SAFETY EVALUATION REPORT
Docket No. 71-9330
Model No. ATR FFSC Package
Certificate of Compliance No. 9330
Revision No. 0

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SUMMARY

By application dated June 27, 2007, as supplemented April 1 and June 24, 2008, the U.S. Department of Energy requested approval of the Model No. ATR FFSC (Advance Test Reactor Fresh Fuel Shipping Container) package as a Type AF package. The package is designed for the transport of a single unirradiated fuel element or unirradiated loose fuel plates for the Advance Test Reactor (ATR). The supplement dated April 1, 2008, superseded, in its entirety, the application dated June 27, 2007.

The packaging is a box-shaped structure composed of three main components: (1) the body, which is a double-walled stainless steel structure, with thermal insulation between the shells; (2) the closure, which is a small disc-shaped end closure with a bayonet style fastener system; and (3) one of two types of internal structures that supports the contents. The outer dimensions of the package are 8-inches square by 74 inches in length, including the handle. 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. The physical tests consisted of full-scale specimens subjected to the normal conditions drop, and 30-foot free drop and puncture tests. 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

U.S. Department of Energy application dated June 27, 2007.

Supplements dated: April 1 and June 24, 2008.

1.0 GENERAL INFORMATION

The Model No. ATR FFSC package is a Type AF package designed for the transport of a single unirradiated fuel element or unirradiated loose fuel plates for the Advance Test Reactor (ATR).

1.1 Packaging

The package is an elongated box-like structure. It has three primary components: (1) the body, which is a double-walled stainless steel structure, with thermal insulation between the shells; (2) the closure, which is a small disc-shaped end closure with a bayonet-style fastener system; and (3) one of two types of internal structures that supports 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 72-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 is composed of circular stainless steel plates with ceramic fiber insulation. The closure 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 is equipped with a handle for ease of installation. The closure does not have a gasket or seal.

The package internals consist of either a Fuel Handling Enclosure (FHE) for holding intact fuel elements, or a Loose Fuel Plate Basket (LFPB) for use when transporting loose fuel plates. The FHE is a hinged thin-gauge aluminum structure that supports the full length of the fuel element. Neoprene pads are positioned to protect the fuel element. The lid is fixed to the base on one side by a full-length, piano-type hinge, and on the other side with a pair of spring plungers that pin into the two end plates. The FHE is for handling and protection of the fuel element, and does not provide a safety function in transport. The LFPB is a full length aluminum structure that restrains the loose 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 (including handle)	74 inches
Packaging weight (without internals)	240 pounds
Maximum package weight (including internals and contents)	290 pounds

1.2 Contents

The package is designed to transport a single unirradiated fuel element or unirradiated loose fuel plates for the Advance Test Reactor (ATR).

1.2.1 Type and form of material

Unirradiated Mark VII Advanced Test Reactor (ATR) fuel. The fuel material is composed of uranium aluminide (UAl_x). The uranium is enriched to a maximum 94 weight percent U-235; the maximum U-234 content is 1.2 weight percent; and the maximum U-236 content is 0.7 weight percent. The fuel is contained in aluminum-clad fuel plates. The fuel meat thickness is a nominal 0.02 inch, and the fuel meat width ranges from approximately 1.5 inches to 3.44 inches. The active fuel length is approximately 48 inches.

For intact fuel elements: Elements are composed of 19 curved plates fitted within aluminum side plates. The maximum mass of U-235 per intact fuel element is 1200 grams. The fuel element must be contained within the Fuel Handling Enclosure, as specified in the packaging drawings.

For loose fuel plates: Loose plates may be flat or curved and may be banded or wire-tied in a bundle. The fuel plates must be contained within a Loose Plate Basket Assembly, as specified in the packaging drawings.

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 not to exceed a Type A quantity

For intact fuel elements: One fuel element.

For loose fuel plates: A maximum of 600 grams U-235.

1.3 Criticality Safety Index 4.0

1.4 Drawings

The packaging is constructed and assembled in accordance with the following Areva Federal Services, LLC, or Packaging Technology, Inc., Drawing Nos.:

60501-10, Sheets 1-5, Rev. 2	ATR Fresh Fuel Shipping Container SAR Drawing
60501-20, Rev. 1	Loose Plate Basket Assembly
60501-30, Rev. 1	Fuel Handling Enclosure

2.0 STRUCTURAL

The Advanced Test Reactor Fresh Fuel Shipping Container (ATR FFSC) package is a Type AF package designed for the transport of a single unirradiated ATR fuel element or loose unirradiated ATR fuel plates. 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 which houses the fuel and the package closure lid. The ATR FFSC has two secondary structural components depending on the type of fuel being shipped: a Fuel Handling Enclosure for a fuel assembly or a Loose Fuel Plate Basket.

Body Assembly. 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 equipped with ceramic fiber insulation.

Closure Lid Assembly. The closure lid assembly is a mechanical closure that does not rely on conventional fasteners to achieve a positive closure. The 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.

Fuel Handling Enclosure. The Fuel Handling Enclosure (FHE) is a thin-walled aluminum weldment with a hinged cover plate used to protect an ATR fuel element from handling damage. The FHE does not provide structural support to the fuel element or the package under NCT or HAC and is neglected for the purposes of the criticality evaluation.

Loose Fuel Plate Basket. The Loose Fuel Plate Basket (LFPB) is a component that 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 plate contents within a defined dimensional envelope under NCT and HAC.

2.1.2 Design Criteria

The applicant demonstrated structural performance of the package by physical testing and hand 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
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 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. The center of gravity is the approximate geometric center of the package, for either type of payload.

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. Structural materials which are important to safety are specified using ASTM standards. Welding procedures and personnel are qualified in accordance with the ASME Code, Section IX. 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. Welds that are important to safety are examined by liquid penetrant test on the final pass using procedures compliant with ASTM E165-02.

2.2 Material Properties and Specifications

This package is designed to transport one ATR fuel element or fuel plates either from a dismantled ATR element or before the plates are assembled into an ATR element. All the fuel is unirradiated. The element is enclosed in an aluminum housing for handling purposes. Each fuel element contains up to 1200 g U-235, with a maximum uranium enrichment of 94 weight percent U-235. The fuel meat is UAl_x mixed with aluminum. The aluminum cladding material is ASTM B209, 6061-T0 and ASTM B209 6061-T651. All aluminum alloys are modeled as pure. The package contains about 0.6 A_2 so it is a Type AF package. 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 made of welded Type 304 stainless steel, with ceramic fiber thermal insulation composed of 50 percent alumina and 50 percent silica. 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 welds are needed for structural stability and have no containment function. All welds will be examined as specified on the drawings. Visual examinations will be in accordance with AWS D1.6 Sec 6, and the dye penetrant examinations will be 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 of the application. The thermal conductivity, specific heat, and density of the aluminum and stainless steel were spot checked against the values in ASME B&PV Code Section II, Part D, (Azom.com) and ASM Matweb, and found to be within tolerance. The properties of the neoprene could not be confirmed since there are many variations of this material. 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. The variance was not enough to affect the calculations of the differential expansion of the inner and outer tubes more then 5 percent, and 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 an inspected polyethylene sheet that does not melt below 225°F. The requirements of 71.43(d) are met.

Since this is fresh fuel there will be no radiation effects on the materials of construction, 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 (Matweb). 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

Sections 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 hand calculations and full scale testing. The former is used primarily for evaluating the lifting and tie-down devices and the latter for the package dynamic response to NCT and HAC drop tests.

2.4.1 Minimum Package Size

The overall package dimensions are approximately 8 inches square and 74 inches in length (including the handle). They 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 a mechanical closure that does not rely on conventional fasteners to achieve a positive closure. The lid 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, achieve 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 71.73 are satisfied.

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

2.5.1 Lifting Devices

The ATR FFSC can be lifted in one of two ways: by forklift on a fork pocket equipped pallet or by a sling attached to overhead lifting equipment. Since the forklift operation involves minimal stress on any structural components 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 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 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 considered 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 did state that the interstitial space between the inner and outer shell may develop a pressure differential and determined 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 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 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 stated that none of the materials of construction used for structural integrity exhibit a ductile to brittle transition above -40°F. Thus, the staff agrees with the applicant's conclusion that the NCT cold condition is of negligible consequence for this design, and 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 ATR FFSC is not designed to retain pressure, therefore an increase in external pressure will result in the same pressure on the package shell. The applicant evaluated 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 Hypothetical Accident Conditions did not adversely affect the package structural integrity; therefore, the requirements of 10 CFR 71.71(c)(4) are satisfied.

2.6.5 Vibration

Section 2.6.5 of the application provides an evaluation of vibration loads on the package. The applicant addressed the effects of vibration on the closure, the thermal insulation, and the package as it is supported during transport. The applicant concluded that the effects of vibration would not be a concern.

2.6.6 Water Spray

Section 2.6.6 of the application notes that due to the materials of construction, the water spray test will 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 and indicated that there was minimal package damage due to this drop. The applicant stated 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 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 demonstrated compliance by analysis and showed that the normal compressive stresses imparted on the sidewalls of the package were an 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 demonstrated 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

Two certification test units were constructed to evaluate the effects of a 30-foot drop on the package performance. The applicant presented 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 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. The damage did not compromise the basis for the assumptions used in the criticality evaluation, nor was any fissile material exposed or released 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.

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 determined three failure modes that were 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 of this Safety Evaluation Report describes the thermal performance of the package. The effects of the thermal test were evaluated with respect to internal pressure and differential thermal expansion. With regard to pressures, the applicant has demonstrated that since this is not a sealed package, internal pressures are not critical to the structural integrity of the package. Differential thermal expansion was evaluated by analysis and the applicant determined that there was 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 stated that optimal moderation was considered in the criticality evaluation and the package exhibited 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 has been met as described above in Section 2.7.5 of this Safety Evaluation Report. The applicant did evaluate the sealed inner cavity for an equivalent pressure due to immersion under 50 feet of water. The conclusion was 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 was adequately described and evaluated to demonstrate its structural capabilities meet the requirements of 10 CFR Part 71.

3.0 THERMAL

The Advanced Test Reactor (ATR) Fresh Fuel Shipping Container (FFSC) package is a Type AF package designed for the transport of a single unirradiated ATR Fuel element. This fuel consists of 19 aluminum-clad uranium aluminide (UAl_x) plates containing uranium enriched to a maximum of 94 weight percent U-235. Additionally, the package is designed to transport loose unirradiated ATR fuel plates.

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 enclosed payloads. These two configurations are shown in Figures 1.2-1 and 1.2-8 of the application. The body consists of two nested shells; the outer shell is a square Type 304 stainless steel tube with 3/16 inch wall thickness and the inner shell is a 6-inch diameter Type 304 stainless steel tube with 0.120 inch wall thickness. 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 Figure 1.2-2 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 Fuel Handling Enclosure (FHE) is a hinged, aluminum weldment used to protect the ATR fuel element from damage during loading and unloading operations. A polyethylene plastic bag may be used as a protective sleeve over the ATR fuel element. The FHE weighs approximately 15 pounds and is fabricated from 0.09-inch thick unfinished 5052-H32 aluminum sheet. The FHE has a hinged lid and neoprene rub strips to minimize fretting of the fuel element side plates where they contact the FHE.

The loose fuel plate basket weights 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 and the fissile mass also being limited.

3.1.2 Decay Heat

The decay heat for unirradiated ATR 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 3.1-1 shown below provides a summary of component temperatures for the NCT and HAC analyses conducted by the applicant. Table 3.1-1 shows that the maximum calculated component temperatures were within the applicable temperature limits.

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 considered an isolated horizontal package in order to analyze the thermal performance of the ATR FFSC package design under Normal Conditions of Transport.

The applicant provided temperature-dependent material properties for all major components of the ATR FFSC 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 fuel plates are a composite material consisting of a fissile fuel matrix sandwiched within aluminum cladding. The fuel composite is treated as a homogenous material with lumped thermal properties.

Using the Thermal Desktop and SINDA/FLUINT computer programs, the applicant constructed a 1/4 symmetry model, extending from the closure to the vertical axial centerlines of the package, of a loaded ATR FFSC, using appropriate detail to represent the fuel plates, FHE, ceramic fiber insulation, closure, and the inner and outer shells. The model simulates one-half of the closure end half of the package, assuming symmetry about the package’s vertical plane, and extends about 36.5 inches along the axial direction, from the closure to the midpoint of the center support rib. Inside the ATR FFSC, both conduction and radiation are allowable means of heat transfer. The ATR FFSC exchanges heat 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 modeled using a diurnal cycle described in Section 3.5.2.1 of the application. The applicant modeled the NCT hot case with insolation. The case without insolation was deemed trivial, as there is no heat input to the package. Similarly, the NCT cold case with an ambient temperature of -40 °F was 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 were within operational limits, even when insolation is accounted for. The applicant also demonstrates that the accessible external surface temperature remained below the regulatory limit in 10 CFR 71.43(g) of 122°F (50°C) without insolation, required for packages under nonexclusive use.

Figures 3.3-1 and 3.3-2 in the application show the transient temperatures of the significant package components under NCT with solar insolation. Figure 3.3-3 illustrates the predicted temperature distribution within the ATR FFSC package at the time of peak temperature.

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). The applicant analyzed two HAC cases, one with an FHE and ATR fuel element, and the other replacing the loaded FHE with an unloaded LFPB. The unloaded LFPB is conservative since the addition of a payload will serve to increase the thermal mass of the basket and therefore reduce its temperature rise under the HAC transient conditions. The HAC transient analysis was 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: a 1.85 inch long segment of insulation was removed between each set of ribs conservatively bounding what was observed in the end drops, and the surface emissivity for the various components of the package were revised as presented in the application in Table 3.2-6 versus that given in Table 3.2-5 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. 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 fuel handling enclosure, 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 fuel element 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 will 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 ATR FFSC components during the 30-minute fire and during the 11.5 hours after the end of the fire. 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. Figure 3.4-5 shows the transient thermal response of the components of the ATR FFSC with the LFPB during the 30-minute fire and during the 11.5 hours after the end of the fire. Figure 3.4-6 shows the temperature distribution for the ATR FFSC with LFPB at the end of the HAC 30-minute fire, while Figure 3.4-7 shows the temperature distribution at the peak LFPB temperature which is at approximately 22 minutes after the end of the fire.

The payload cavity of the ATR FFSC is vented to the atmosphere, therefore there will be 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 due to ideal gas expansion will be less than 38 psig.

3.4.4 Maximum Thermal Stresses

The temperature difference between the inner and outer shells during the HAC event will result 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 will fail and permit 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 will occur. 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 will be released, and the outer shell and the associated end plate will extend away from the inner shell at the point of the weld failure. The applicant determined that 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 remained bounding, while the maximum temperature of the ATR fuel element increased by less than 25°F.

3.5 Convection Coefficient Calculation

The applicant used 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 were given for natural convection from a vertical surface and for heated or cooled horizontal surfaces facing upward or downward. Correlations were also given for forced convection applied during the HAC fire event.

3.6 Confirmatory Analysis

The staff modeled and meshed the ATR FFSC 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. The NCT and HAC confirmatory analyses indicated agreement with the applicant's analyses, and confirmed that the package design provides sufficient thermal safety margins for all its components.

3.7 Conclusions

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

4.0 CONTAINMENT

The Model No. ATR FFSC is a Type AF package designed for the transport of a single fuel element or loose fuel plates for the ATR. A containment review was performed to ensure that the package design was described and evaluated to meet the containment requirements of 10 CFR Part 71 under normal conditions of transport and hypothetical accident conditions.

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 U-235. The maximum contents of U-234 (1.2 weight percent) and U-236 (0.7 weight percent) are also specified. The maximum fissile mass per package is 1200 grams U-235, which is for an intact fuel element. Section 4.1.1 of the application provides an assessment that demonstrates that the contents do not exceed a Type A quantity of radioactive material.

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 packaging is described in Section 1.1 of this Safety Evaluation Report. The closure is by way of a bayonet closure, with four bayonets rotated into slots in the body top flange. The closure 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 (the FHE for fuel elements and the LFPB for loose 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 physical 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 demonstrated that the package retains the fuel element and loose plates under HAC.

4.4 Conclusions

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

5.0 SHIELDING

The contents of the package are limited to unirradiated ATR fuel elements or fuel plates. There are no special shielding components incorporated into this package design. As stated in Section 5.0 of the application, 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 that could be affected by accident conditions, the applicant stated that the one-meter dose rate under accident conditions would be 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

The criticality review ensures that the package design meets the criticality safety requirements of 10 CFR Part 71 under normal conditions of transport (NCT) and hypothetical accident conditions (HAC). 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.

6.1 Description of Criticality Design

The applicant proposed a new package to transport fresh Advanced Test Reactor (ATR) fuel, the ATR FFSC. The package is designed to contain a single ATR Mark VII fuel element in an aluminum fuel handling element (FHE) or a collection of loose ATR Mark VII fuel plates in an aluminum loose fuel plate basket (LFPB). The ATR FFSC is composed of a 6 inch (outer diameter) stainless steel cylindrical tube surrounded by 1 inch thick insulation in an 8 inch by

8 inch stainless steel square tube 72-1/2 inches in length (excluding the handle). 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 provided 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 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 used 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 calculated 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 described the proposed contents in Sections 1.2.2 and 6.2 of the application. The proposed contents are of two forms: a single ATR Mark VII fuel element or a bundle of individual ATR Mark VII fuel plates. The ATR fuel element has a maximum uranium enrichment of 94 weight percent U-235 and a fissile mass limit of 1200 grams U-235. There are four types of the ATR Mark VII fuel elements that may be loaded into the ATR FFSC. All four types are 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 loose ATR fuel plate contents also are limited to a uranium enrichment of 94 weight percent U-235, and the total U-235 mass is limited to 600 grams per package. 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. Both forms of contents may be placed in a plastic bag prior to loading into the ATR FFSC, leading to another possibility for preferential flooding in the package cavity.

A complete ATR fuel element has 19 different plate types; thus, the package's loose plate contents may be composed of a combination of these plate types. Also, the plates may be flat or they may be curved to their final shape when in an element. The applicant states, however, that a given payload of loose fuel plates will contain only flat plates or curved plates, but not a combination of flat and curved plates. The applicant stated that this restriction is for facilitating packaging of the plates. All loose plate contents will be confirmed to meet the 600 gram U-235 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 provided 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 is Section 6.2 of the application. These dimensions are based on Drawing No. 405400, Rev. 19, for which a sketch is included in the application (see Figure 6.2-1) 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 U-235 enrichment and mass limits. Based on the applicant's analysis and confirmatory calculations, the staff finds the proposed contents limits to be acceptable. The enrichment and mass limits, as well as the fuel element/plate type specification, are included in the Certificate of Compliance. Due to the large margins in the analysis, no additional parameter limits were 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 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 these tests and their results is described Sections 2 and 3 of this Safety Evaluation Report. Additionally, the applicant neglected the FHE for the fuel element contents, and the LPFB material beyond the portion forming the rectangular cavity of the basket in both the NCT and HAC models. The packaging and contents ends beyond the active fuel length are also neglected. The loose plate contents analyses are performed with one plate type, which is determined by analysis to result in the most reactive contents configuration for this contents type.

The applicant performed NCT analyses with both the fuel element and 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 included 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 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. 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.

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 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.

6.3.2 Material Properties

The staff reviewed the material properties used in the criticality analysis. As stated in Section 6.2 of this Safety Evaluation Report, the staff found the atom densities and mass densities of the fuel mixtures to be consistent. The applicant used the atom densities for the calculations. Staff determined that these densities are consistent with the U-235 masses listed for each fuel plate type in Table 6.2-1. For the loose plate contents analysis, fuel mixture atom densities were modified to ensure that each evaluated plate type would result in a payload of 600 g U-235 (with an integer number of plates).

Properties for the other materials included in the models are described in Section 6.3.2 of the application. The applicant provided neoprene properties and performed analyses with neoprene present. Based upon the HAC analysis for the single package, the applicant ignored the chlorine component of the neoprene and reduced 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 evaluated the ATR FFSC package using MCNP5 v1.30. MCNP is a three-dimensional Monte Carlo code with continuous-energy neutron cross sections. Developed by Los Alamos National Laboratory, this code has been used extensively in a variety of criticality safety evaluations. The staff finds that this code is appropriate for the present analysis. The applicant used 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 used 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 performed several calculations for the fuel element contents and loose fuel plate contents. Calculations were performed for a single package and for arrays of packages with both contents types. Staff reviewed the applicant's analyses and finds reasonable assurance that the most reactive configuration of the package is considered. Optimum moderation conditions were identified, and appropriate consideration was given regarding preferential flooding. Further descriptions of these analyses and their results are provided in Sections 6.4 through 6.6 of this Safety Evaluation Report.

6.3.5 Confirmatory Analyses

Staff performed a number of independent calculations to confirm 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's analysis results were bounded by or in close agreement with the applicant's results.

6.4 Single Package Evaluation

The staff reviewed the applicant's evaluation of a single package. The single package was modeled with full water reflection on all sides. The fissile material was modeled in the most reactive credible configuration consistent with the condition of the package and contents. For the loose plate contents, the most reactive plate type, fuel plate 5 was used. The plates were 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 included optimum moderation of both the fuel element and loose fuel plate contents, with the contents rotated and shifted toward the array center. The applicant analyzed a 9x9x1 array surrounded by a full water reflector. For the loose plate contents, the applicant performed 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 was full density water between the fuel element plates, 0.3 g/cc water density in the package cavity with neoprene (without chlorine) and insulation present, and void between the steel tubes forming the package cavity and outer wall. For the loose plate contents, the most reactive configuration is 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, the NCT array reactivity exceeds the HAC array reactivity, with the fuel element contents resulting in the highest k-effective for the analysis. The maximum k-effective is significantly less than the applicant's Upper Subcritical Limit (USL).

6.6 Evaluation of Package Arrays under Hypothetical Accident Conditions

The staff reviewed the applicant's analysis of an array of damaged packages. 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 of this Safety Evaluation Report), 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 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 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 fuel element contents than for the loose fuel plate contents.

6.7 Air Transport of Fissile Material

The applicant did 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 within the ATR fuel. The applicant evaluated the USL as a function of two experimental parameters, the energy of the average neutron lethargy causing fission (EALF) and the fissile isotope's (U-235) number density. The applicant expanded 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 were most applicable to the package analysis. The applicant selected 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.

In its review of the expanded benchmark evaluation, the staff noted 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. There is also a relatively large area where no data exists over the range analyzed for each parameter. Thus, the staff considered using only the most under-predicted experiment to determine a USL but found that the applicant's USL is more conservative. The applicant also stated that for some parameters, the package analysis for the loose plate contents extends far beyond the range of applicability of the benchmarks. However, the applicant argues that these parameters (e.g., channel width) deal with system moderation, which affects the EALF parameter; the analyses for the loose plate contents fall 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 ATR FFSC analysis.

6.9 Evaluation Findings

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. Package loading operations include visual and operational inspections of the empty packaging prior to loading. Operations are described for loading fuel elements as well as loose fuel plates. Preparation for transport includes application of a tamper-indicating device, radiation and contamination surveys, package marking and labeling, and vehicle placarding. 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 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 designed, built for, and used by the Idaho National Laboratory (INL). Procurement, design, fabrication, assembly, testing, maintenance, repair, modification, and use of the package are done under quality assurance programs that meet applicable Subpart H 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 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.

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