CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES

1. a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE	PAGES
5797	24	71-5797	USA/5797/B(U)F-96	1	OF 3

2. PREAMBLE

   a. This certificate is issued to certify that the package (packaging and contents) described in Item 5 below meets the applicable safety standards set forth in Title 10, *Code of Federal Regulations*, Part 71, "Packaging and Transportation of Radioactive Material."

   b. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

3. THIS CERTIFICATE IS ISSUED ON THE BASIS OF A SAFETY ANALYSIS REPORT OF THE PACKAGE DESIGN OR APPLICATION

a. ISSUED TO *(Name and Address)*

U.S. Department of Energy
Washington, D.C. 20585

b. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION

Safety Analysis Report for the HFIR Unirradiated Fuel Element Shipping Package, ORNL/RRD/INT-180, Rev. 1, dated June 2025.

4. CONDITIONS

This certificate is conditional upon fulfilling the requirements of 10 CFR Part 71, as applicable, and the conditions specified below.

5.

(a) Packaging

(1) Model No.: Inner HFIR Unirradiated Fuel Element Shipping Container, and Outer HFIR Unirradiated Fuel Element Shipping Container

(2) Description

Packaging for unirradiated fissile radioactive material as fuel elements for the High Flux Isotope Reactor (HFIR). The containers are right circular cylinders with an 11-gauge carbon steel shell. The lid is attached to the container with sixteen 3/8-16x1-inch steel bolts. The steel shell is filled with stacked fir plywood rings. The plywood rings form a central cavity which is lined with 1-inch thick polyethylene foam.

The packaging for the inner HFIR fuel element has overall dimensions of 25 inches OD by 44-7/8 inches high, a 10-7/8 inch diameter by 30-3/8 inch deep cavity, and a 700-pound gross weight.

The packaging for the outer HFIR fuel element has overall dimensions of 31-1/2 inches OD by 45-3/4 inches high, a 17-3/8 inch diameter by 31-1/4 inch deep cavity, and a 1,100-pound gross weight.

(3) Drawings

(i) The packaging for the inner HFIR fuel is constructed in accordance with Oak Ridge National Laboratory Drawing Nos. M-20978-EL-003F, Rev. 0; M-20978-EL-003G, Rev. 0; and M-20978-EL-003H, Rev. 0.

5. (a) (3) Drawings (continued)

(ii) The packaging for the outer HFIR fuel is constructed in accordance with Oak Ridge National Laboratory Drawing Nos. M-20978-EL-002F, Rev. 0; M-20978-EL-002G, Rev. 0; and M-20978-EL-002H, Rev. 0.

(b) Contents

(1) Type and form of material

Uranium as U_3O_8-Al cermet, enriched up to 95% in the U-235 isotope, and each fuel plate clad in aluminum, 10-mils thick. Only intact assemblies comprised of whole fuel plates with no known or suspected cladding defects are authorized, and:

(i) For the packaging described in 5(a)(3)(i), the contents are described in the Oak Ridge National Laboratory Drawing No.: M-20978-EL-008C, Rev. 0.

(ii) For the packaging described in 5(a)(3)(ii) the contents are described in the Oak Ridge National Laboratory Drawing No.: M-20978-EL-008D, Rev. 0.

(2) Maximum quantity of material per package

(i) For the contents described in 5(b)(1)(i) not more than 2.63 kg of U-235.

(ii) For the contents described in 5(b)(1)(ii) not more than 6.88 kg of U-235.

(c) Criticality Safety Index 0.4

6. The lid lifting attachments must be blocked as shown on Oak Ridge National Laboratory Drawing Nos. M-20978-EL-002H, Rev. 0; and M-20978-EL-003H, Rev. 0, to prevent inadvertent use of the attachments during transport.

7. In addition to the requirements of Subpart G of 10 CFR Part 71:

(a) Each package shall be maintained in accordance with the Maintenance Program in Chapter 8 of the application; and

(b) Each package shall be operated and prepared for shipment in accordance with the Operating Procedures in Chapter 7 of the application.

8. The packaging authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR 71.17.

9. Transport by air of fissile material is not authorized.

10. Revision 23 of this certificate may be used until October 31, 2027.

11. Expiration date: September 30, 2030.

REFERENCES

Safety Analysis Report for the HFIR Unirradiated Fuel Element Shipping Package, ORNL/RRD/INT-180, Rev. 1, dated June 2025.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

Signed by Diaz-Sanabria, Yoira
on 01/09/26

Yoira Diaz-Sanabria, Chief
Storage and Transportation Licensing Branch
Division of Fuel Management
Office of Nuclear Material Safety
and Safeguards

Date: January 9, 2026

SAFETY EVALUATION REPORT

Docket No. 71-5797
Model No. Inner High Flux Isotope Reactor Unirradiated Fuel Element Shipping Container, and Outer High Flux Isotope Reactor Unirradiated Fuel Element Shipping Container
Certificate of Compliance No. 5797
Revision No. 24

SUMMARY

By application dated July 30, 2024 (Agencywide Documents Access and Management System Accession No. ML24229A121), as supplemented November 13, 2024 (ML24338A187) and May 20, 2025 (ML25155A082), the U.S. Department of Energy (DOE [referred to as the applicant]) requested an amendment to Certificate of Compliance (CoC) No. 5797 Rev. 23 for the Model No. Inner High Flux Isotope Reactor (HFIR) Unirradiated Fuel Element Shipping Container and Outer HFIR Unirradiated Fuel Element Shipping Container (hereon referred to as HFIR package). DOE requested an upgrade of the HFIR package from -85 to -96 certification in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) 71.19(d).

The NRC staff reviewed the application using the guidance in NUREG-2216, “Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material” Based on the statements and representation in the application, as supplemented, and the conditions listed below, the NRC staff agrees that these changes do not affect the ability of the package to meet the requirements of 10 CFR Part 71.

1.0 GENERAL INFORMATION

1.1 Package Description

The HFIR package is a Type B(U)F package, with its contents described as U_3O_8-Al cermet, enriched up to 95 percent in U^{235} and is currently licensed under the NRC CoC No. 5797, “Model Inner HFIR Unirradiated Fuel Element Shipping Container and Outer HFIR Unirradiated Fuel Element Shipping Container.” The HFIR package was designed by the Oak Ridge National Laboratory (ORNL) in 1965, and it has been updated and documented numerous times since then. In 2023, the applicant performed the physical full scale model tests on the package and submitted the consolidated safety analysis report (SAR) that includes the results of the model tests.

There are two models of the HFIR package: one to transport inner HFIR fuel elements and one to transport outer HFIR fuel elements. The primary difference in configuration is their physical size, reflecting the dimensional differences between the inner and outer fuel elements. The package materials of construction for each design are identical. The ORNL HFIR package, which is used synonymously with the inner and outer HFIR package identifications in this SAR, is fabricated from carbon steel (CS) and contains plywood assemblies. The CS body and the plywood assemblies constitute the principal structural features of the package.

1.2 Contents

No changes were made to the contents of the package.

1.3 Drawings

The application included revised drawings for the HFIR package contents and packaging. The drawings were changed to update materials that cannot be procured in the current market.

2.0 STRUCTURAL EVALUATION

The applicant submitted an application to amend the NRC CoC No. 5797, "Model Inner HFIR Unirradiated Fuel Element Shipping Container and Outer HFIR Unirradiated Fuel Element Shipping Container." The application is a consolidated SAR, "Safety Analysis Report for the HFIR Unirradiated Fuel Element Shipping Package, ORNL/RRD/INT-180, Revision 0". This consolidated SAR has been adapted from ORNL/TM-11656, Volumes 1 and 2 (Reference 2) and compiled with additional information and formatting in accordance with the NRC Regulatory Guide (RG) 7.9 (Reference 3). This SAR includes the results of the physical full-scale model tests performed in 2023 for the purpose of demonstrating compliance with the test requirements of the Type B fissile packages specified in 10 CFR Part 71 (Reference 4). The objective of the structural evaluations in this safety evaluation report (SER) section 2.0 is to verify that the structural performance of the package meets the regulatory requirements of 10 CFR 71.

2.1 Description of Structural Design

2.1.1 General

The applicant provided the detailed descriptions of the HFIR package in section 1.2, "PACKAGE DESCRIPTION," and the detailed drawings of the package in section 1.4. "APPENDIX," in chapter 1, "GENERAL INFORMATION," of the SAR.

The applicant used a combination of closed-form solutions, hand calculations, finite element (FE) analyses and full-scale model tests to evaluate the structural performance of the package under normal conditions of transport (NCT) and hypothetical accident conditions (HAC). The applicant stated that the design criteria used for the HFIR package comply with the requirements of 10 CFR 71.55 for ground transport. The applicable load combinations are summarized in table 2.1 of section 2.1, "STRUCTURAL DESIGN," of the SAR. These loading configurations are in accordance with RG 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material."

The applicant provided information regarding the weights and centers of gravity of the package. The maximum gross package weights are 700 and 1100 lbs. for the inner and outer HFIR models, respectively. The center of gravity of the package is approximately at the geometric center. The center of gravity for the package is identified on the full-scale test models, as shown in figure 2.1 of the SAR. Table 2.2 in subsection 2.1.3, "Weights and Centers of Gravity," of the SAR provides package component and assembly weights. This information was used for structural evaluations to demonstrate compliance with the NCT and HAC requirements of 10 CFR 71.33.

2.1.2 Identification of codes and standards for package design

The applicant previously submitted an application in 1991 that contained information regarding the codes and standards used for the design and fabrication of the HFIR package. The NRC staff reviewed the application and issued an SER in 1992. There were no changes of the codes and standards in this application, therefore, the NRC staff determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.33.

2.2 General Requirements for All Packages

2.2.1 Minimum package size

The NRC staff reviewed section 2.4, "GENERAL REQUIREMENTS FOR ALL PACKAGES," of the SAR and found that the smallest overall dimensions of the inner and outer HFIR packages are 25 in. and 31.5 in., respectively, which exceed the minimum dimension requirement of 4 in. specified in 10 CFR 71.43(a). Therefore, the NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.43(a).

2.2.2 Tamper-Indicating feature

The NRC staff reviewed section 2.4 of the SAR and found that the package has a tamper indicating seal, which is placed on the package. The seal is connected through a pin welded to the lid that is inserted through the closure flange angle. The presence of the security seal indicates that the unauthorized opening of the package has not occurred. This tamper-indicating feature meets the requirements of 10 CFR 71.43(b). Therefore, the NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.43(b).

2.2.3 Positive closure

The NRC staff reviewed section 2.4 of the SAR and found that there is no fastening device included in the containment system. The lid and body of the package are secured with sixteen 3/8-in. fasteners, which cannot be inadvertently opened. The NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.43(c).

2.3 Lifting and Tie-Down Standards for All Packages

2.3.1 Lifting devices

The applicant described the lifting devices of the package in section 2.5, "LIFTING and TIE-DOWN STANDARD for ALL PACKAGES," of the SAR. It indicates that the package has no lifting device. It is designed to be lifted by a forklift truck. The lid of the package is designed to be lifted through the open ends of the top brace angle. Lifting the entire package using the open-ended lid brace angle is not permitted. To ensure that the lid is not used for lifting the entire package, a covering device, which is constructed from threaded rod, plugs, and fasteners that are removable for package content loading and unloading operations, is utilized during transport. This covering device is illustrated in figure 2.4 of the SAR. The NRC staff reviewed the applicant's descriptions and statements in the SAR and found them acceptable. There were no changes impacting lifting devices, therefore, the NRC staff determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.45(a).

2.3.2 Tie-down devices

The applicant described the tie-down devices of the package in section 2.5 of the SAR. The applicant stated that the package has no tie-down device as part of its structure. A clamshell tie-down band secured by two bolts positioned above the package center rib angle is used to secure the package to a pallet or trailer floor, as illustrated in figure 2.5 of the SAR. The NRC staff reviewed the applicant's descriptions and statements and found them acceptable. The NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.45(b).

2.4 General Considerations for Structural Evaluation of Package

The applicant performed structural analyses for the HFIR package under both NCT and HAC using the FE method with the computational modeling programs, DYNA2D and DYNA3D, which are software applications that can be used for both the modeling and analysis of structural components and assemblies. The DYNA codes were developed at the Lawrence Livermore National Laboratory for use in simulating impact of nuclear weapons.

The applicant had submitted an application to amend the NRC CoC No. 5797, Rev. 9 in 1991 with a companion SAR for the HFIR packages that included the safety evaluations based on its structural analyses using the DYNA codes. The NRC staff reviewed the application and issued a SER in 1992.

However, the application submitted in 1991 did not contain structural evaluations by the model tests required by 10 CFR Part 71. As a result, the applicant recently performed a series of model tests on the HFIR shipping packages in 2023 and submitted its safety evaluations of the HFIR packages based on the results of the tests to demonstrate compliance with the requirements of 10 CFR Part 71. To demonstrate compliance, four prototype HFIR packages (two inner HFIR packages and two outer HFIR packages) were fabricated and tested to meet the requirements of 10 CFR 71.71 and 71.73 for NCT and HAC, respectively. Packages were loaded with dummy fabricated fuel elements. The dummy elements were nearly identical to production fuel without uranium.

The applicant provided a reference document that contains a model test plan. The NRC staff reviewed the test plan and found that the test plan identifies the regulatory conditions and tests for each HFIR package. Detailed information for the model tests (i.e., test sequences, methods, and system requirements for measuring and recording results during and after each test) are provided in the reference document. Package loading, closing and destructive and non-destructive examinations are also addressed in the reference document. Isometric views of the two test packages are illustrated in figure 1 of the test plan. Figure 2 of the test plan illustrates the inner and outer HFIR fuel elements loaded within each package. Based on the review and findings, the NRC staff concluded that the inner and outer HFIR package models were adequately developed to evaluate the performance of the package under NCT and HAC. Therefore, the NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.41(a).

2.5 Normal Conditions of Transport

The applicant evaluated the inner and outer HFIR unirradiated fuel element shipping containers by the analyses and model tests for NCT heat, cold, reduced external pressure, increased external pressure, vibration, water spray, free drop, corner drop, compression, and penetration as required by 10 CFR 71.71 and provided the evaluations in section 2.6, "NORMAL CONDITIONS OF TRANSPORT," of the SAR to demonstrate their performance under NCT.

2.5.1 Heat

The applicant analytically performed thermal analyses for the HFIR package and presented the evaluation findings in chapter 3, "THERMAL EVALUATION," of the SAR. The NRC staff's detailed safety evaluations on the applicant's thermal analyses are provided in section 3.0, "THERMAL EVALUATION," of this SER. Here is a summary of the thermal evaluations related to the structural performance of the package under the NCT heat condition.

Pressures and Temperatures: The applicant used a computational model in chapter 3 of the SAR to analyze the package exposed to direct sunlight. The steady-state maximum temperature calculated with direct sunlight at an ambient temperature of 100°F was 169°F, as shown in section 3.3.1.1 of the SAR. No increase in internal pressure would result from air expansion because there are four weep holes provided in the lid flange area. As explained in section 3.3, "THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT," of the SAR, the entire package will achieve a steady-state temperature equal to the ambient temperature due to the absence of any significant heat load from the package contents. Therefore, the maximum accessible surface temperature will be 100°F.

Differential Thermal Expansion: The temperature does not adversely affect the package since the materials of construction for structural members do not undergo significant changes of physical properties at these temperatures. The thermal analysis computed in section 3.3.1.1 of the SAR assumed an initial ambient temperature of 37.8°C (100°F). Thus, the packaging components and contents are assumed to reach a maximum temperature of 76.1°C (169°F). The linear expansion of the fuel elements was calculated by multiplying the linear thermal expansion coefficient by the height of the fuel elements and temperature change. Assuming a linear thermal expansion coefficient of 13.5×10^{-6} in./in. °F for 6061 aluminum, the linear expansions were calculated as 0.085 in. and 0.088 in. for the inner and outer elements, respectively. Since these values are within the design clearances of the inner and outer packages, the applicant concluded that there will be no interference between package materials.

Stress Calculations: The application did not perform an additional structural analysis to calculate stresses due to the NCT heat condition because there was no pressure and temperature increase.

The applicant did not perform a model test on the package under the NCT heat condition because the applicant previously submitted a SAR in 1991 with these analyses, and the NRC staff reviewed and accepted the results in a 1992 SER. Since the NRC staff previously reviewed the applicant's analytical evaluations and there has not been a major design change to the package, the evaluations remain acceptable. Therefore, the NRC staff determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.71(c)(1).

2.5.2 Cold

The applicant evaluated the effects of cold on the package material through model testing by chilling the HFIR package to -42.8°C (-45°F). Following the cold condition test, the package was opened without difficulty and its contents were inspected. A visual inspection was performed on the package and the components were not damaged. The applicant found that the cold condition test resulted in some condensation in the polyethylene bag surrounding the fuel element but it was not considered to adversely impact the package performance.

Additionally, the applicant found that the aluminum material properties of the HFIR fuel did not exhibit a glass transition at low temperatures and ductility was not adversely impacted. Also, it was found that the CS body performance by the full-scale low temperature testing was not adversely impacted by the NCT cold condition. The NRC staff reviewed the applicant's evaluations and found them acceptable because the package performance under NCT was not affected by the cold condition, which is consistent with the NRC staff's conclusion presented in the previous SER. Therefore, the NRC staff determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.71(c)(2).

2.5.3 Reduced external pressure

The applicant stated that there can be no differential pressure between the package and the atmosphere because there are four 1/16-in. weep holes in the outer body just beneath the closure flange to ensure the maximum normal operating pressure is nominally atmospheric during transport. The NRC staff reviewed the applicant's statement and design drawing and confirmed that there is no effect on the components of the package by the reduced external pressure of 3.5 psia. The NRC staff determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.71(c)(3).

2.5.4 Increased external pressure

There is no effect on the package by the increased external pressure because (1) the 1/8-in. neoprene gasket between the lid and the closure flange does not provide a seal, and (2) four weep holes provided in the outer body just beneath the closure flange ensure that the package is not sealed. Hence, the external and internal pressures on the package will equalize quickly, and the steady-state differential pressure will always be zero. The NRC staff reviewed the applicant's statement and design drawing and confirmed that there is no effect on the components of the package by the external pressure of 20 psia. Therefore, the NRC staff determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.71(c)(4).

2.5.5 Vibration

Vibration testing was performed on the HFIR package for a duration of at least 60 minutes. The applicant stated that no damage to the package was observed by the NCT vibration. In addition, the applicant stated that operating experience of greater than 50 years with these packages has demonstrated that no damage to the fuel elements, fasteners, or other package components is caused by vibration. The NRC staff reviewed the statements and concluded that the rationale for the conclusion is acceptable and determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.71(c)(5).

2.5.6 Water spray

The spray test was performed on the packages. The results of the water spray test showed that there was no adverse effect on package performance as a result of water retention. It is known that the water spray test is primarily intended for package relying on material that absorbs water and/or are softened by water. The NRC staff observed that the package does not have any external surfaces that are absorbent to water. The NRC staff reviewed the applicant's test results and confirmed that the water spray would not impair the package. Therefore, the NRC staff determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.71(c)(6).

2.5.7 Free drop

The applicant performed NCT free drop tests of the package with the following orientations: (1) center of gravity over top corner drop, (2) end vertical drop, and (3) side horizontal drop. The applicant performed external visual and dimensional inspections on each package prior to and following the tests and observed that each package sustained only minor damage that would neither decrease the effectiveness of the package nor allow loss or dispersal of the contents.

Additionally, the applicant previously performed NCT free drop analyses with the three orientations: (1) center of gravity over top corner drop, (2) end vertical drop, and (3) side horizontal drop. The applicant used the energy balance and FE methods for the structural analyses. The FE method used the DYNA codes (DYNA2D and DYNA3D) to analyze the structural performance of the package for the NCT free drops. The applicant submitted the results of the analyses to the NRC. The NRC staff reviewed the applicant's structural evaluations and issued a SER in which the NRC staff concluded that the package met the requirements of 10 CFR 71.71(c)(7) because the packages remain intact during the NCT drops. In addition, the results of the analyses showed that the induced stresses in the aluminum cladding of the fuel plates were below the yield stress of the material and there was no permanent deformation or damage to the fuel elements. The NRC staff reviewed the results of the FE analyses and model tests and determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(7).

2.5.8 Corner drop

The applicant indicated that the corner drop test does not apply to the HFIR unirradiated fuel element shipping package since the package is not fabricated from fiberboard or wood and its weight is in excess of 220 pounds. As a result, 10 CFR 71.71(c)(8) is not applicable. The NRC staff confirmed the applicant's statement and determined that the regulatory requirements of 10 CFR 71.71(c)(8) are not applicable to the HFIR package.

2.5.9 Compression

The applicant performed two NCT compression tests on the packages. The applicant performed external visual and dimensional inspections on each package prior to and following the tests. Visual observation of the one model package following testing indicated a small tear in the perimeter edge of the gasket. However, there was no measurable deformation of the packages as shown in figures 2.16 and 2.17 of the SAR. The NRC staff reviewed the applicant's statement and the figures in the SAR and confirmed the deformation of the package. Therefore, the NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(9).

2.5.10 Penetration

The applicant performed two NCT penetration tests on the packages. The applicant performed external visual and dimensional inspections on each package prior to and following the tests. The applicant showed that a 13-pound steel cylinder dropped 40 in. did not have a significant effect on the packages. The drop of the steel cylinder resulted in a nickel-sized dent approximately 1/16 in. deep, which would not impact on the integrity of the packages as shown in figure 2.18 of the SAR. The NRC staff reviewed the applicant's evaluation and its finding of a very small dent. The NRC staff confirmed that the small dent would not cause any changes to the functional characteristics of the package. Therefore, the NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(10).

2.6 Hypothetical Accident Conditions

The applicant evaluated the HFIR package for free drop, crush, puncture, thermal, and water immersion under HAC as required by 10 CFR 71.73. The applicant evaluated the load combinations per RG 7.8. The load combinations used for the HAC analyses and tests are tabulated in table 2.1, "Testing Matrix and Load Combinations for NCT and HAC," of the SAR.

2.6.1 Free drop

The applicant performed HAC free drop tests of the HFIR packages with two orientations: corner drop and oblique drop. The applicant performed external visual and dimensional inspections on each package prior to and following the drop tests. The following observations were made from the corner tests: (1) the drop impact deformed the lid and flange angle down into the upper support angle through the second set of bolts adjacent to the lid reinforcing angle at approximately 68 degrees, (2) the lid remained securely in place, (3) the impact to the package bottom adjacent to the open region between C-channels resulted in approximately 3 in. of deformation toward the lid, and (4) the C-channels experienced minor deformation. The pictures showing the damaged areas of the packages are presented in section 2.7.1.3, "Corner Drop," of the SAR. The NRC staff reviewed the applicant's model test results and confirmed that the damage to the packages was localized with only minimal secondary damage and the lid remained in place and there were no breaches of the packages.

Additionally, the applicant previously performed structural analyses of the package for the HAC free drop using the DYNA2D FE code and the energy balance method. Three orientations were considered for the structural analyses: (1) end vertical drop, (2) side horizontal drop, and (3) corner drop. The applicant submitted a SAR with its evaluations including the results of the analyses to the NRC in 1991 and the NRC staff reviewed and approved the changes in a 1992 SER. Based on the NRC staff's previous review of the structural FE analyses for the vertical, horizonal and corner drops documented in the final safety analysis report (FSAR), and the model test results for the corner and oblique drops presented in this application, the NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(1).

2.6.2 Crush

The applicant performed HAC crush tests on the HFIR packages with two orientations (horizonal and center of gravity over bottom [CGB]) since the mass of the HFIR package is less than 1,100 pounds. Visual and dimensional inspections were performed on each package prior to and following the tests. The applicant reported its observations: (1) crush plate flattened all rib angles on impact, (2) cut-like damage on the edges of the impact site of the crush plate, and (3) additional deformation at the tamper indicating device (TID) section facing the pad. The pictures showing the damaged areas of the packages are presented in section 2.7.2, “Crush,” of the SAR. The NRC staff reviewed the applicant’s model test results and confirmed that there were no breaches of the packages. Therefore, the NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(2).

2.6.3 Puncture

The applicant performed the puncture drop tests of the HFIR packages. Two drop orientations were considered: (1) drop horizontally over the center of gravity of the packages, and (2) drop in a CGB configuration. Visual and dimensional inspections were completed on each package prior to and following the tests. The applicant stated that the damage to the packages from the horizontal puncture drop tests was limited to a circular indentation where the package impacted the puncture pin, and the damages to the packages from the CGB orientation were a localized buckling of the drum edge at the impact site and limited to a circular indentation where the package impacted the puncture pin. The NRC staff reviewed the analyses results and evaluations and found that (1) the applicant demonstrated that the package function will not be impaired due to the puncture accident, and (2) the applicant’s conclusion is acceptable because the containment boundary will be maintained during the puncture accident. Therefore, the NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(3).

2.6.4 Thermal

The applicant analytically performed thermal analyses for the HFIR package under HAC and presented the evaluation findings in chapter 3, “THERMAL EVALUATION,” of the SAR. The NRC staff’s detailed safety evaluations on the applicant’s thermal analyses are provided in section 3.0, “THERMAL EVALUATIONS,” of this SER. The following is a brief summary of the thermal evaluations related to the structural performance of the package under the HAC heat condition.

<u>Pressures and Temperatures</u>: The applicant used a computational model in chapter 3 of the SAR to analyze the package exposed to 801.7°C (1475°F). As indicated previously, there was no expected accumulation of pressure during HAC thermal conditions because there are four weep holes provided in the lid flange area. Table 2.8 of the SAR provides a summary of the temperature variations in the package. The maximum interior temperature of the package is 180.5°C (357°F) and 181.6°C (359°F) for the outer and inner model, respectively, after the initiation of the HAC fire.

Differential Thermal Expansion: The applicant stated that due to the clearances between package components and contents, differential thermal expansion of the constituent package materials during the HAC fire will not result in stresses that could affect fuel containment integrity. The applicant stated in section 3.4, "HYPOTHETICAL ACCIDENT THERMAL EVALUATION," of the SAR that portions of the plywood and plastic foam immediately adjacent to the steel body will decompose, char, or melt, but will not result in stresses due to differential thermal expansion. Therefore, despite the increased temperatures of the contents relative to NCT, there are no significant stresses to the containment boundary of the fuel element as a result of the HAC fire.

Stress Calculations: The application did not perform an additional structural analysis to calculate stresses due to the HAC thermal condition because there was no pressure increase and there were no significant thermal stresses in the packaging body due to the negligible temperature gradient across the thin metal wall structure of the carbon steel body. Additionally, the containment boundary of the package will not sustain a significant load under HAC thermal conditions due to the thermal gradients in the fuel matrix and aluminum cladding.

The applicant did not perform a model test on the package under the HAC thermal condition. However, the applicant submitted a SAR with its evaluations including the results of the analyses to the NRC in 1991. The NRC staff reviewed the SAR, accepted it and issued a SER in 1992. Since the NRC staff previously reviewed and accepted the applicant's analytical evaluations and there has not been a major design change, the NRC staff concluded that the thermal evaluations remain acceptable. The NRC staff determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.73(c)(4).

2.6.5 Immersion - fissile material

The applicant stated that the HFIR package satisfies the regulatory requirements of 10 CFR 71.73(c)(5) because chapter 6, "CRITICALTY EVALUATION," of the SAR demonstrates subcriticality under the assumption that the package allows in-leakage of water. The NRC staff reviewed the SAR and found it acceptable because it demonstrated subcriticality with the assumption of water in-leakage. The NRC staff's detailed review of the applicant's criticality evaluations are provided in chapter 6, "CRITICALITY EVALUATION," of this SER. The NRC staff determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(5).

2.6.6 Immersion - all packages

The applicant stated that the immersion test does not affect the package because the package lid closure does not provide a seal. Therefore, the package is expected to leak when immersed in water. Water exposure could result in damage to the plywood, necessitating replacement, but it would not degrade the other materials. The NRC staff previously accepted the applicant's conclusions in its 1991 SER. Therefore, the NRC staff determined that the application continues to satisfy the regulatory requirements of 10 CFR 71.73(c)(6).

2.7 Air Transport Accident Conditions for Fissile Material

The applicant stated that this section is not applicable because the HFIR package has not been evaluated for air transport of fissile material as stated in section 2.9, "ACCIDENT CONDITIONS FOR FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT," of the SAR. The NRC staff confirmed that the HFIR package is not qualified to transport the fissile material by air and the regulatory requirements of 10 CFR 71.55(f) are not applicable to the HFIR package.

2.8 Special Requirement for Type B Packages Containing More than 10^5 A_2

The applicant stated that this section is not applicable because the HFIR package contains less than 10^5 A_2, as stated in section 2.7.7, "Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A_2)," of the SAR. The NRC staff confirmed that the regulatory requirements of 10 CFR 71.61 are not applicable to this HFIR package.

2.9 Air Transport of Plutonium

The applicant stated that the test does not apply to the HFIR package because the package has not been evaluated for air transport of plutonium, as stated in section 2.8, "ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM," of the SAR and it is not qualified to transport plutonium by air. The NRC staff confirmed that the regulatory requirements of 10 CFR 71.64 and 10 CFR 71.74 are not applicable to this HFIR package.

2.10 Evaluation Findings

The NRC staff reviewed and evaluated the applicant's statements and representations in the application. Based on the review and evaluations, the NRC staff concludes that the HFIR package is adequately described, analyzed, tested, and evaluated to demonstrate that its structural capability and integrity meet the regulatory requirements of 10 CFR Part 71.

3.0 Thermal Evaluation

3.1 Review Objectives

The objective of the NRC staff review of HFIR shipping package is to verify that the thermal performance of the package has been adequately evaluated for the tests specified under NCT and HAC, in accordance with 10 CFR Part 71.

3.2 Description of the Thermal Design

3.2.1 Design Features

The HFIR package is fabricated from CS and contains plywood inserts and a polyethylene foam liner. The plywood assembly constitutes the principal thermal design features of the package. The applicable functional criterion for the plywood is to provide thermal insulation during the fire test.

3.2.2 Thermal Design Criteria

Package design criteria are listed below:

- 10 CFR Part 71.71(c)1, requires that no loss of effectiveness shall result if the package is subjected to an ambient temperature of 37.8°C (100°F) in sunlight.
- Consistent with 10 CFR 71.43(g) the maximum temperature of the accessible packaging surfaces in the shade is limited to 85°C (185°F).
- The NCT ambient temperature is -40°C (-40°F) per 10 CFR 71.71(c)2.

- The maximum temperature achieved during the HAC thermal test must not challenge the package containment boundary such that a release of the radioactive contents beyond an amount A_2 is possible within one week, per 10 CFR 71.51(a)2.

3.2.3 Content's Decay Heat

The decay heat of the contents is negligible.

3.2.4 Summary Tables of Temperatures

The summary table of key package component temperatures for NCT and HAC (SAR table 3-1) was reviewed by the NRC staff. The temperatures are consistently presented throughout the SAR for NCT and HAC.

3.2.5 Summary Tables of Maximum Pressures

No significant pressure increases are expected during NCT or HAC, since the HFIR package has holes that allow air to vent to the environment.

The NRC staff reviewed the thermal design description of HFIR transportation package and finds it acceptable. The NRC staff reviewed the temperature and pressure design limits and calculated temperatures and pressures for the package and found them to be acceptable and consistent in the SAR.

3.3 Material Properties and Component Specifications

3.3.1 Material Properties

The package application provided material thermal properties such as thermal conductivity, density, specific heat, and emissivity for all modeled components of the package. The NRC staff found these properties acceptable. The convection coefficient of the package surface is conservatively represented by laminar flow with the larger characteristic dimension represented by the cask body.

3.3.2 Component Specifications

The application provided component thermal technical specifications for the HFIR packaging and contents. The applicant provided temperature ranges for the different materials. These ranges ensure that the cask can be operated safely, provided the thermal specifications for these materials are not exceeded.

The NRC staff reviewed the thermal properties used for the package analyses and determined that they were appropriate for the materials specified and for the package conditions required by 10 CFR Part 71 during NCT and HAC. NRC staff reviewed the component specifications for the HFIR package and determined that the specifications were sufficiently clear to be evaluated as part of the thermal evaluation results.

3.4 Thermal Evaluation under Normal Conditions of Transport

3.4.1 Thermal Models

The applicant used an analytical approach to calculate the exterior surface and package temperatures. The applicant assumed that the packaging and their contents may be treated as homogeneous bodies which are in steady-state equilibrium with the ambient conditions and solar heating. The external heat load to the package is based on the insolation conditions identified in 10 CFR 71.71 and the convection coefficient of the package surface represented by laminar flow. Per 10 CFR 71.71, ambient temperature is assumed to be 37.8°C (100°F).

Based on the information provided in the application regarding the developed thermal model, staff concludes that the description of the thermal model is acceptable because the description satisfies NUREG-2216 and subsequently meets the requirements of 10 CFR Part 71.

3.4.2 Heat and Cold

The applicant performed steady-state analysis using the HFIR thermal model without insolation to determine the accessible surface temperature in the shade. The calculated surface temperature is about 37.8°C (100°F) since the heat generated by the package contents is negligible. The calculated temperature is well below the limit of 185°F.

The applicant stated that under the minimum ambient temperature of -40°C (-40°F), the resulting packaging component temperatures will approach -40°C (-40°F) if no credit is taken for the decay heat load. Since the package materials, including containment structures and seals continue to function at this temperature, the minimum temperature condition has no adverse effect on the performance of the HFIR cask.

3.4.3 Maximum Normal Operating Pressure

As stated in Section 3.2.5 of this SER, no significant pressure increase is expected since the HFIR package has holes to vent any air inside the package.

NRC staff reviewed the applicant’s analysis of the HFIR shipping package during NCT and concludes that the NCT analysis is acceptable because the analysis and results satisfy NUREG-2216 and subsequently meets the requirements of 10 CFR Part 71.

3.5 Thermal Evaluation under Hypothetical Accident Conditions

The applicant developed a thermal model of the package assuming no damage from the free drop, crush, and puncture tests. The HAC thermal model developed by the applicant is based on the HEATING thermal code. HEATING is a finite element computer program with multidimensional heat transfer analysis capabilities. The applicant’s thermal model included the outer package and its contents. From the analysis results of the outer package model, the applicant determined that the inner package could be conservatively represented by a model that did not include the contents. The applicant performed transient runs considering HAC conditions, per 10 CFR 71.71(c)(4).

3.5.1 Initial Conditions

The initial temperatures for the HFIR shipping package transient model are determined using the same boundary conditions for NCT (37.8°C [100°F] ambient with insolation) described in the SAR.

3.5.2 Fire Test Conditions

Based on the requirements in 10 CFR 71.73, a fire temperature of 801.7°C (1475°F), fire emissivity of 0.9, and a period of 30 minutes are considered for the fire conditions in the applicant's thermal model.

3.5.3 Maximum Temperatures and Pressure

The maximum component temperatures for transient runs are listed in table 3.5 of the SAR. This table shows that the maximum temperatures of the HFIR package calculated for HAC are lower than the allowable limits.

The applicant stated that the existing vent holes in the package can relieve the gases formed during pyrolysis of the wood with a significant pressure buildup. Degradation of the lid closure gasket is expected to prevent this pressure buildup and limit the internal pressure to essentially atmospheric.

3.5.4 Maximum Thermal Stresses

Thermal stresses for the HFIR package are discussed in chapter 2 of the SAR.

3.5.5 Accident Conditions for Fissile Material Packages for Air Transport

The HFIR shipping package is not designed for air transport.

Based on the information provided in the application NRC staff concludes that the HAC analysis is acceptable because the analysis and results satisfy NUREG-2216 and subsequently meets the requirements of 10 CFR Part 71.

3.6 Thermal Tests

The applicant stated in the SAR that no acceptance or periodic thermal test is required, since the thermal analysis provided in SAR chapter 3 is based on bounding evaluations and no significant material degradation is expected during the package operation.

3.7 Evaluation Findings

Based on review of the statements and representations in the application, the NRC staff concludes that the thermal design has been adequately described and evaluated, and that the thermal performance of the package meets the thermal requirements of 10 CFR Part 71.

4.0 Containment Evaluation

The applicant stated that this amendment application of the HFIR B(U)F-96 CoC addresses the latest changes in the *Code of Federal Regulations* with the most significant being the inclusion of the sequential crush test for fissile packaging (-96).

The containment review is to verify that the HFIR package design and performance satisfy the containment requirements of 10 CFR Part 71 under NCT and HAC.

4.1 Description of Containment System

The applicant stated, in SAR section 4.1, "Description of the Containment System," that (1) the HFIR shipping package contents of Materials Testing Reactor (MTR)-type fuel (such as HFIR) will release no fission products when maintained at less than 500°C (932°F), and (2) the contents are contained in a fuel matrix and aluminum clad. Together the fuel matrix and aluminum cladding provide the primary boundary or containment. The applicant also provided fuel plate containment boundary in SAR figure 4.1 and summarized aluminum clad integrity tests in SAR table 4.1.

NRC staff confirmed that the containment system and the clad integrity tests of the HFIR shipping package is well described in SAR section 4.1 for containment review.

4.2 General Requirements

4.2.1 Characteristics of Irradiated HFIR Fuel

The applicant calculated A_2 value of the HFIR fuel as a mixture of isotopes and presented fuel activity calculations of inner and outer fuel elements in SAR section 4.1 and table 4.2. Based on the calculated results, the applicant concluded that an amount of fuel bearing material exceeding 90 percent of an inner element or exceeding 34 percent of the uranium in an outer element constitutes a quantity exceeding the A_2 value.

NRC staff reviewed the fuel activity calculations and accepted the A_2 value of the uranium fuel mixture and the uranium fuel activities, respectively, for the inner element and the outer fuel element. NRC staff also confirmed that the secondary boundary, formed by the packaging cavity and lid, surrounds the containment or fuel cladding, and establishes the cavity conditions to contain the fuel cladding.

4.2.2 Seals, Welds, and Closure

The applicant stated, in SAR section 4.1.3, "Seals and Welds," that the HFIR fuel plates are welded to the inner and outer side plates of both inner and outer fuel elements, and the fuel elements are designed such that these welds do not penetrate through the aluminum cladding that forms a frame around the fuel boundary. As discussed in SAR section 4.2.1, "Containment of Radioactive Material," normal fabrication and inspection requirements for the HFIR fuel elements limit radioactive contamination of the external surfaces of the fuel plates to an insignificant value.

The applicant stated, in SAR section 4.1.4, "Closure," that (1) the initial cladding integrity is verified by ultrasonic inspection and a blister test (nonbond indication) at 500°C (932°F) for

every fuel plate at HFIR, and (2) the verification inspection/test of the closure, presented in SAR section 4.1.4, are maintained for fuel plates that serve as the containment boundary for this package.
NRC staff checked SAR table 3.1 and confirmed that the maximum fuel temperatures of 76.1°C (169°F) for NCT and 143.3°C (290°F) for HAC are below the test temperature of 500 °C (932°F). Therefore, the NRC staff accepts the test temperature of 500°C (932°F) for verification of the fuel cladding integrity. The NRC staff reviewed SAR sections 4.1.3 and 4.1.4 and finds that description of the seals/welds is sufficient, and verification inspection/test of the closure is acceptable to ensure that appropriate integrity is maintained for the fuel plates and fuel elements.

4.3 Containment under Normal Conditions of Transport

The applicant stated, in SAR section 4.2.1, “Containment of Radioactive Material,” that there was no significant damage observed for either the packaging or the contents of the HFIR package during NCT testing and any release of radioactive material of the HFIR shipping package is less than 10^{-6} A_2 per hour for NCT, in compliance with 10 CFR 71.51(a)(1).

The applicant stated, in SAR section 4.2.2, “Pressurization of Containment Boundary,” that the unirradiated HFIR fuel elements contain no fission products, and therefore, no source for internal pressurization of the fuel matrix or cladding will exist. The applicant noted, in SAR section 4.2.2, that the actual experiments at 500°C (932°F) for irradiated fuel plates verify that the 0.010-in. aluminum cladding is sufficient to ensure that the irradiated fuel plate provides containment at a conservative analysis limit of 400°C (752°F) for spent fuel. Therefore, this same containment boundary for irradiated fuel plates provides for a very conservative containment boundary for unirradiated fuel plates.

NRC staff reviewed SAR sections 4.2.1 and 4.2.2 and confirmed that (1) the aluminum cladding can provide containment effectiveness on the unirradiated HFIR fuel elements during the NCT and (2) the integrity of packaging cavity and lid, as the secondary boundary (packaging cavity, lid and gasket), can provide adequate protection for HFIR fuel cladding and ensure compliance with the NCT structural analysis. The NRC staff determined that the HFIR shipping package meets the NCT containment requirements, in compliance with 10 CFR 71.51(a)(1).

4.4 Containment under Hypothetical Accident Conditions

The applicant stated, in SAR section 4.3, “Containment under Hypothetical Accident Conditions,” that the fuel plate core matrix and cladding provide the containment which can withstand the HAC for HFIR fuel when transported in the HFIR shipping package. The applicant then stated in SAR section 4.3.1, “Containment of Radioactive Material,” that the secondary boundary (e.g., packaging cavity, lid, and gasket) can provide adequate protection for cladding and contents during the HAC and is sufficient for the HAC pressure test.

The applicant stated, in SAR section 4.3.2, “Pressurization of Containment Boundary,” that the unirradiated HFIR fuel elements contain no fission products, and therefore, no fission-product gas will be released from the fuel matrix to pressurize the containment boundary during the HAC.

The applicant presented, in SAR section 4.3.3, “Containment Criterion,” that (1) based on the bounding worst-case thermal analysis which assumed no barrier protection was offered by the shipping packaging, less than 25 percent of the fuel bearing material (U_3O_8) of the outer or inner fuel element will melt when only the fuel element is subjected to the HAC thermal event, and (2) based on the HAC structural tests described in SAR chapter 2, no significant damage is experienced to the package.

NRC staff reviewed SAR section 4.3, including sections 4.3.1 through 4.3.3, and confirmed that (1) there is no significant damage to the package in the HAC tests as described in SAR chapter 2, and (2) there is no escape of radioactive material exceeding an A_2 amount in one week, because less than 25 percent of the fuel bearing material of the outer or inner fuel element will melt when compared to the allowable limits of 90 percent for inner fuel bearing material and 34 percent for outer fuel bearing material. Therefore, NRC staff has reasonable assurance that there will be no escape of radioactive material exceeding a total amount of A_2 in one week under the HAC, and the HFIR shipping package meets the HAC containment requirements, in compliance with 10 CFR 71.51(a)(2).

4.5 Evaluation Findings

NRC staff reviewed containment evaluation of the HFIR shipping package under this amendment request of the HFIR B(U)F-96 CoC, and concludes that (1) the HFIR shipping package has been described and evaluated to demonstrate the performance of the packaging and the fuel elements on the containment requirements of 10 CFR Part 71, and (2) the package meets the requirements of 10 CFR 71.51(a)(1) that any release of radioactive material be less than 10^{-6} A_2 per hour for NCT and 10 CFR 71.51(a)(2) that any release of radioactive material be less than A_2 in 1 week for HAC.

5.0 SHIELDING EVALUATION

The objective of this shielding evaluation is to ensure that the HFIR shipping container, as it pertains to shielding, protects immediate area workers and members of the public against radiation that is above the regulatory limits stated in 10 CFR Part 71. The NRC staff reviewed this application using the guidance in NUREG-2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material". The applicant is requesting a -96 certification for this container.

For this review, NRC staff reviewed the application and found the package satisfactorily meets the requirements of 10 CFR Part 71 of 200 mrem/hr on the external surface of the package for NCT and 1000 mrem/hr for hypothetical accident conditions (HAC). The applicant's safety margin is greater than 95 percent relative to the NCT regulatory limit and greater than 95 percent relative to the HAC regulatory limit. The NRC staff finds the shipping container materials provide adequate shielding for unirradiated U_3O_8-Al materials.

5.1 Evaluation Findings

Based on the statements and representations contained in the application, as supplemented, and the conditions listed above, the NRC staff concludes that the design has been adequately described and evaluated, and the Model No. Inner Unirradiated Fuel Element Shipping Container and Outer HFIR Unirradiated Fuel Element Shipping Container meet the requirements of 10 CFR Part 71 and the guidance on format and content in NUREG-2216.

6.0 CRITICALITY EVALUATION

The objective of the criticality review is to verify that the HFIR package design meets the nuclear criticality safety requirements in 10 CFR Part 71.

6.1 Contents

The HFIR package will ship U_3O_8-Al unirradiated fuel elements containing up to 95 percent U-235 enriched uranium. The inner element package will contain less than 2.63 kg U-235, and the outer element package will contain less than 6.88 kg U-235. Each fuel element consists of several fuel plates angled around the annulus. The applicant modeled the inner and outer fuel element packages to ensure 10 CFR Part 71 criticality compliance. Each model consisted of various simplifications, including 'smearing' materials, omission of structural and containment elements, and simplification of channels and fuel. Instead of modeling individual fuel plates, the applicant homogenized all material within the fuel element zone, conserving atomic densities but not geometry. This approach can be explained through more efficient moderation and a higher chance of fission due to the availability of uranium when a neutron is in the thermal energy range. This efficient moderation results in a lower neutron leakage factor than a discrete geometry, increasing the k_{eff} of the system.

6.2 Evaluation

The applicant conducted a sensitivity study to determine optimum moderation within the fuel zone, and NRC staff found this simplification acceptable. The applicant self-identified an error when modeling the neoprene gasket. The model used a density of 1.46 g/cc instead of the correct 0.96 g/cc. This model increases the hydrocarbon mass of the package by, at most, 350 g. Although not insignificant, this mass difference compared to the total moderator mass of the package, along with the location of the neoprene, provides an inconsequential error to the calculation of the packages' k_{eff}. The applicant analyzed this assumption, and NRC staff found the analysis acceptable. The fuel plates used within the package are curved. Due to the possible straightening of these elements during HAC, the applicant enlarged the fuel-containing zone of the package to accommodate the potential distortion of the elements. This assumption is conservative due to the increased package-to-package interaction that the applicant uses during the HAC finite array calculation. The other difference between the HAC and NCT models was the exclusion of 1 in. of hydrogen and carbon on the outside of the wood zone, representing the burning of the outside of the wood packaging during HAC conditions. When determining maximum reactivity through optimum moderation, the applicant found that full-density water created the highest k_{eff}. Therefore, excluding 1 in. of lower density wood and replacing it with full-density water is conservative.

NRC staff has reviewed the package and concludes that the applicant used packaging features, content configurations, and material properties in the criticality safety analysis bounding for the package’s design basis. The applicant performed Criticality calculations with the KENO V.a computer code with a 16-energy group cross-section library. The applicant performed validation within CSASI and CSAS25.

The applicant conducted criticality studies to determine the most reactive material properties and configuration of packages. Because of the amount of wood in the package and the variable nature of wood density, the applicant varied the density between 0.479 and 0.623 g/cc, with the more reactive configuration having the lower density. The applicant varied water density to determine optimum moderation within the voids of the package, with full-density water having the highest reactivity. The final bounding model used by the applicant to decide the maximum k_{eff} had the minimum density wood, flooded element, distorted fuel zone, and no water between packages. The results were k_{eff} values of 0.78858 for the inner element package and 0.87651 for the outer element package. The applicant's inner element package model used a finite array of 252 packages, and the applicant's outer element package model used a finite array of 260 packages.

10 CFR Part 71 requires a determination of subcriticality for a single package and an array of packages for NCT and HAC. The original HFIR criticality evaluation, performed in the 1990s, did not explicitly determine single package subcriticality. This application argues that the HAC array bounds all single package evaluations. Because of the demonstration of added reactivity with additional packages, along with the conservative assumptions within the array models, NRC staff determines this to be acceptable.

As stated in 10 CFR Part 71, under NCT and HAC, the package must stay subcritical with a margin of safety. The applicant defined their upper subcritical limit (USL) as shown in Eq. 1.

$$USL = 0.95 - \Delta K_u + \beta \quad \text{(Eq. 1)}$$

Where ΔK_u is calculational uncertainty and β is calculational bias. When calculating the k_{eff} values as described above, the average calculational uncertainty was 0.003431. To determine this calculational bias, the applicant applied a benchmarking process different than the process described in NUREG-6698, "Guide for Validation of Nuclear Criticality Safety Calculational Methodology." However, the applicant relied on the fact that HFIR fuel elements have been used during accepted benchmarking experiments. The applicant used four different groups of benchmarks to determine code bias: HFIR Elements, Army Package Power Reactor, poorly moderated uranium metal slabs, and wood-moderated uranium metal. The HFIR package utilizes elements of each of these experiments. Using these benchmarks creates an area of applicability that covers the application analyses' Energy of the Average Lethargy of Fission (EALF), enrichment, moderator (wood, polyethylene, and water), and H/U ratio. NRC staff reviewed the applicant's benchmarking evaluation and determined that the applicant used appropriate experiments, creating an adequate area of applicability. The applicant's calculated bias was positive, and according to the guidance (NUREG/CR-6698), the applicant must conservatively adjust the bias to 0. The applicant followed the guidance and did not apply a positive bias uncertainty. Using a 3-sigma calculation to determine the calculational uncertainty, the USL resulted in 0.9397. However, the applicant rounded to 0.94. Although rounding up is considered non-conservative, because the applicant used a 3-sigma uncertainty, the USL of 0.94 is still a conservative estimate compared to the acceptable 2-sigma uncertainty. NRC staff reviewed the determination of calculational uncertainty and bias and the USL and found them acceptable.

The applicant determined the Criticality Safety Index (CSI) by 10 CFR 71.59(b). As discussed above, the applicant determined an array of 252 inner element shipping packages and 260 outer element shipping packages to be subcritical with an approved margin of safety. The applicant calculated the CSI with the most limiting array, the inner element package, resulting in a CSI of 0.4. The NRC staff has reviewed and concluded that the application accurately determines the CSI.

6.3 Evaluation Findings

NRC staff has reasonable assurance that the proposed package design and contents satisfy the nuclear criticality safety requirements in 10 CFR Part 71. In making this finding, NRC staff considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

7.0 MATERIALS EVALUATION

For the materials evaluation, the primary change for the updated SAR is the evaluation of the crush test. Thus, the materials review below discusses the material and mechanical properties of the impact limiter, made of Douglas Fir wood, to verify the HFIR package meets the requirements of 10 CFR Part 71.

7.1 Material Properties and Component Specifications

The applicant stated in table 2.5, “Mechanical Properties Used in Analysis,” that the material properties given in table 2.5 for plywood are based on in-plane data. The applicant also stated that the compressive strength values utilized in the analysis are discussed in SAR Reference 2.12.10, “*Evaluation of Structural Integrity of HFIR Shipping Containers for Impact Forces Resulting from Normal and Hypothetical Accident Drop Conditions of 10 CFR 71.”* In the SAR, U.S. Forest Service Agricultural Handbook No. 72, *Wood Handbook: Wood as an Engineering Material* (1974), is referenced for the calculation of the compressive strength of plywood parallel to the face grain, F_{cw}, and perpendicular to the face grain, F_{cx}. The values for F_{cw} and F_{cx} are tabulated in the SAR reference as within a range of 3262 and 3805 psi. Moreover, the "Wood Handbook," Reference 8 of FSAR Reference 2.12.10, provides a minimum range for compression parallel to the grain (max crushing strength) of 3110 to 6220 psi for Douglas Fir. Therefore, the compressive strength of 3250 psi, as used in the FSAR, was judged to be a reasonable value.

The NRC staff evaluated the material properties provided by the applicant and reviewed the SAR reference for the basis of the crush strength and found the properties to be reasonable and in accordance with the requirements of 10 CFR 71.35.

7.2 Normal Conditions of Transport

The applicant stated that four full scale packagings were fabricated for testing at Savannah River National Laboratory (SRNL) test facilities, with the NCT penetration and drop tests performed at the SRNL test pad. The results of the structural testing, as described in SAR section 2.6, through analysis and testing, demonstrated the HFIR package for NCT will experience no loss or dispersal of radioactive material, and no significant increase in surface radiation, and no substantial reduction in effectiveness of the package.

7.3 End-Drop and Crush Tests

The applicant stated that, for the end-drop evaluation of the package, the plywood placed above and below the fuel element cavity absorbs the impact forces by loading perpendicular to the plywood laminates.

The applicant described the HFIR prototype crush testing in SAR section 2.7.2, following the 30-ft free drop tests. The HFIR packaging was evaluated both by analysis and by full-scale testing of four prototypical test units, as summarized in the preceding sections. The primary damage caused by the HAC sequential structural testing is from the 30-ft. free drop and crush tests. No analyzed or tested configurations indicated a failure of the package as compared with the acceptance criteria specified in SAR section 2.1.2. The structural testing and analyses demonstrate that the HFIR package design is sufficient to protect the fuel during sequential HAC regulatory tests. As such, a thermal analysis is used in chapter 3, “Thermal Evaluation,” to demonstrate that the fuel will retain its containment integrity throughout all hypothetical accident conditions.

The NRC staff evaluated the NCT evaluation and end-drop and crush test evaluation provided by the applicant and found that the HFIR package design demonstrated sufficient performance under normal conditions of transport and hypothetical accident conditions and is in accordance with the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a).

7.4 Evaluation Findings

Based on the review of the statements and representations in the application, the NRC staff concludes that the materials of construction have been adequately described and evaluated, and that the package meets the requirements of 10 CFR Part 71.

Conditions

In addition to small editorial changes, the following changes have been made to the certificate:

Condition No. 5(a)(2) was changed to update dimensions of the inner and outer HFIR package.

Condition No. 5(a)(3) was updated to reflect the latest revisions for drawings pertaining to packaging and contents.

Condition No. 6 was updated to reflect the latest revision for drawings pertaining to lifting attachments.

Condition No. 8, which stated “Use of packagings fabricated after December 31, 1976, is not authorized,” was deleted. Conditions following were subsequently renumbered.

Condition No. 10, formerly Condition No. 11, was updated to allow use of the previous revision of the certificate until October 31, 2027.

Condition No. 11, formerly Condition No. 12, was updated to reflect the new expiration date for the certificate of September 30, 2030.

CONCLUSION

Based on the statements and representations contained in the application, as supplemented, and the conditions listed above, the NRC staff concludes that the design has been adequately described and evaluated, and the Model No. Inner HFIR Unirradiated Fuel Element Shipping Container and Outer HFIR Unirradiated Fuel Element Shipping Container package meets the requirements of 10 CFR Part 71.

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