June 16, 2009

Dr. James Shuler, Manager
Packaging Certification Program
Safety Management and Operations
Office of Environmental Management
U.S. Department of Energy
Washington, D.C. 20585

SUBJECT: REVISION NO. 1 OF CERTIFICATE OF COMPLIANCE NO. 9330 FOR THE MODEL NO. ATR-FFSC PACKAGE

Dear Dr. Shuler:

As requested by your application dated September 8, 2008, supplemented March 4, 2009, and June 16, 2009, enclosed is Certificate of Compliance No. 9330, Revision No. 1, for the Model No. ATR-FFSC package. This certificate supersedes, in its entirety, Certificate of Compliance No. 9330, Revision No. 0, dated July 22, 2008. The staff's Safety Evaluation Report is also enclosed.

Those on the attached list have been registered as users of the package under the general license provisions of 10 CFR 71.17 or 49 CFR 173.471. This approval constitutes authority to use the package for shipment of radioactive material and for the package to be shipped in accordance with the provisions of 49 CFR 173.471. Registered users may request, by letter, to remove their names from the Registered Users List.

If you have any questions regarding this certificate, please contact me or Pierre Saverot of my staff at (301) 492-3408.

Sincerely,

/RA/

Eric J. Benner, Chief
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
And Safeguards

Docket No. 71-9330
TAC No. L24248

Enclosures:
1. Certificate of Compliance No. 9330, Rev. No. 1
2. Safety Evaluation Report
3. Registered Users

cc w/encls. 1& 2: R. Boyle, Department of Transportation
Registered Users

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OFC:	SFST	E	SFST		SFST		SFST		SFST	
NAME:	PSaverot		JPiotter		MCall		CRegan		LCampbell	
DATE:	04/24/09		5/8/09		4/30/09		5/19/09		5/20/09	

OFC:	SFST	E	SFST		SFST		SFST		SFST	
NAME:	MDeBose		EJBenner							
DATE:	5/28/09		6/16/09							

C = COVER E = COVER & ENCLOSURE N = NO COPY

SAFETY EVALUATION REPORT
Docket No. 71-9330
Model No. ATR FFSC Package
Certificate of Compliance No. 9330
Revision No. 1

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SAFETY EVALUATION REPORT
Model No. ATR FFSC Package
Certificate of Compliance No. 9330
Revision No. 1

SUMMARY

By application dated September 08, 2008, supplemented March 4, 2009, and June 16, 2009, the U.S. Department of Energy requested approval of the Model No. ATR FFSC (Advanced Test Reactor Fresh Fuel Shipping Container) as a Type AF-96 package for transportation of a single unirradiated fuel element for the Advanced Test Reactor (ATR), the Massachusetts Institute of Technology (MIT) Research Reactor, and the Missouri University Research Reactor (MURR) or for unirradiated loose ATR fuel plates

The packaging is composed of three components: (1) a double-walled stainless steel structure body, with thermal insulation between the shells; (2) a disc-shaped end closure with a bayonet style fastener system; and (3) one of four types of internal structures to support the contents. The outer dimensions of the package are 8 inches square by 73 inches in length. The maximum weight of the package, including contents, is 290 pounds.

The package was evaluated against the regulatory standards in 10 CFR Part 71, including the general standards for all packages, and performance standards for fissile material packages under normal conditions of transport and hypothetical accident conditions. The applicant demonstrated the structural integrity of the package by a combination of analysis and physical testing i.e., normal conditions drop, 30-foot free drop, and puncture tests of full-scale specimens. The fire test condition was evaluated by analysis. The physical tests, combined with analyses, demonstrated that the package provides adequate thermal protection, containment, shielding, and criticality control under normal and accident conditions.

NRC staff reviewed the application using the guidance in NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material." Based on the statements and representations in the application, and the conditions listed below, the staff concluded that the package meets the requirements of 10 CFR Part 71.

References

Department of Energy application dated September 08, 2008.

Supplements dated: March 4, 2009; June 16, 2009.

1.0 GENERAL INFORMATION

1.1 Packaging

The package has three primary components: (1) the body; (2) the closure; and (3) one of four types of internal structures to support the contents.

The body is composed of two thin-walled, stainless steel shells. The outer shell is a square tube with an 8 inch cross section, a 73 inch length, and a 3/16 inch wall thickness. The inner shell is a round tube with a 6 inch diameter and a 0.120 inch wall thickness. The inner tube is wrapped with ceramic fiber thermal insulation, overlaid with a 28 gauge stainless steel sheet. At the bottom end, the shells are welded to a 0.88 inch thick stainless steel base plate. At the top end (closure end), the shells are welded to a 1.5 inch thick stainless steel flange.

The closure, composed of circular stainless steel plates with ceramic fiber insulation, engages the top end flange by way of four bayonets that are rotated to engage the closure end body flange. The closure is secured from rotating by two spring pins. The closure, equipped with a handle for ease of installation, does not have a gasket or seal.

The package internals consist of Fuel Handling Enclosures (FHEs) for holding either intact ATR, MIT, or MURR fuel elements, or a Loose Fuel Plate Basket (LFPB) for transporting ATR loose fuel plates. The ATR FHE is a hinged thin-gauge aluminum structure that includes neoprene pads positioned to protect the fuel element. The MIT and MURR FHEs are very similar and comprised of two identical machined segments which surround the fuel element secured by two end spacers and locked together using ball lock pins. The LFPB is a full length aluminum structure that restrains the loose ATR fuel plates within a fixed geometry for criticality control. The two sides of the LFPB are secured together by eight screws with wing nuts torqued to 175-195 lb-in.

The approximate dimensions and weights of the package are:

Overall package outer width and height	8 inches
Overall package length	73 inches
Packaging weight (without internals)	240 pounds
Package weight with ATR/MIT/MURR fuel	280/275/285 pounds
Maximum package weight with ATR loose plates (including internals and contents)	290 pounds

1.2 Contents

The ATR FFSC package is a Type AF package designed for the transport of four payload types: ATR fuel element, MIT fuel element, MURR fuel element, and unassembled ATR fuel element plates.

1.2.1 Type and Form of Material

Unirradiated ATR Mark VII fuel plates are composed of aluminum-clad uranium aluminide (UAl_x). The uranium is enriched to a maximum 94 weight percent ^{235}U; the maximum ^{234}U content is 1.2 weight percent; and the maximum ^{236}U content is 0.7 weight percent. The fuel meat thickness is a nominal 0.02 inch, and the nominal active fuel length is approximately 48 inches. Each ATR fuel element is composed of 19 curved plates, secured within aluminum side plates. The fuel plates are typically spaced with a 0.08 inch gap. The maximum fissile mass is 1200 grams ^{235}U per fuel element. The fuel element may be inserted in a plastic bag or wrapped in plastic, and is contained within the ATR FHE.

Unirradiated MIT fuel plates in the form of a complete fuel element are composed of aluminum-clad uranium aluminide (UAl_x). The uranium is enriched to a maximum 94 weight percent ^{235}U; the maximum ^{234}U content is 1.2 weight percent; and the maximum ^{236}U content is 0.7 weight percent. The fuel meat thickness is a nominal 0.03 inch and the active fuel length is approximately 23 inches. Each MIT fuel element is composed of 15 flat fuel plates, secured within aluminum side plates. The fuel plates are nominally 0.08 inches apart. The maximum fissile mass is 515 grams ^{235}U per fuel element. The fuel element may be inserted in a plastic bag or wrapped in plastic, and is contained within the MIT FHE.

Unirradiated MURR fuel plates in the form of a complete fuel element are composed of aluminum-clad uranium aluminide (UAl_x). The uranium is enriched to a maximum 94 weight percent ^{235}U; the maximum ^{234}U content is 1.2 weight percent; and the maximum ^{236}U content is 0.7 weight percent. The fuel meat thickness is a nominal 0.02 inch and the active fuel length is approximately 25.5 inches. Each MURR fuel element is composed of 24 curved plates, secured within aluminum side plates. The fuel plates are typically spaced with a 0.08 inch gap. The maximum fissile mass is 785 grams ^{235}U per fuel element. The fuel element may be inserted in a plastic bag or wrapped in plastic, and is contained within the MURR FHE.

Loose fuel plates to be transported include only ATR fuel plates. The fuel plates may be curved or flat and may be banded or wire-tied together. The fuel plates may be wrapped or bagged with plastic. The fuel plates must be contained within the ATR LFPB, as specified in the packaging drawings. The loose plate payload content is limited to 600 grams ^{235}U.

1.2.2 Maximum Quantity of Material per Package

The maximum total weight of contents and internals, including dunnage and other secondary packaging, is 50 lbs. Radioactive contents are not to exceed a Type A quantity.

For ATR, MIT, or MURR fuel elements: A maximum of one fuel element.

For loose ATR fuel plates: Maximum fissile mass of 600 grams U-235.

1.3 Criticality Safety Index

The Criticality Safety Index (CSI) of the package is 4.0.

1.4 Drawings

The packaging is constructed and assembled in accordance with the following Drawing Nos.:

60501-10, sheets 1-5, Rev. 2	ATR Fresh Fuel Shipping Container Drawing
60501-20, Rev. 1	ATR Loose Fuel Plate Basket
60501-30, Rev. 1	ATR Fuel Handling Enclosure
60501-40, Rev. 0	MIT Fuel Handling Enclosure
60501-50, Rev. 0	MURR Fuel Handling Enclosure

2.0 STRUCTURAL

The ATR FFSC package is a Type AF-96 package designed for the transport of a single unirradiated ATR, MIT, or MURR fuel element or loose unirradiated ATR fuel plates. Each fuel element is contained within a corresponding FHE and ATR loose plates are contained within the LFPB. The objective of the structural review is to verify that the structural performance meets the requirements of 10 CFR Part 71, including performance under the tests and conditions for normal conditions of transport (NCT) and hypothetical accident conditions (HAC).

2.1 Structural Design

2.1.1 Description of Structural Design

The packaging is made of two principal structural components: the body assembly and the package closure lid. The packaging has two secondary structural components depending on the type of fuel being shipped: a FHE specific to an ATR, MIT, or MURR fuel assembly, or an ATR LFPB.

The body assembly is a single weldment structure that provides protective structural support as well as thermal protection of the unirradiated fuel. It is comprised of a square, thin-walled tube outer shell and an interior cylindrical shell which houses the contents. The interstitial space between the inner and outer shells is lined with ceramic fiber insulation.

The closure lid is fabricated with integral steel tabs that fit into the machined head ring on the body assembly. When rotated relative to the long axis of the body assembly, the tabs, or bayonets, achieve a positive closure. In addition to this mechanical interlock, the lid is fitted with two spring loaded pins that engage mating holes machined into the body assembly head ring.

The ATR, MIT, or MURR FHE is a thin-walled aluminum weldment with a hinged cover plate used to protect an ATR, MIT, or MURR fuel element from handling damage. The MIT and MURR FHEs use ball lock pins and end spacers to lock closed while the ATR FHE uses a spring plunger. The MIT and MURR FHEs restrict postulated fuel element pitch expansion under HAC conditions.

The LFPB is comprised of four essentially identical machined segments joined by permanently installed threaded fasteners. For the criticality analysis, the LFPB is design to keep the loose ATR plate contents within a defined dimensional envelope under NCT and HAC conditions.

2.1.2 Design Criteria

The applicant demonstrated structural performance of the package by both physical testing and calculations. Section 2.1 of the application summarizes the structural design criteria for the package, including codes and standards. The identified design objectives for this package are as follows:

1) For NCT, the package prevents dispersal of the contents and maintains its structural integrity to withstand the Hypothetical Accident Conditions (HAC).
2) For HAC, the package prevents dispersal of the contents and maintains a structural configuration within the bounds considered in the criticality evaluation.
3) For HAC, the package performance demonstrates that the thermal insulating material remains in place such that the thermal evaluation remains valid.

Other miscellaneous structural failure modes such as brittle fracture, fatigue, and buckling were evaluated and found by the applicant to be satisfactory. The staff agrees that brittle fracture and buckling were adequately characterized and evaluated.

2.1.3 Weights and Centers of Gravity

The maximum gross weight of the package is 290 pounds. Table 2.1-1 of the application summarizes weights of individual parts of the package and their weights depending upon the ATR, MIT, or MURR fuel types. Regardless of payload, the center of gravity remains 35 inches from the face of the closure end and 4 inches from the bottom and sides of the package.

2.1.4 Codes and Standards

As specified in the packaging drawings, the following codes and standards are applicable to the package design and fabrication:

(1) Structural materials which are Important To Safety (ITS) are specified using ASTM standards.
(2) Welding procedures and personnel are qualified in accordance with the ASME Code, Section IX.
(3) Welds are visually examined on each pass per the requirements of AWS D1.6:1999 for stainless steel, and AWS D1.2:2003 for aluminum.
(4) Welds that are ITS are examined by liquid penetrant test on the final pass using procedures compliant with ASTM E165-02.

2.2 Material Properties and Specifications

The unirradiated ATR, MIT, or MURR fuel element is enclosed in its respective housing (ATR, MIT, or MURR FHE) for handling purposes. The aluminum cladding material is ASTM B209, 6061-T0 and ASTM B209 6061-T651. All aluminum alloys are modeled as pure. There is no plutonium in the package, so special requirements for plutonium shipments do not apply. The requirements of 71.33(b)(3) are met.

The package is fabricated primarily of Type 304 stainless steel, 5052-H32 and 6061-T651 aluminum, ceramic fiber insulation and neoprene rubber. There is no moderator or neutron absorption material in the package (71.33(a)(5)(ii)). The requirements of 71.33(a)(5) are met. The contents may be wrapped in polyethylene for product protection before being placed in the package. Neoprene pads are used to protect the fuel element from damage. Materials of construction have been designated on the drawings.

Steel components are joined using full-thickness fillet welds, and full and partial penetration groove welds. The weld consumable material is ASTM Type 308-308L, which results in weld metal deposits which have properties at least as great as the base metal. The welds are needed for structural stability and have no containment function. All welds are examined as specified on the drawings. Visual examinations are in accordance with AWS D1.6 Sec. 6, and the dye penetrant examinations are done under ASTM procedure E165-02, "Standard Method for Liquid Penetrant Examination," where indicated on the drawings.

The thermal properties of the packaging and fuel materials used in the thermal analysis are given in Tables 3.2-1 through 3.2-3, and Tables 3.6-3 through 3.6-4 of the application. The thermal conductivity, specific heat, and density of the aluminum and stainless steel were checked, found to be within tolerance, and matched those used in the Thermal Desktop modeling.

The properties of the neoprene could not be confirmed since there are many variations of this material. However, since the neoprene pads do not provide a safety function in transportation, the exact values for the behavior of the neoprene are unimportant.

The thermal expansion coefficients of the Type 304 stainless steel (Section 3.4.3.1 of the application) were checked against the ASME B&PV Code Section II, Part D, for the specified temperatures and found to vary slightly. However, the variance was not big enough to affect the calculations of the differential expansion of the inner and outer tubes by more than 5 percent, and the variance would be in the direction that would mitigate any interference of the tubes. Likewise, the thermal expansion coefficient of the aluminum (Section 2.7.4.2 of the application) was checked and found to be within the appropriate tolerance.

The potential for galvanic, chemical and other reactions has been evaluated (Section 2.2.2 of the application) and found to be insignificant. The stainless steel and its abutting alumina/silica insulation do not interact. There is also no chemical or galvanic action between the stainless steel packaging and the aluminum payload since the payloads are wrapped in a polyethylene sheet that does not melt below 225°F. The requirements of 10 CFR 71.43(d) are met.

There are no radiation effects on the materials of construction with fresh fuel during transportation, and the staff agrees that the requirements of 10 CFR 71.43(e) are met.

The minimum yield and ultimate strengths of the aluminum alloys and stainless steel (Tables 2.2-1 and 2.2.2 of the application) used in the structural analysis to assure meeting the requirements of 71.55(d)(1) and (2) were checked and found to be adequate. Type 304 stainless steel has no ductile to brittle transition at the normal operating temperatures above -40°F. The melting point of the Type 304 stainless steel (2700°F) is well above any temperature the package is expected to experience. The concern with aluminum is not melting (it has a melting point of approximately 1100°F) but, rather, loss of structural strength due to softening and slumping. This occurs at about 200°C (400°F); well above the normal operating temperature of this package.

The long duration operating temperature range of the neoprene seal material was confirmed to be -30°C to 100°C. The application states that the Parker O-Ring handbook supports a short term operating temperature of 525°F, but the maximum short term temperature found in Fig. 2-3 of the handbook has a short term limit of 302°F. Even though there is a large discrepancy, there is no safety consequence to the loss of the neoprene. The requirements of 10 CFR 71.71(b) are met.

2.3 Fabrication and Examination

Section 2.3.1 of the application indicates that the package is fabricated using conventional metal forming and welding techniques and all components are fabricated based on the requirements delineated on the packaging drawings. The applicant states that each component is examined as specified on the packaging drawings. Codes and standards used in packaging fabrication and examination are described above (Section 2.1.4).

2.4 General Standard for All Packages (10 CFR 71.43)

The applicant demonstrated structural performance of the package by analysis using both calculations and full scale testing. Calculations are used primarily for evaluating the lifting and tie-down devices while full scale testing is used for the package dynamic response to NCT and HAC drop tests.

2.4.1 Minimum Package Size

The overall package dimensions, approximately 8 inches square and 74 inches in length, are greater than the minimum overall dimension of 4 inches. Therefore, the package meets the requirements of 10 CFR 71.43(a) for minimum size.

2.4.2 Tamper-Indicating Features

The package is equipped with one small post on the closure lid and two small posts on the package body to facilitate two possible closure orientations. A wire cable tamper indicating lock wire and seal is looped through holes in the small posts.

The package cannot be opened by an unauthorized person without damaging the seal. This satisfies the tamper-indication requirement of 10 CFR 71.43(b).

2.4.3 Positive Closure

The closure lid assembly is fabricated with integral steel tabs that fit into the machined head ring on the body assembly and, when rotated relative to the long axis of the body assembly, achieves a positive closure (so-called bayonet closure).

In addition to this mechanical interlock, the lid is also fitted with two spring-loaded pins which engage mating holes machined into the body assembly head ring.

Therefore, the containment system cannot be opened unintentionally and the requirements of 10 CFR 71.43 are satisfied.

2.5 Lifting and Tie-Down Standards for All Packages (10 CFR 71.45)

2.5.1 Lifting Devices

The package can be lifted in one of two ways: by forklift on a fork pocket equipped pallet or by a sling attached to the overhead lifting equipment. Since the forklift operation involves minimal stress on any structural component of the package, no further analysis was performed for this case. For overhead lifting operations, the applicant calculated a minimum working load of 300 pounds based on the maximum weight of the package and the minimum horizontal sling angle. The applicant then calculated the capacity of the integral structural components for this package which consisted of the welded threaded bar attached to the outer square shell. The applicant assumed a safety factor of three against yielding and applied this factor to the dead load due to the package weight on the weld. The applicant subsequently calculated the combined effects of tension, shear, and bending and determined a margin of safety of 2.6. Thus, the requirements of 10 CFR 71.45(a) are satisfied.

2.5.2 Tie-Down Devices

The package contains no tie-down attachment points that are integral to the structural design; however, each package does have index lugs that are used to maintain the horizontal position of the package arrangement during transport. As such, only the lateral loads imparted by the conveyance are considered when evaluating the structural integrity of the package. The applicant determined the maximum resultant lateral force by combining the fore-aft and lateral loads and equally applied half of the calculated load to each index lug.

The applicant determined that the fastener, while having a margin of safety of 0.66, would fail at a load that is approximately half of the failure load for the groove weld of the threaded insert. This ensures that the excessive load will not impair the ability of the package to meet other requirements of 10 CFR Part 71. Thus, the tie-down requirements of 10 CFR 71.45(b) are satisfied.

The closure handle, deemed a structural part of the package, is rendered inoperable for lifting or tie-down prior to transport. The handle is either fitted with a fixture that prevents tie-downs from being attached to it or the handle is removed.

2.6 Normal Conditions of Transport (10 CFR 71.71)

2.6.1 Heat

The applicant considers an ambient temperature of 100°F in still air to calculate a maximum package bounding temperature of 186°F. This package contains no seals that serve as a pressure boundary, and as such, the internal gauge pressure is 0 psi. This requires no additional evaluation for structural performance of the package due to internal pressure. The applicant does state that the interstitial space between the inner and outer shell may develop a pressure differential and determines that due to an ideal gas expansion, the maximum pressure change inside this sealed cavity would be less than 4 psi gauge.

Section 2.6.1.2 of the application evaluates differential thermal expansion (DTE) of package components for possible interference resulting from a reduction in longitudinal gap sizes. The staff reviewed the structural performance of the package under the heat condition and concluded that the DTE and stress effects have properly been evaluated.

Thus, the requirements of 10 CFR 71.71(c)(1) are satisfied.

2.6.2 Cold

Section 2.6.2 of the application evaluates the effects of cold environment on the package performance by considering an ambient temperature of -40°F combined with zero insolation, zero decay heat, and zero internal pressure. The applicant states that none of the materials of construction used for structural integrity exhibit a ductile to brittle transition above -40°F.

The staff agrees with the applicant's conclusion that the NCT cold condition is of negligible consequence for this design. The requirements of 10 CFR 71.71(c)(2) are satisfied.

2.6.3 Reduced External Pressure

The ATR FFSC is not designed to retain pressure; therefore, a small external reduction in pressure will result in negligible stress in the package shell.

Thus, the requirements of 10 CFR 71.71(c)(3) are satisfied.

2.6.4 Increased External Pressure

The package is not designed to retain pressure; therefore, an increase in external pressure will result in the same pressure on the package shell. The applicant evaluates the effect of this increased pressure on the internal sealed cavity between the outer and inner shell of the package.

This larger pressure increase (22 psi gauge rather than 20 psi gauge) for HAC does not adversely affect the package structural integrity. Therefore, the requirements of 10 CFR 71.71(c)(4) are satisfied.

2.6.5 Vibration

The applicant demonstrates that vibration has no effect on the placement or condition of the thermal insulation, and that closure is not expected to apply any vibrational loadings to the bayonet lugs.

In addition, the ATR, MIT, and MURR FHEs, and the ATR LFPB are designed to be form fitting, preventing any complete fatigue failure of the FHEs or basket due to transportation vibration.

The applicant concludes that the effects of vibration incident to transport are not significant for the packaging.

2.6.6 Water Spray

Section 2.6.6 of the application notes that due to the materials of construction, the water spray test does not significantly affect the package, and the staff agrees with the applicant's conclusion that the requirements regarding the water spray test of 10 CFR 71.71(c)(6) are satisfied.

2.6.7 4 Foot Free Drop

The applicant performed a single CG-over-corner free drop from a height of 4 feet. Test results indicate that the damage from the drop case is minimal and that there is no loss or dispersal of package contents and no substantial reduction in the effectiveness of the packaging.

The applicant states that, due to the absence of an impact limiting medium, such as a crushable foam, the CG-over-corner NCT drop in conjunction with the HAC drops bound the damage that would be expected for this package.

The staff reviewed these results and agrees with the applicant's conclusion that the package is capable of maintaining its structural integrity, and thus meets the requirements of 10 CFR 71.71(c)(7).

2.6.8 Corner Drop

The package is a rectangular fissile material package weighing more than 110 lbs. Therefore, the corner drop test in 10 CFR 71.71(c)(8) does not apply.

2.6.9 Compression

The applicant demonstrates compliance by analysis and shows that the normal compressive stresses imparted on the sidewalls of the package are one order of magnitude lower than the buckling strength of the package walls. Thus, the requirements of 10 CFR 71.71(c)(9) are satisfied.

2.6.10 Penetration

The applicant demonstrates compliance by comparison with the more severe HAC puncture bar evaluation. Due to the fact that the drop heights are identical and more energy is imparted to the package during the HAC test, it can reasonably be concluded that the HAC puncture test bounds the NCT penetration test.

Thus, the staff agrees with the applicant's conclusion that the package need not be evaluated explicitly for the NCT penetration for satisfying the requirements of 10 CFR 71.71(c)(10).

2.7 Hypothetical Accident Conditions (10 CFR 71.73)

2.7.1 9-Meter Free Drop

Section 2.7.1 of the application presents a structural evaluation of the package with an ATR payload by analysis for the HAC 9-meter (30-foot) free drop tests.

Two certification test units were constructed to evaluate the effects of a 30-foot drop on the package performance. The applicant presents results for three different package orientations (bottom end drop, side drop, and CG over top corner drop), two temperature regimes (ambient and cold), and two ATR payload conditions. The test matrix was arranged such that all credible package configurations and conditions would be bounded by the test series. Some tests were repeated due to misalignments during impact such that the desired test orientation was achieved. The package exhibited damage within expected ranges. In no case was the package compromised so that the assumptions used in the criticality evaluation were modified, nor was any fissile material exposed or ejected from the payload cavity. The insulating material exhibited no major damage or redistribution thereby allowing the material to perform its required function of thermal protection.

Regarding an MIT or MURR payload, the MIT and MURR FHEs restrict postulated fuel element pitch expansion under HAC conditions. The applicant states that the energy attenuation afforded by the end spacers is not considered in the structural analysis. As such, the FHEs are exposed to the same loading conditions with or without the spacers. Therefore, by assuming that the MIT or MURR FHE spacers fail with no energy absorption, the impact velocities of the respective FHEs on the end fitting of the package are nearly identical. Under end drop conditions, the damage to the MURR or MIT fuel elements is bounded by the damage sustained by the ATR fuel element in the structural drop tests which have demonstrated that the ATR fuel element survives the impact loads with minimal damage that has no impact on reactivity. Also, the applicant considers for conservatism a fuel element plate pitch that expands beyond the maximum possible extent allowed by the FHE to evaluate the potential worst case increase in reactivity for MURR and MIT fuel elements.

The 30-foot free drop tests, in aggregate, as demonstrated by the full scale testing, satisfy the requirements of 10 CFR 71.73(c)(1).

2.7.2 Crush

The application notes that the crush test must be performed on fissile material packages which have a mass less than 1100 lbs and a package density less than 62.4 lb/ft^3. Since this package has a density of 108 lb/ft^3, the crush test does not apply. The requirements of 10 CFR 71.73(c)(2) do not apply.

2.7.3 Puncture

The applicant determines three failure modes that are evaluated by the puncture test: (1) failure of locking pins which prevent lid rotation; (2) outer shell penetration; and (3) lid rotation. These failure modes were tested by an axial drop, an oblique 30-degree side drop, and an oblique drop onto the lid ribs. These tests showed no significant damage beyond some denting and scratching of the package. With regard to the closure lid, no locking pins were sheared and no relative rotation of the lid with respect to the package body was observed.

This demonstrates adequate structural integrity of the package to meet the 10 CFR 71.73(c)(3) requirements.

2.7.4 Thermal

Section 3.0 below describes the thermal performance of the package. The effects of the thermal test are evaluated with respect to internal pressure and differential thermal expansion. The applicant demonstrates that, since this is not a sealed package, internal pressures are not critical to the structural integrity of the package. Differential thermal expansion is evaluated by analysis and the applicant determines that there is no interference for worst-case temperature conditions. This satisfies the requirements of 10 CFR 71.73(c)(4).

2.7.5 Immersion - Fissile Material

The applicant states that optimal moderation is considered in the criticality evaluation and the package exhibits no loss of payload material under the accident conditions test sequence, therefore, the intent of 10 CFR 71.73(c)(5) is met.

2.7.6 Immersion - All Packages

With regard to water in-leakage and loss of payload material, the intent of the immersion test requirement is met as described above in Section 2.7.5 above. The applicant does evaluate the sealed inner cavity for an equivalent pressure due to immersion under 50 feet of water. The conclusion is that the 21.7 psig pressure was insignificant to the structural integrity of the package. Therefore, the structural performance of the package satisfies the water immersion test requirements of 10 CFR 71.73(c)(6).

2.7.7 Deep Water Immersion Test

This test is not applicable, since the package is a Type A Fissile package, as specified in 10 CFR 71.61.

2.8 Conclusions

On the basis of the review of the statements and representations in the application, the staff concludes that the package is adequately described and evaluated to demonstrate its structural capabilities meet the requirements of 10 CFR Part 71.

3.0 THERMAL

3.1 Thermal Design Features

Design features include the body and closure which serve as the primary impact and thermal protection for the package internals (the Fuel Handling Enclosure (FHE) or the Loose Fuel Plate Basket (LFPB)) and their respective enclosed payloads. The body consists of two nested shells; three, 1-inch thick ribs are attached to the inner shell by fillet welds, but the ribs are not attached to the outer shell to help thermally isolate the inner shell from the outer shell during the fire test. A nominal 0.06 inch air gap exists between the ribs and the outer shell, with a larger nominal gap existing at the corner of the ribs. The inner tube is wrapped with two, ½ inch thick, layers of ceramic fiber thermal insulation as shown on Figures 1.2-2 and 1.2-3 of the application which is overlaid with 28 gauge stainless steel sheet, maintaining the insulation around the inner shell. Thermal insulation is also built into the bottom end of the package.

The closure weighs approximately 10 pounds and provides 1 inch of ceramic fiber thermal insulation at the closure end which can be seen in Figure 1.2-4 of the application. The closure engages the body by a bayonet closure system, and does not include a seal.

The ATR, MIT, and MURR FHEs are used to protect the fuel element from damage during loading and unloading operations. A polyethylene plastic bag may be used as a protective sleeve over the fuel element. The ATR FHE weighs approximately 15 pounds and is fabricated from 0.09 inch thick unfinished 5052-H32 aluminum sheet. The MIT FHE weighs approximately 25 pounds and is fabricated from 3 inch thick unfinished 6061 aluminum. The MURR FHE weighs approximately 30 pounds and is fabricated from 3 inch thick unfinished 6061 aluminum. All types of FHE have a hinged lid and neoprene rub strips to minimize fretting of the fuel element side plates where they contact the FHE.

The LFPB weighs approximately 30 pounds, is machined from 6061-T651 aluminum, and serves to maintain the fuel plates within a defined dimensional envelope during transport. A variable number of ATR fuel plates may be housed in the basket with the maximum payload weight being limited to 20 pounds. Like the FHE, the surface of the LFPB is left with its “as machined” finish.

3.1.2 Decay Heat

The decay heat for unirradiated fuel is negligible and therefore no special devices or features are needed to dissipate the decay heat.

3.2 Summary Tables of Temperatures and Pressures

Table 3.6-1 of the application provides a summary of the maximum package component temperatures achieved under NCT and HAC for either the MIT or MURR fuel element payloads. These temperatures are bounded by those reported in Table 3.1-1 “Maximum Temperatures for NCT and HAC Conditions” for the ATR fuel element.

The results indicate that significant thermal margins exist for all package components for NCT conditions and that the design of the package provides sufficient thermal protection during HAC conditions.

Table 3.1-1 Maximum Temperatures for NCT and HAC Conditions					
Location / Component		NCT Hot Conditions (°F)	Accident Conditions (°F)	Maximum Allowable	
				Normal (°F)	Accident (°F)
ATR Fuel Element Fuel Plate		147	690	400	1100
ATR Fuel Element Side Plate		148	786	400	1100
Neoprene Rub Strips/Polyethylene Bag		151	975	225	N/A
Fuel Handling Enclosure (FHE)		151	975	400	1100
Loose Fuel Plate Basket (LFPB)		151	712	400	1100
Inner Shell		157	1377	800	2700
Ceramic Fiber Insulation, Body	Maximum	185	1411	2300	2300
	Average	151	1176	2300	2300
Ceramic Fiber Insulation, Closure	Maximum	145	1376	2300	2300
	Average	144	1254	2300	2300
Closure		145	1402	800	2700
Outer Shell		186	1427	800	2700

Table 3.1-2 in the application shows the maximum pressures under the NCT heat test and under HAC for the fuel cavity (0 psi gauge for both because the package cavity is vented to atmosphere) and the outer/inner shell cavity maximum pressure (4 psi gauge and 38 psi gauge respectively).

3.3 Thermal Evaluation for Normal Conditions of Transport

The applicant considers an isolated horizontal package in order to analyze its thermal performance under NCT and yield the bounding maximum and minimum temperatures achieved by any package in a stack of multiple packages.

The applicant provides temperature-dependent material properties for all major components of the package as well as acceptable temperature ranges of operation (minimum and maximum allowable values) in Section 3.2 of the application. Anisotropic thermal conductivities for each of the fuel plates are separately derived using a “k effective” approach, described in Section 3.5.2.4 of the application. The ATR, MIT, and MURR fuel plates are a composite material consisting of a fissile fuel matrix sandwiched within aluminum cladding. The fuel composite is treated as a homogeneous material with lumped thermal properties. Thermal properties for each individual plate making up the ATR, MIT, and MURR fuel element are presented in Table 3.5-1 for the 19 plates of the ATR fuel, Table 3.6-8 for the 15 plates of the MIT fuel element, and Table 3.6-9 for the 24 plates of the MURR fuel element respectively.

Using the Thermal Desktop® and SINDA/FLUINT computer programs, the applicant constructs a 1/4 symmetry model of a loaded ATR package. Inside the package, both conduction and radiation are allowable means of heat transfer. Heat is exchanged with the surrounding environment through convection and radiation.

As the decay heat of the payload is negligible, the only heat input to the package under NCT is solar insolation, which the applicant models using a diurnal cycle described in Section 3.5.2.1 of the application. The applicant models the NCT hot case with insolation. The case without insolation is deemed trivial, as there is no heat input to the package. Similarly, the NCT cold case with an ambient temperature of -40°F is also considered trivial. In both cases, all parts of the package could be assumed to reach the ambient temperature with no adverse effects.

The applicant shows that component temperatures are within operational limits, even when insolation is accounted for. The applicant also demonstrates that the accessible external surface temperature remain below the regulatory limit in 10 CFR 71.43(g) of 122°F (50°C) without insolation, as required for packages under nonexclusive use.

Figures 3.3-1 and 3.6-1 in the application show the transient temperatures of the significant package components under NCT with solar insolation with an ATR or MIT payload respectively.

Figures 3.3-3, 3.6-2 and 3.6-3 illustrate the predicted temperature distribution within the package at the time of peak temperature for an ATR, MIT, and MURR fuel element respectively.

3.4 Thermal Evaluation for Hypothetical Accident Conditions

Section 3.4 of the application presents the predicted system temperatures and pressures for the package under the HAC thermal test specified in 10 CFR 71.73(c)(4). Section 3.6-8 of the application presents the predicted system temperatures and pressures for the MIT and MURR payload.

The applicant analyzes two HAC cases, one with an ATR, MIT, or MURR fuel element FHE, and the other replacing the loaded FHE with an unloaded LFPB. The unloaded LFPB is conservative since the addition of a payload serves to increase the thermal mass of the basket and therefore reduces its temperature rise under the HAC transient conditions. The HAC transient analysis is continued for 11.5 hours after the end of the fire to ensure that all package components reached their peak temperatures.

3.4.1 Initial Conditions

Based on the results from the free and puncture drop events that are assumed to precede the HAC fire, the HAC model is a modified version of the quarter symmetry NCT model.

Modifications include the removal of a 1.85 inch long segment of insulation between each set of ribs to conservatively bound what was observed in the end drops, and the revision of the surface emissivities for various components of the package due to sooted/oxidized conditions.

3.4.2 Fire Test Conditions

The initial ambient conditions are assumed to be 100°F ambient with no insolation. A fully engulfing fire consisting of 1475°F ambient with an effective emissivity of 0.9 at the start of the fire is used to simulate the average flame temperature of the hydrocarbon fuel/air fire event. The convection heat transfer coefficients between the package and ambient during the 30-minute fire are based on an average gas velocity of 10 m/sec. Following the 30-minute fire event, the convection coefficients are based on still air. The ambient condition of 100°F with insolation is assumed following the 30-minute fire event. A solar absorptivity of 0.9 is assumed for the exterior surfaces to account for potential soot accumulation on the package surfaces.

3.4.3 Maximum Temperatures and Pressure

The maximum temperatures of the package components for the HAC thermal test are summarized in Table 3.4-1 of the application for an ATR fuel payload, in Table 3.6-6 for an MIT payload and in Table 3.6-7 of the application for a MURR payload.

The results show that the maximum temperatures of the package components are all considerably lower than the maximum allowable temperatures. The smallest temperature margin for the HAC thermal test occurs in the FHE, which reaches a maximum temperature of 975 °F versus an HAC temperature limit of 1100 °F. It is expected that the neoprene rub strips and polyethylene bag used as a protective sleeve for the ATR, MIT or MURR fuel will experience thermal degradation due to the level of temperature achieved, but these components are not critical to the safety of the package and any out-gassing associated with their thermal degradation does not contribute to package pressurization since the payload cavity is vented.

Figures 3.4-1 and 3.4-2 of the application show the transient thermal response of the package components with an ATR payload during the 30-minute fire and during the 11.5 hours after the end of the fire. Figures 3.6-4 and 3.6-5 of the application show the transient thermal response of the package with an MIT and MURR payload. Figure 3.4-3 shows the temperature distribution at the end of the 30-minute fire, while Figure 3.4-4 shows the temperature distribution at the peak ATR fuel element temperature which is at approximately 22 minutes after the end of the fire. Figures 3.6-6 and 3.6-7 of the application show the temperature distribution at the time of peak MIT and MURR fuel temperature respectively.

The thermal performance of the package with either the MIT or MURR payload is similar to that seen for the ATR payload.

The payload cavity of the package is vented to the atmosphere; therefore, there is no internal pressure in the package cavity under HAC. Because the volume between the outer and inner shells is sealed, the maximum pressure rise within the sealed volume is less than 38 psig.

3.4.4 Maximum Thermal Stresses

The temperature difference between the inner and outer shells during the HAC event results in differential thermal expansion between the shells. The largest positive differential thermal expansion between the outer and inner shell takes place at approximately six minutes of exposure to the fire and is equal to 0.9 inch. The largest negative differential thermal expansion between the outer and inner shell takes place at approximately seven minutes after the end of the fire and is equal to 0.25 inch. The result of this variation in differential thermal expansion may take one of three forms: (1) the outer shell buckles outward; (2) the outer shell buckles inward; or (3) the weld attaching the inner shell to either the closure plate or the bottom end plate fails and permits the outer shell and the affected plate to move freely.

The outer shell buckling outwards is seen as likely, but will act to lower the rate of inward heat transfer, thus the HAC thermal model, which ignores the buckling, yields conservative results. The outer shell buckling inwards will leave 0.5 inch or more of insulation separating the inner shell from the outer shell; therefore, no significant impact on the predicted peak HAC temperatures occurs. If the differential thermal expansion causes failure of one of the welds attaching the inner shell to the closure and bottom end plates, potential pressure buildup between the inner and outer shells is released, and the outer shell and the associated end plate extend away from the inner shell at the point of the weld failure. The likely and worst case scenario is that the movement of the outer shell, the insulation jacket, and the insulation will create a gap of approximately 0.9 inch at the interface between the first support rib and the insulation. Combining this gap with an insulation shift at the same locations due to the pre-fire 30-foot end drop could result in a scenario where there is a 0.9 inch gap between the support rib and the insulation jacket and up to a 2.65 inch gap between the support rib and the end of the insulation wrap.

The applicant performed a sensitivity thermal analysis of this geometry and stated that the peak inner shell temperature reported in Table 3.4-1 remains bounding, while the maximum temperature of the ATR fuel element increases by less than 25°F. The thermal impact related to the potential package geometry displacement due to the differential thermal expansion is found not to be significant to the safety of the package.

3.5 Confirmatory Analysis

The staff modeled and meshed the package geometry using ANSYS 11.0, based on the design drawings in Appendix 1.3 of the application. Material properties were used from Section 3.2 of the application. NCT and HAC cases were run and confirmed that the package design provides sufficient thermal safety margins for all its components.

3.6 Convection Coefficient Calculation

The applicant uses SINDA to compute natural convection from each surface based on semi-empirical relationships using the local Rayleigh number and the characteristic length for the surface. Correlations are given for natural convection from a vertical surface and for heated or cooled horizontal surfaces facing upward or downward. Correlations are also given for forced convection applied during the HAC fire event.

3.7 Conclusions

NRC staff identified a potential non-compliance with the regulations regarding the HAC fire outlined in 10 CFR 71.73(c)(4). Specifically, the applicant had reduced the fire temperature for radiative heat transfer to the package from 1475°F, as specified in the regulations, to 1425°F. The staff re-ran the thermal calculations with the appropriate fire temperature and confirmed that all package component temperatures remained within limits. Therefore, the staff has reasonable assurance that the package meets the requirements of 10 CFR 71.73 for HACs.

Based on the staff's review of the thermal sections of the application, the staff finds reasonable assurance that the package meets the thermal standards of 10 CFR Part 71.

4.0 CONTAINMENT

Section 1.2.2 of the application provides a description of the contents. The radioactive material consists of uranium enriched to a maximum 94 weight percent ^{235}U. The maximum contents of ^{234}U (1.2 weight percent) and ^{236}U (0.7 weight percent) are also specified. The maximum fissile mass per package is 1200 grams ^{235}U, which is for an intact ATR fuel element.

4.1 Description of the Containment System

The fissile material is contained within the fuel plate cladding. The fuel element and fuel plates are retained within the package by the package body and closure. The package is composed of a double-walled stainless steel body, with a stainless steel closure. The closure, by way of a bayonet closure, with four bayonets rotated into slots in the body top flange, is maintained in the secured position by two spring loaded pins in the closure that fit into the body top flange. There is no containment system gasket or seal.

The contents are positioned within internals (FHE for ATR, MIT, or MURR fuel elements and the LFPB for loose ATR fuel plates), but these components do not provide a containment function for the fuel.

4.2 Containment Under Normal Conditions of Transport

Section 4.2 of the application describes the containment under normal conditions of transport. The full scale testing of the package demonstrated that there was no release of radioactive material under normal conditions of transport tests.

4.3 Containment Under Hypothetical Accident Conditions

Section 4.3 of the application addresses containment under hypothetical accident conditions. Because the package is limited to a Type A quantity, release of radioactive material is not restricted except to maintain criticality safety.

In addition, the physical testing demonstrates that the package retains the fuel elements or loose fuel plates under hypothetical accident conditions events sufficient to maintain criticality control.

The staff agrees that the package meets the containment requirements in 10 CFR Part 71 for a Type AF package.

5.0 SHIELDING

The package is monitored for both gamma and neutron radiation to demonstrate compliance with 10 CFR 71.47 prior to shipment. Because there are no shielding components, incorporated into this package design, that could be affected by accident conditions, the applicant states that the one-meter dose rate under accident conditions is essentially the same as the one-meter dose rate measured prior to shipment.

The staff agrees that the package design meets the external dose rate standards in 10 CFR Part 71.

6.0 CRITICALITY

6.1 Description of Criticality Design

The package is designed to contain a single ATR, MIT, or MURR fuel element in an aluminum fuel handling element (FHE) or a collection of loose ATR fuel plates in an aluminum loose fuel plate basket (LFPB). The package is composed of a 6 inch (outer diameter) stainless steel cylindrical tube surrounded by 1 inch thick insulation in an 8 inch x 8 inch stainless steel square tube 72.5 inches in length. The package closure seats into the end of the packaging and engages the packaging using four lugs in a bayonet-style design. The closure does not have any gaskets or seals. There are no neutron poisons in the package. Neoprene, a material with neutron moderating properties, is attached to the inside of the FHE to minimize fretting of the fuel element side plates. With the use of a separate FHE and LFPB, there is the potential for preferential flooding in the package. Further, there is void space between the insulation and outer package wall in the corner areas of the package. Package tolerances are described on the engineering drawings included in the application.

The applicant provides tables summarizing the results of the criticality evaluation for a single package and arrays of packages with both content types under NCT and HAC. Tables 6.1-1 and 6.1-2 for an ATR fuel element payload or loose ATR plates payload, and Table 6.10-1 for MIT and MURR fuel elements, show that the applicant's calculated maximum k-effective values, including two standard deviations, are less than the Upper Subcritical Limit (USL). The applicant's USL, including the administrative margin and bias, is 0.9209.

The applicant uses a 9x9x1 array and a 5x5x1 array of packages for the NCT and HAC array calculations, respectively. For the purposes of determining a Criticality Safety Index (CSI), the HAC array is the most limiting. The applicant calculates a CSI of 4.0. Based upon the applicant's analysis and staff's confirmatory calculations, the staff finds that the applicant correctly derived the package CSI and that a CSI of 4.0 is appropriate for the package.

6.2 Fissile Material Contents

The applicant describes the proposed contents in Sections 1.2.2, 6.2 and 6.10.2 of the application.

The ATR fuel element has a maximum uranium enrichment of 94 weight percent ^{235}U and a fissile mass limit of 1200 grams ^{235}U. There are four types of the ATR Mark VII fuel elements that may be loaded into the ATR FFSC package, all types being of the same construction with only variations in the content of the fuel matrix. One type (the type used in the analysis as the bounding fuel element contents) has 19 fuel-bearing plates without burnable poison; two types have multiple fuel plates with boron as a burnable poison; and the fourth type replaces the nineteenth fuel plate with an aluminum alloy plate. The latter type of fuel element may also have side plates with a slightly reduced width. The fuel is in the form of uranium aluminide mixed with additional aluminum and clad in an aluminum alloy. Fuel element side plates are also made from an aluminum alloy. Contents may be placed in a plastic bag prior to loading into their respective Fuel Handling Elements (FHE) and into the ATR FFSC package. The criticality evaluation considers the bagging of the contents and the FHE for the potential for preferential flooding.

The MIT fuel element contains up to 515 g ^{235}U enriched up to 94 weight percent with each fuel element containing 15 flat fuel plates. The MURR fuel element contains up to 785 g ^{235}U enriched up to 94 weight percent with each fuel element containing 24 curved fuel plates. For both the MIT and MURR fuels, the fuel meat is a mixture of uranium metal and aluminum, while the cladding and structural materials are an aluminum alloy.

The loose ATR plate payload is limited to 600 grams ^{235}U. The applicant states that, for handling convenience, a given payload of loose fuel plates will contain only flat plates or curved plates, but not a combination of flat and curved plates. All loose plate content is confirmed to meet the 600 gram ^{235}U mass limit during loading operations. Additional aluminum plates, used as dunnage, may be included with the loose plate contents; however, this material is neglected in the criticality analysis.

The applicant provides the nominal dimensions and tolerances for the fuel plates, fuel element side plates and the channels between fuel plates in an assembled fuel element as well as the fuel mixture densities for each fuel plate in Sections 6.2 and 6.10.2 of the application. These dimensions are based on Drawings No. 405400, Rev. 19, 409406, Rev. E, 409407, Rev. N, 410368, Rev. A, and 419486, Rev. A. Sketches are included in the application (see Figure 6.2-1 for ATR fuel, Figure 6.10-1 for MURR fuel, and Figure 6.10-2 for MIT fuel element dimensions) showing the dimensions and tolerances that are important to the criticality evaluation.

Staff reviewed the dimensions provided by the applicant and finds them to be consistent with or bounded by those used in the applicant's analysis. Staff reviewed the fuel mixture mass and atom densities and finds them to be consistent. Staff reviewed the fuel element and plate descriptions and the ^{235}U enrichment and mass limits.

Based on the applicant's analysis and confirmatory calculations, the staff finds the proposed contents limits to be acceptable. Due to the large margins in the analysis, no additional parameter limits are found to be necessary to include in the certificate.

6.3 General Considerations

6.3.1 Model Configuration

The staff reviewed the applicant's model descriptions in Section 6.3.1 and 6.10.3 of the application. These models take into account the effects of the NCT and HAC tests specified in 10 CFR 71.71 and 71.73. The staff's review of the test results is described in Sections 2 and 3 above. Additionally, the applicant neglected the FHE for the ATR fuel element contents, and the LFPB material beyond the portion forming the rectangular cavity of the basket in both the NCT and HAC models. The loose plate contents analyses are performed with the ATR plate type.

The applicant performs NCT analyses with both the ATR fuel element and ATR loose plate contents and assumed optimum moderation. The applicant used the contents and packaging tolerances that maximize reactivity. Moderator was assumed only in the package cavity since there is no damage to the package such that water can access the gap between the insulation and the outer steel wall of the package due to the NCT conditions tests. Additionally, analyses for the HAC array indicate that inclusion of moderator between the cavity and outer package steel tubes reduces system reactivity. The applicant's NCT array models also include rotation of and shifting of the contents to the center of the array. The impact of neoprene was also examined. The analyses include preferential moderation; the applicant justified the sufficiency of this approach as encompassing the effects of the ATR FHE due to the FHE's approximately conforming to the fuel element's shape and the inclusion of the FHE resulting in greater distance between contents in the array. For the MURR and MIT contents, the respective FHE was included in the model. The FHE tolerances that maximize reactivity were included in the analysis. The staff reviewed the applicant's analysis models, and, based upon the information provided by the applicant as well as its own confirmatory calculations, the staff finds the model configurations and analysis to be acceptable.

For the ATR fuel element, the models do not account for the slight buckling of the fuel element plates that was observed upon inspection of a package tested with the fuel element contents.

The applicant determined that such buckling was localized to the ends of the fuel element and the openings in the side plates where the fuel plates are not supported and that the effect on overall system reactivity would be small. Staff reviewed this determination and, based upon the applicant's descriptions of the deformation as being localized to small areas as well as the large margin to the USL and conservatisms built into the model (such as modeling of the fuel plates at the most reactive thickness, accounting for tolerances), finds this modeling assumption acceptable. Modeling of the ATR loose plate contents also neglected the buckling of the plates that resulted from the package tests (i.e., no damaged plate models were developed). This buckling was confined to the ends of the loose plates and did not affect the entire length of the plates. The NCT analyses optimize the pitch of the loose plate contents, determining reactivity at the optimum separation of the plates; due to the similarity between the NCT and HAC models, this same optimum plate separation is used in the HAC analysis models as well. The staff finds that this HAC analysis method bounds, as is noted by the applicant, the reactivity affects that would be introduced by the buckling identified in the package test inspections.

For the HAC calculations with MURR and MIT fuel elements, the applicant assumes that the FHE splits open, expanding to the maximum extent possible in the package cavity. Also, in the array, the FHE was shifted toward the array center. The applicant also assumes uniform expansion of the pitch of the fuel element plates to the maximum extent allowed by the expanded FHE cavity with the side plates lost for the MURR fuel and stretched for the MIT fuel. Based upon the structural evaluation, this expansion of the FHE and the fuel element bounds any damage the FHE and fuel element would sustain under HAC conditions; the MIT and MURR fuel elements should only experience a limited amount of damage, similar in extent to that experienced by ATR fuel elements.

6.3.2 Material Properties

The staff reviewed the material properties used in the criticality analysis. As stated in Section 6.2 above, the staff found the atom densities and mass densities of the fuel mixtures to be consistent. Staff determined that the atom densities are consistent with the ^{235}U masses listed for the ATR fuel plate type in Table 6.2-1 of the application and that the computation of the total density of the MURR and MIT fuel matrix was correct. For the ATR loose plate contents analysis, the fuel mixture atom densities are modified to ensure that the ATR plate type would result in a maximum payload of 600 g ^{235}U (with an integer number of plates).

Properties for the other materials included in the models are described in Sections 6.3.2 and 6.10.3.2 of the application. The applicant provides neoprene properties and performs analyses with neoprene present. Based upon the HAC analysis for the single package, the applicant ignores the chlorine component of the neoprene and reduces the material's density accordingly. This modified neoprene is used in the remaining analyses, as appropriate. The staff finds these material properties to be acceptable and consistent with the packaging and contents' actual properties.

6.3.3 Computer Codes and Cross Section Libraries

The applicant evaluates the package using MCNP5 v1.30, a three-dimensional Monte Carlo code with continuous-energy neutron cross sections developed by Los Alamos National Laboratory and used extensively in a variety of criticality safety evaluations. The staff finds that this code is appropriate for the present analysis.

The applicant uses the most up-to-date cross section libraries for the model materials that are available in MCNP. These libraries were derived from ENDF/B-V, VI, and VII cross section data. For water, the applicant uses the appropriate code option to simulate hydrogen bound to oxygen for the hydrogen cross sections. Calculations were run so that the results have a standard deviation of approximately 0.001.

The staff finds the applicant's use of the code acceptable. The application contains two sample input files which staff reviewed to confirm that the model inputs were consistent with the descriptions in the application.

6.3.4 Demonstration of Maximum Reactivity

The applicant performs several calculations for the ATR fuel element contents for a single package and for arrays of packages with either ATR intact fuel elements or ATR loose plates. Staff reviewed the applicant's analyses and finds reasonable assurance that the most reactive configuration of the package for single packages and the package arrays are identified. Optimum moderation conditions are identified, and appropriate consideration is given regarding preferential flooding.

For the HAC package arrays for the MURR and MIT fuel element contents, some configurations are not considered. One configuration is non-uniform pitch expansion. With the loss of fuel element integrity as assumed in the applicant's criticality analysis, non-uniform expansion of the pitch should be considered. Also, the effects of having 'stretched' element side plates versus neglecting the side plates are not addressed; MURR calculations neglect side plates while MIT calculations include 'stretched' side plates.

Additionally, staff notes that neoprene is kept in the HAC arrays for MURR fuel, while the HAC single package showed the absence of neoprene to be more reactive. However, given the margin to the USL of the identified most reactive case, the level of sensitivity to the presence of the neoprene in the HAC single package calculations and the conservative nature of the assumptions regarding the fuel element damage due to HAC conditions, as evaluated in Section 2 above, the staff finds the identified maximum reactivity for the HAC package arrays to be acceptable.

Further descriptions of these analyses and their results are provided in Sections 6.4 through 6.6 below.

6.3.5 Confirmatory Analyses

Staff performed a number of independent calculations to confirm both the applicant's results and that the most reactive conditions had been correctly identified. Staff calculations were performed with the CSAS26 criticality sequence of the SCALE 5.1 suite of codes. SCALE 5.1 was developed by Oak Ridge National Laboratory for use in criticality and shielding analyses. The CSAS26 sequence is a criticality sequence that uses KENO-VI geometry and multi-group cross sections. Staff used the 238-group cross section library derived from ENDF/B-V data. Staff analyses included calculations to confirm appropriate consideration of conditions such as preferential package flooding and the contents and packaging tolerances. Staff also considered the impact of neglecting the neoprene in the MURR model as well as non-uniform expansion of the fuel plate pitch for the HAC array. Staff's analysis results are in close agreement with or bounded by the applicant's results. Staff notes that neglect of neoprene in the HAC array for MURR fuel did increase reactivity, though the increase was small.

6.4 Single Package Evaluation

The staff reviewed the applicant's evaluation of a single package. The single package is modeled with full water reflection on all sides. The fissile material is modeled in the most reactive credible configuration consistent with the condition of the package and contents. For the loose ATR plate contents, the plates are separated to optimize moderation, which occurred for the plates set in a 2x5 array with a non-uniform pitch and full density water throughout the package.

The applicant's results show that a single package is significantly subcritical.

6.5 Evaluation of Package Arrays under Normal Conditions of Transport

The staff reviewed the applicant's analysis of an array of undamaged packages. The analysis includes optimum moderation of both the fuel element and loose fuel plate contents, with the contents rotated and shifted toward the array center. The applicant analyzes a 9x9x1 array surrounded by a full water reflector.

For the loose ATR plate contents, the applicant performs several calculations to determine the most reactive fuel plate and the optimum pitch, or separation, including non-uniform separation.

The most reactive array configuration for the fuel element contents is full density water between the MURR fuel element plates and inside the FHE, 0.4 g/cc water density in the package cavity with neoprene (without chlorine) and insulation present, the FHE wall at its maximum thickness, and void between the steel tubes forming the package cavity and outer wall. For the MIT fuel element contents, the most reactive configuration is similar to that for the MURR fuel element except with 0.6 g/cc water density in the package cavity surrounding the FHE and the FHE wall at its minimum thickness. The second most reactive array configuration is for the ATR fuel element payload with full density water between the ATR fuel plates, and 0.3 g/cc water density inside the inner tube. In both cases, the maximum results are far below the applicant's Upper Subcritical Limit (USL) of 0.9209.

For the loose plate contents, the most reactive configuration is the ATR plate type 5 with an optimized non-uniform separation in the loose plate basket, full density water in the loose plate basket, 0.5 g/cc water density in the package cavity, void between the package cavity and outer steel wall, and insulation present.

Due to the similarity of the NCT and HAC models for the ATR contents (loose plates and fuel elements), the NCT array reactivity exceeds the HAC array reactivity, with the fuel element contents resulting in the highest k-effective for the analysis. For the MURR and MIT fuel elements, the HAC array is more reactive than the NCT array. The maximum k-effective is significantly less than the applicant's USL.

6.6 Evaluation of Package Arrays under Hypothetical Accident Conditions

The staff reviewed the applicant's analysis of an array of damaged packages loaded with ATR fuel elements. The package array (a 5x5x1 array) was surrounded by a full water reflector. The contents were oriented and shifted toward the center of the array. The applicant included the outer tube of the packaging in its analysis. Tolerances were used in the analysis to maximize reactivity. Based upon the structural evaluation (see Section 2 above), the HAC tests resulted in only localized deformation of the package; i.e., there is no overall deformation of the package that would increase system reactivity. Therefore, the staff finds the analytical model to be acceptable. The analysis also includes the impact of the insulation. For the ATR fuel element contents, the most reactive conditions were full density water between fuel plates, 0.7 g/cc water density in the package cavity, void between the package cavity and outer steel wall, and neoprene (without chlorine) and insulation present. For the loose ATR plate contents, the most reactive conditions were full density water in the loose plate basket, 0.8 g/cc water density in the package cavity, void between the package cavity and outer steel wall/tube, and insulation present. As for the NCT array, the HAC array was more reactive for the ATR fuel element contents than for the loose ATR fuel plate contents.

The staff reviewed the applicant's analysis of an array of damaged packages loaded with MIT and MURR fuel elements. As described in Section 6.3 above, the HAC array models assume the MIT or MURR FHE expands to the maximum extent allowed by the package cavity and shifts toward the array center. Also, the MIT or MURR fuel element plates are allowed to expand uniformly to the maximum extent allowed by the FHE. The array size is 5x5x1 packages. Based upon the considerations described in Section 6.3.1 above, the staff finds these HAC models acceptable for the MURR and MIT fuel elements. For the MURR contents, the most reactive conditions are identified as void between the package cavity and outer wall, insulation present, full density water between fuel plates and inside the expanded FHE, maximum FHE wall thickness, neoprene present, and 0.8 g/cc water density in the package cavity surrounding the FHE. For the MIT contents, the most reactive conditions are similar but with the FHE wall at its minimum thickness.

Based upon the structural evaluation (see Section 2 above), the HAC tests result in only localized deformation of the package; i.e., there is no overall deformation of the package that would increase system reactivity.

6.7 Air Transport of Fissile Material

The applicant does not address special requirements for transport of fissile material by air as specified in 10 CFR 71.55(f). Therefore air transport of fissile material is not authorized.

6.8 Benchmark Evaluations

The applicant examined 35 critical experiment cases from 3 experiment series described in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*. The experiments were selected based upon similarity of fuel geometry, fissile isotope, enrichment, and neutron spectrum with the ATR fuel. The applicant evaluates the USL as a function of two experimental parameters, the energy of the average neutron lethargy causing fission (EALF) and the fissile isotope's (^{235}U) number density. The applicant expands the benchmark evaluation to include consideration of other parameters for trends in the USL, clarify the applicability of the selected benchmark experiments, and separately consider those experiments which are most applicable to the package analysis. The applicant selects the minimum USL from this expanded benchmark evaluation (0.9209) as the USL for the package analysis. This USL value is derived from the evaluations of the several parameters for the most applicable experiments, which includes 17 of the 35 experiments considered.

The applicant relies upon the benchmark analysis and resultant USL (0.9209) developed for the ATR fuel to evaluate its applicability to the MIT and MURR fuel elements. Staff continues to note that, with the exception of the EALF, trends in the parameters are determined for only a couple distinct parameter values, especially when only the most applicable experiments are considered. The staff notes that for some parameters (e.g., pitch and channel width) both the MURR and the MIT fuel elements were outside the range of the benchmarks' applicability. In some cases, they were significantly beyond the range of applicability (compared against the width of the range of applicability). Staff also notes that, for parameters where the proposed evaluation was within the range of applicability, the analysis (at the most reactive conditions) was at parameter values where data was sparse. Hence, extrapolation outside the applicable range of experiments as well as interpolation within this range where benchmark results are lacking should be done with care and appropriately account for the uncertainty from a lack of benchmarks in the area of the package analysis.

However, the staff notes the applicant's argument that parameters where the analysis exceeds the range of applicability (e.g., channel width) deal with system moderation, which affects the EALF parameter; the same analysis falls within the range of applicability for the EALF. Based upon a review of the benchmark analysis, including consideration of different methods of determining a USL, the significantly large margin between the USL and the most reactive package cases, and risk-informed considerations, the staff finds the applicant's USL to be acceptable for the proposed analysis. The staff notes, however, that, particularly as margins are reduced, the benchmark analysis should be revisited. This may include adding new experiments, as the number of the most applicable experiments is currently small (only 17).

6.9 Evaluation Findings

The staff reviewed the description of the proposed package design and contents and the applicant's calculation method and results for a single package as well as arrays of packages under NCT and HAC, including the benchmark analysis, as provided in the application. The staff also performed confirmatory calculations as part of the review.

Based on the review of the statements and representations in the application and confirmatory analyses, the staff finds reasonable assurance that the nuclear criticality safety design has been adequately described and evaluated and that the package meets the criticality safety requirements of 10 CFR Part 71.

7.0 PACKAGE OPERATIONS

Section 7.0 of the application provides a description of package operations, including package loading and unloading operations, and preparation of an empty package for shipment. Operations are described for loading either an ATR, MIT, or a MURR fuel element as well as loose ATR fuel plates.

Package loading operations include visual and operational inspections of the empty packaging prior to loading, including damages to the spring plunger for an ATR enclosure or to the ball lock pins and end spacers for MIT and MURR enclosures.

Preparation for transport includes application of a tamper-indicating device, radiation and contamination surveys, package marking and labeling, and vehicle placarding. Package unloading operations include radiation and contamination surveys, inspection for damages and of the tamper indicating device, as well as removal of contents.

The package operations were reviewed and found to be adequate.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Section 8.1 of the application provides a description of the acceptance tests to be performed prior to first use of any packaging. Packaging dimensions, tolerances, general notes, materials of construction and assembly are examined according to the information specified in the packaging drawings. Specifications are provided for the compression spring and roll pin components of the closure locking system and the thermal insulating blanket. Weld examination standards are specified.

Section 8.2 of the application provides the maintenance program for the package. This section specifies that packagings that do not conform to the drawings in the Certificate of Compliance are removed from service. Section 8.2.3 identifies components of the packaging body, the ATR, MIT, or MURR Fuel Handling Enclosures and of the Loose ATR Fuel Plate Basket that are visually inspected prior to each use. The acceptance tests and maintenance program were reviewed and found to be adequate.

9.0 QUALITY ASSURANCE

Section 9 of the application describes the quality assurance program applicable to the package. The ATR FFSC package is anticipated to be used by both U.S. Department of Energy and U.S. Nuclear Regulatory Commission licensed users. Procurement, design, fabrication, assembly, testing, maintenance, repair, modification, and use of the package are done under quality assurance programs that meet all applicable NRC and DOE requirements. The 18 criteria specified in Subpart H of 10 CFR Part 71 were addressed individually.

Based on the review of Section 9, the staff agrees that the quality assurance program as described meets the requirements of Subpart H of 10 CFR Part 71.

CONDITIONS

The following conditions are included in the Certificate of Compliance:

- Fuel elements and fuel plates may be bagged or wrapped in polyethylene.

- Air transport of fissile material is not authorized.

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

  (a) The package must be loaded and prepared for shipment in accordance with the Package Operations in Section 7 of the application.
  (b) The package must be tested and maintained in accordance with the Acceptance Tests and Maintenance program in Section 8 of the application.

CONCLUSION

Based on the statements and representations contained in the application, and the conditions listed above, the staff concluded that the Model No. ATR FFSC package meets the requirements of 10 CFR Part 71.

Issued with Certificate of Compliance No. 9330, Revision No. 1, on June 16, 2009.