savannah River National Laboratory (SRNL),[1] at the request of the Department of Energy's (DOE) Richland Operations Office,[2] for the shipment of unirradiated and irradiated sodium-bonded carbide fuel pins. The sodium-bonded carbide fuel pins are currently stored at the Fast Flux Test Facility (FFTF) awaiting shipment to Idaho National Laboratory (INL).

Normally, modified contents are included into the next revision of the SARP. However, the contents, identified to be shipped from FFTF to Idaho National Laboratory, are a one-way shipment of 18 irradiated fuel pins and 7 unirradiated fuel pins, where the irradiated and unirradiated fuel pins are shipped separately, and can be authorized with a letter amendment to the existing Certificate of Compliance (CoC).[3]

Chapter 1: General Information

This Safety Evaluation Report (SER) covers the staff's findings, regarding the review of the Submittal, *Justification for Shipment of Sodium-Bonded Carbide Fuel Pins in the T-3 Cask.*[1] This section of the SER covers the review of the General Information provided in Chapter 1 of the Submittal. Specifically, the review examined shipment of irradiated and unirradiated sodium-bonded carbide fuel-pin contents, contained in the 6CVL (i.e., 6-inch Containment Vessel—Long), placed inside the T-3 Cask. The results of the General Information review for the proposed new contents are discussed below.

Sodium-Bonded Carbide Fuel Pin Contents

The Submittal provided justification for amending *U.S. Department of Energy Certificate of Compliance for Radioactive Materials Packages, Model No. T-3*, Rev. 13, USA/9132/B(M)F (DOE)[3] to include sodium-bonded carbide fuel pins placed in a 6CVL Independent Fuel Canister Containment Vessel Assembly, as described in the *Addendum to the Consolidated Safety Analysis Report for the T-3 Spent Fuel Shipping Cask Demonstrating Compliance to the Requirements of 10 CFR 71, Sodium-Bonded Fuel*.[4] [Note: Revision 14 of this DOE CoC was issued on August 14, 2007 and this justification also applies to this Revision.]

The sodium-bonded carbide fuel-pin contents include 18 irradiated fuel pins and 7 unirradiated fuel pins (see Table 1.1, ACN-1 Fuel Element Data, of the Submittal for details about each fuel pin). The proposed contents meet the specifications for content Number 11 (Content 2 in the current CoC), defined in the Consolidated Safety Analysis Report (SAR),[5] with the following exceptions:

- Six of the fuel pins have less than 6 wt% sesquicarbide (Pu_2C_3) content,
- All of the fuel pins are sodium-bonded carbide fuel each containing 15 grams sodium metal, (1 g is additionally assumed to be on the surface of each fuel pin), and
- The irradiated fuel pins have suspect cladding per the definition of ISG-1, *Damaged Fuel*.[6]

Irradiated fuel pins and unirradiated fuel pins will be shipped separately and no other fuel will be included in the shipments of sodium-bonded carbide fuel. The irradiated fuel pins will be inserted into stainless steel, failed fuel-pin storage tubes (FPSTs), incorporating a threaded confinement closure. The storage tubes fit into an Inner Pin Container Assembly (IPCA) that is, in turn, stored in the 6CVL. The 6CVL is shipped in the T-3 Cask. Furthermore, the T-3 Cask and the 6CVL provide dual, nested, *leak-tight* containment boundaries, per American National Standards Institute (ANSI) N14.5.[7] Unirradiated sodium-bonded fuel pins are also placed in IPCAs.

The IPCA for holding irradiated fuel pins, placed within FPSTs as discussed above, has a component divider which is about 2.75 inches longer than for IPCAs used for other fuel pins. This will have no significant impact on the center of gravity of the Packaging. Also, no IPCA details were modeled in any stress analysis of the 6CVL in FFTF-30866, Rev. 1.[4]

Findings
Based on the review of the statements and representations in the Submittal, the staff has concluded that the packaging design has been adequately described to meet the requirements of 10 CFR 71.[8]

Conditions of Approval
The staff has concluded that no additional conditions of approval need to be added to the existing CoC[3] for the approval of this request.

Chapter 2: Structural Evaluation

This section of the SER covers the assessment of the Structural Evaluation information provided in Chapter 2 of the Submittal. Details of the items reviewed are noted above in the introduction to Chapter 1. The results of the structural review are discussed below.

Sodium-Bonded Carbide Fuel Pin Contents
In agreement with the SARP, the staff has determined that the new contents, i.e., 25 sodium-bonded carbide fuel pins, will not significantly change the structural performance of the package and its compliance with the requirements of 10 CFR 71. The fuel pins will be placed inside IPCAs (the irradiated fuel pins will be additionally placed within FPSTs) nested in the 6CVL. This determination is based on the following considerations:

- The contents weight is less than the 700 lb evaluated in FFTF-30866,
- The length of the IPCA is 2.75 inches longer than the IPCA's noted in FFTF-30866, but this difference will not significantly alter the location of the package center of gravity, and
- Both Maximum Normal Operation (MNOP) and maximum pressure during Hypothetical Accident Conditions (HAC) inside the 6CVL are less than those previously determined in FFTF-30866.

Consequently, no degradation in the structural performance of the Package is expected due to this content.

Findings
Based on the review of the statements and representations in the Submittal, the staff has concluded that the structural design of the modified content configurations has been adequately described. The staff has also concluded that the possible effects of the modified content configurations on the structural integrity of the T-3 Cask packaging have been properly evaluated in accordance with the requirements of 10 CFR 71.

Conditions of Approval
The staff has concluded that no additional conditions of approval need to be added to the existing CoC for the approval of this request.

Chapter 3: Thermal Evaluation

This section of the SER covers the review of the Thermal Evaluation information provided in Chapter 3 of the Submittal. Details of the items reviewed are noted above in the introduction to Chapter 1. The results of the thermal review are discussed below.

Sodium-Bonded Carbide Fuel Pin Contents
In agreement with the SARP, the staff has determined that the new contents, i.e., 25 sodium-bonded fuel pins, will not significantly change the thermal performance of the Package and its compliance with the requirements of 10 CFR 71. This determination is based on the following considerations:

- The content heat load is less than that evaluated in FFTF-30866, and
- The change in content configuration does not affect the thermal performance of the Package.

Consequently, no degradation in the thermal performance of the Package is expected due to these contents.

Findings
Based on the review of the statements and representations in the Submittal, the staff has concluded that the packaging design has been adequately described to meet the requirements of 10 CFR 71.

Conditions of Approval
The staff has concluded that no additional conditions of approval need to be added to the existing CoC for the approval of this request.

Chapter 4: Containment

This section of the SER covers the review of the Containment information provided in Chapter 4 of the Submittal. Details of the items reviewed are noted above in the introduction to Chapter 1. The results of the containment review are discussed below.

Sodium-Bonded Carbide Fuel Pin Contents
The containment boundaries of the T-3 Cask and 6CVL were not changed to accommodate the proposed contents. The sodium-bonded carbide fuel-pin contents have no adverse affect on the ability of the 6CVL or the T-3 Cask to provide *leak-tight* containment.

Findings
Based on the review of the statements and representations in the Submittal, the staff has concluded that the packaging design has been adequately described to meet the requirements of 10 CFR 71.

Conditions of Approval
The staff has concluded that no additional conditions of approval need to be added to the existing CoC for the approval of this request.

Chapter 5: Shielding Evaluation

This section of the SER covers the review of the Shielding Evaluation information provided in Chapter 5 of the Submittal. Details of the items reviewed are noted above in the introduction to Chapter 1. The results of the shielding review are discussed below.

Sodium-Bonded Carbide Fuel Pin Contents
The contents for these shipments consist of 7 unirradiated fuel pins and 18 irradiated fuel pins that will be shipped separately. In determining the source terms for both neutron and gamma, the applicant has used a 127-pin basis to compare to the analysis basis source terms used for the sodium bonded metallic fuel shipments.[4] The basis for the source terms was 90 driver pins, 19 helium-bonded pins, and 18 sodium-bonded pins.

The gamma source term is bounded by the analysis basis source term at least by a factor of 3.8 except at a few high energies. However, the contribution to the source term from these high energies is very small. In addition, the actual shipment will contain only a maximum of 18 sodium-bonded pins making the evaluated source term very conservative.

The calculated (α,n) contribution to the neutron source term is approximately 70% of the analysis basis (α,n) source term.[4] The spontaneous fission source term is approximately 80% higher, making the over all neutron source term approximately 12% higher for the carbide fuel when compared with the analysis basis neutron source term.[4] However, the fact that only 18 irradiated fuel pins will be shipped more than offsets this increase.

Therefore, based on these source term evaluations, the carbide fuel shipment radiation dose rates for the T-3 Cask will be adequately bounded by those for the sodium-bonded metallic fuel shipments.[4]

The staff performed independent calculations based on a single pin and determined that the arguments presented were valid, and that the external radiation dose rates will be in compliance with the 10 CFR Part 71 limits.

Findings
Based on the review of the statements and representations in the Submittal, the staff has concluded that the shielding design has been adequately described and evaluated and that the Package meets the external radiation requirements of 10 CFR 71.

Conditions of Approval
The staff has concluded that no additional conditions of approval need to be added to the existing CoC for the approval of this request.

Chapter 6: Criticality Evaluation

This section of the SER covers the review of the Criticality Evaluation information provided in Chapter 6 of the Submittal. Details of the items reviewed are listed above in the introduction to Chapter 1. The results of the criticality review are discussed below.

Sodium-Bonded Carbide Fuel Pin Contents
This section evaluates shipment of sodium-bonded carbide fuel pins from FFTF in the T-3 Cask. Two types of sodium-bonded carbide fuel contents are addressed in this evaluation.

- Seven unirradiated sodium-bonded carbide fuel pins (ACN-1) in an IPCA. The fuel composition is U (80 wt%), Pu (15 wt%) and C (5 wt%).
- Eighteen irradiated sodium-bonded carbide fuel pins (ACN-1)—each fuel pin will be placed in a stainless steel storage tube. All storage tubes are then placed in an IPCA.

The fissile content is considerably less than for the sodium-bonded metallic fuel pins (169 test pins of type IFR-1 or MFF series) considered in the earlier evaluation.

The applicant's analysis considered 18 unirradiated fuel pins. Thus, the analysis is conservative and bounds two types of contents.

Total Fissile Mass for 18 Unirradiated Sodium-Bonded Carbide Fuel Pins (grams)	
^{235}U	17.593
^{239}Pu	1434.960
^{241}Pu	16.496
Total	1469.049

The evaluation addresses water inleakage into the T-3 Cask as required by 10 CFR 71.55(b). The 6CVL is a *leaktight* design and prevents water inleakage under HAC. Therefore, it is justified to assume dry conditions inside the 6CVL.

Either the seven-unirradiated set or the 18-irradiated set is placed inside the 6CVL. The sodium-bonded carbide fuel material is conservatively configured as a sphere. This configuration is very conservative.

The criticality analyses were performed for dry conditions inside the 6CVL, with and without a stainless steel reflector. This evaluation does not take credit for the integrity of the fuel or for any geometry control for the fissile material that may be provided by the fuel assembly hardware, fuel pins, or IPCA. However, considering the fact that no credit is taken for geometry control provided by the 6CVL or the IPCA, this configuration conservatively meets the requirements of 10 CFR 71.55(b) and 10 CFR 71.55(e)(1).

Single-Package Evaluation
The maximum k_{eff} for a single T-3 Cask with 18 ACN-1 carbide fuel pins is only 0.337 (Cask cavity flooded, 6CVL cavity filled with steel, 30-cm water around the cask). This shows that the sphere model is very conservative and still there is a substantial subcritical margin, because the maximum k_{eff} is well below the k-safe limit of 0.910.

Evaluation of T-3 Cask Arrays under Normal Conditions of Transport (NCT) and HAC Scenarios
The maximum k_{eff} for the NCT or HAC array scenario of the T-3 Cask with 18 ACN-1 sodium-bonded carbide fuel pins is only 0.351. An infinite number of T-3 Casks were considered, corresponding to a Criticality Safety Index (CSI), CSI = 0.

The NCT and HAC array models used for the analyses are identical. This is justified because there is essentially no deformation of the T-3 Cask under the regulatory accident scenarios, as noted in the earlier evaluation for the sodium-bonded metal fuel.[4] Optimum interspersed moderation is essentially no moderation, as was also noted in previous analysis for the sodium-bonded metal fuel.

Benchmark Evaluation
This analysis uses the same code (MCNP5) and cross section library (0.60c set) to determine the bias values from the selected benchmark experiments and to calculate the k_{eff} values for the evaluation. The identical limiting subcritical value (k-safe) of 0.910 is used as in the previous analysis for the sodium-bonded metal fuel, and it is acceptable.

Findings
The Summary of Criticality Safety Evaluation Results in Table 6.4 shows the input file names as acndry02 and acninf02. However, the input listing shows two additional input files, namely, acndry01 and acninf01 without any details. It is preferable to give a table with all results, from which the most limiting cases are selected for the Summary Table 6.4. However, this deficiency is acceptable for this SER, because the most limiting cases that are shown in Table 6.4 have plenty of reactivity margin.

Based on results for the sodium-bonded metal fuel that was evaluated in the previous Submittal, and a review of the statements and representations in the Submittal, the staff has concluded that

the nuclear criticality safety design has been adequately described and evaluated, and that the package meets the nuclear criticality safety requirements of 10 CFR 71. The criticality safety analyses were performed with a very conservative model. The staff also notes the analyses demonstrated that there is an adequate margin of safety for this package. The T-3 Cask with the sodium-bonded carbide fuel pins can be shipped with a CSI of 0.

Conditions of Approval
The staff has concluded that no additional conditions of approval need to be added to the existing CoC for the approval of this request.

Chapter 7: Package Operations

This section of the SER covers the review of the Package Operations information provided in Chapter 7 of the Submittal. Details of the items reviewed are noted above in the introduction to Chapter 1. The results of the operating procedures review are discussed below.

Sodium-Bonded Carbide Fuel Pin Contents
The T-3 Cask SAR provides the basic required procedural step for operating the T-3 Cask.[5] The procedural steps found in Chapter 7 of the T-3 Cask SAR Addendum[4] are unchanged with respect to the sodium-bonded carbide fuel content. Since the fuel pin storage tubes are not credited in the package safety basis, a description of their loading was not included in the present Submittal by the applicant. However, content verifications will be carried out using Table 1.1 of Chapter 1 in the Submittal.

Findings
Based on the review of the statements and representations in the Submittal, the staff has concluded that the packaging design has been adequately described to meet the requirements of 10 CFR 71.

Conditions of Approval
The staff has concluded that no additional conditions of approval need to be added to the existing CoC for the approval of this request.

Chapter 8: Acceptance Tests and Maintenance

This section of the SER covers the review of the Acceptance Tests and Maintenance information provided in Chapter 8 of the Submittal. Details of the items reviewed are noted above in the introduction to Chapter 1. The results of the acceptance tests and maintenance review are discussed below.

Sodium-Bonded Carbide Fuel Pin Contents
The proposed package contents of sodium-bonded carbide fuel does not affect the maintenance of the packaging, nor does it affect prior acceptance testing. The packaging acceptance testing and maintenance program, documented in Revision 1 of the T-3 SAR Addendum, is valid for the sodium-bonded carbide fuel contents.

Findings
Based on the review of the statements and representations in the Submittal, the staff has concluded that the packaging design has been adequately described to meet the requirements of 10 CFR 71.

Conditions of Approval
The staff has concluded that no additional conditions of approval need to be added to the existing CoC for the approval of this request.

Chapter 9: Quality Assurance

This section of the SER covers the review of the Quality Assurance (QA) program description and packaging-specific QA requirements provided in Chapter 9 of the Submittal. Details of the items reviewed are noted above in the introduction to Chapter 1. The results of the quality assurance review are discussed below.

Sodium-Bonded Carbide Fuel Pin Contents
As described in Chapter 1 of this SER, the sodium-bonded carbide fuel-pin contents are a change in fuel-type to the T-3 Cask Addendum. The applicant stated in the *Justification for Shipment of Sodium-Bonded Carbide Fuel Pins in the T-3 Cask* that Chapter 9 of the SARP Addendum[4] is the applicable description of the QA program, and there are no changes to it as result of this change of contents. The staff concurs, as Chapter 9 of the Addendum[4] was recently reviewed, and contains an up-to-date description of the applicant's QA program and packaging-specific QA requirements. The staff also concurs that the addition of the sodium-bonded carbide fuel-pin contents would not require a change to Chapter 9.

Findings
Based on review of the statements and representations in the Submittal, the staff concludes the QA program has been adequately described and meets the QA requirements of 10 CFR 71, Subpart H. Packaging-specific requirements are adequate to assure the packaging is designed, fabricated, assembled, tested, used, maintained, modified, and repaired in a manner consistent with its evaluation.

Conditions of Approval
The staff has concluded that no additional conditions of approval need to be added to the existing CoC for the approval of this request.

References

[1] *Justification for Shipment of Sodium-Bonded Carbide Fuel Pins in the T-3 Cask*, Savannah River Packaging Technology, Savannah River National Laboratory for the Fast Flux Test Facility, FFTF-35120, September 2007.

[2] *Transmittal of Justification for Shipment of Sodium-Bonded Carbide Fuel Pins Using USA/9132/B(M)F(DOE), T-3 Spent Fuel Shipping Cask Safety Analysis Report for Packaging*, David A. Brockman to Dae Y. Chung, September 2007.

[3] USA/9132/B(M)F (DOE), *U.S. Department of Energy Certificate of Compliance for Radioactive Materials Packages, Model T-3*, Rev. 13, U.S. Department of Energy, Washington, D.C.

[4] *Addendum to the Consolidated Safety Analysis Report for the T-3 Spent Fuel Shipping Cask Demonstrating Compliance to the Requirements of 10 CFR 71, Sodium-Bonded Fuel*, Rev. 1, FFTF-30866, June 2007, Fluor Hanford, Inc., Richland, Washington.

[5] *Consolidated Safety Analysis Report for the T-3 Spent Fuel Shipping Cask*, Rev. 6a, WHC-1990, August 1990, Westinghouse Hanford Company, Richland, Washington.

[6] *Spent Fuel Project Office Interim Staff Guidance-1, Damaged Fuel*, ISG-1, Revision 1, October 25, 2002, Spent Fuel Project Office, Office of Nuclear Materials Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C.

[7] American National Standards Institute, *American National Standard for Radioactive Materials-Leakage Tests on Packages for Shipment*, ANSI N14.5-1997, New York, New York, 10036.

[8] *Packaging and Transportation of Radioactive Material, Code of Federal Regulations*, 10 CFR 71, as amended.