71-9309

GNF

Global Nuclear Fuel

A Joint Venture of GE, Toshiba, & Hitachi

Global Nuclear Fuel – Americas, LLC
Castle Hayne Road, Wilmington, NC 28401

October 28, 2004

Mr. E. William Brach, Director
Spent Fuel Project Office, M/S O-13D13
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: Response to NRC Questions Regarding Stress on Fuel, Basis for Selecting Container Orientation for Testing and Wording in SAR Relating to Damage During HAC Test

References:
(1) Docket Number 71-9309
(2) Application for Approval of the RAJ-II Package Dated 3/31/04
(3) Request for Revision to the Application for the RAJ-II Package Dated 4/22/04
(4) NRC Request for Addition Information for Model No. RAJ-II Package Dated 7/19/04
(5) Response to RAI Letter and Revisions for the RAJ-II Package Dated 09/03/04
(6) Modification to the 9/3/04 Application for the RAJ-II Package Dated 9/16/04

Dear Mr. Brach:

Pursuant to our telephone conversation with the your office and Framatome ANP on 10/27/04, we hereby provide the information discussed relating to: (1) stress on the fuel due to thermal effects on cladding, (2) basis for selecting the angle of slap down and puncture tests and (3) that wording in Section 6.0 of the SAR implied there was no damage to the inner container when other sections of SAR identified damage resulting from the drop test.

The following Attachments are provided with this letter:

Attachment 1 contains the "Description of Changes".

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Attachment 2 contains page changes for the SAR as described in Attachment 1 above. These replacement pages are marked with a vertical line in the right hand column by the line(s) where the changes have been made. Please note that a new Section has been added at the end of the SAR for the Supplement describing package orientation for the slapdown and puncture tests.

Six copies of this submittal are provided for your use, and as replacement pages.

Please contact me on (910) 675-5656 if you have any questions or would like to discuss the matter further.

Sincerely,

Global Nuclear Fuel-Americas, LLC

Richard Foleck for

Charles M. Vaughan, Manager
Facility Licensing

Attachments

cc: CMV-04-045

Attachment 1

Description of Changes

Section Changed	Description of Changes
Table of Contents	Revised to reflect addition of Supplement 1 and new revision and date.
Supplement 1	This supplement has been added and referenced in Sections 2.7.1.4 and 2.7.1.6. The purpose of the supplement is to provide additional justification for the orientations selected for the drop tests.
Section 2.6.1.2	Clarification of text in several sentences. The formula for calculating strain was corrected to fix a typographical error. The change did not affect the results of the calculation since they were calculated with the correct formula. Data references added to the text and shown at the bottom of the page.
Table 2-6	New column added for thermal expansion and temperature heading changed to reflect proper use of degrees C in lieu of degrees F.
Table 2-7	New column added for thermal expansion and temperature heading changed to reflect proper use of degrees C in lieu of degrees F.
Section 6.3.1.1.2	Clarified text regarding inner container damage.
Table 2-11	Clarified text regarding inner container damage.

Attachment 2

Contains page changes for the SAR as described in Attachment 1. These replacement pages are marked with a vertical line in the right hand column by the line(s) where the changes have been made. Please note that a new Section has been added at the end of the SAR for the Supplement describing package orientation for the slapdown and puncture tests.

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The RAJ-II package's ability to survive HAC, 30-foot free drop, 40-inch puncture drop, and 30-minute thermal event also demonstrated the packages ability to also survive the NCT. Evaluations are performed, when appropriate, to supplement or expand on the available test results. This combination of analytic and test structural evaluations provides an initial configuration for NCT thermal, shielding and criticality performance. In accordance with 10 CFR 71.43(f), the evaluations performed herein successfully demonstrate that under NCT tests the RAJ-II package experiences "no substantial reduction in the effectiveness of the packaging". Summaries of the more significant aspects of the full-scale free drop testing are included in Section 2.6.7, with details presented in Appendix 2.12.1.

2.6.1 Heat

The NCT thermal analyses presented in Section 3.0, consist of exposing the RAJ -II package to direct sunlight and 100 °F still air per the requirements of 10 CFR 71.71(b). Since there is negligible decay heat in the unirradiated fuel, the entire heating came from the solar insolation. The maximum temperature of 77°C (171°F) was located on the lid of the outer container.

2.6.1.1 Summary of Pressures and Temperatures

The fuel assembly exhibits negligible decay heat. The RAJ-II package and internal components, when loaded with the required 10 CFR 71.71(c) (1) insulation conditions, develop a maximum temperature of 77 °C (171 °F). The resulting pressure at the maximum temperature is 1.33 MPa (192.9 psia).

2.6.1.2 Differential Thermal Expansion

With NCT temperatures throughout the packaging being relatively uniform (i.e. no significant temperature gradients), the concern with differential expansions is limited to regions of the RAJ-II packaging that employ adjacent materials with sufficiently different coefficients of thermal expansion. The IC is a double-walled, composite construction of alumina silicate thermal insulator between inner and outer walls of stainless steel. The alumina silicate thermal insulator is loosely packed between the two walls and does not stress the walls. Differential thermal expansion stresses are negligible in the OC for three reasons: 1) the temperature distribution throughout the entire OC is relatively uniform, 2) the OC is fabricated from only one type of structural material, and 3) the OC is not radially or axially constrained within a tight-fitting structure due to the relatively low temperature differentials and lack of internal restraint within the RAJ-II package.

The cladding of the fuel which serves as containment is not stressed due to differential thermal expansion since a gap remains between the fuel pellet and the cladding at both the cold temperature -40°C and the highest temperature the fuel could see due to the HAC which is 800°C. This is demonstrated as follows:

The nominal fuel pellet and cladding dimensions and the resulting radial gap (0.00335 inches) is shown below based on a temperature of 20°C:

As-Built Dimensions (inches)		
Nominal Clad OD	D_{co}	0.3957
Nominal Clad ID	D_{ci}	0.348
Nominal Pellet OD	D_{fo}	0.3413
Nominal Radial Pellet/Clad Gap	g_n	0.00335

The strain due to thermal expansion or contraction in the Zr cladding is equal to[1]:

$$\left(\frac{\Delta D}{D}\right)_{clad} = 7.4\times10^{-6}(\Delta T)$$

Where ΔT is positive for an increase in temperature and negative for a decrease in temperature.

The strain due to thermal expansion or contraction in the fuel pellet is equal to[2]:

$$\left(\frac{\Delta D}{D}\right)_{fuel} = -3.28\times10^{-3} + 1.179\times10^{-5}T - 2.429\times10^{-9}T^2 + 1.219\times10^{-12}T^3$$

Where T is the absolute final temperature in degrees Kelvin (K).

The following table summarizes the thermal strain and the thermal growth in the cladding and pellets with a temperature change from 20°C to -40°C $(\Delta T = -60°C, T = 233\ K)$. All dimensions are expressed in inches.

Table 2 - 6 Thermal Contraction at -40°C

	Strain at -40°C $\left(\frac{\Delta D}{D}\right)$	Thermal Expansion at -40°C $\left(\frac{\Delta D}{D}\right)D$	Dimension at -40°C $D+\left(\frac{\Delta D}{D}\right)D$
Pellet OD	-6.49×10^{-4}	-2.22×10^{-4}	0.3411
Cladding ID	-4.44×10^{-4}	-1.55×10^{-4}	0.3478

This results in a radial gap at -40°C of:

$$g_{-40} = \frac{0.3478 - 0.3411}{2} = 0.0034 \cdot in$$

[1] Framatome ANP MOX Material Properties Manual 51-5010288-03
[2] Framatome ANP MOX Material Properties Manual 51-5010288-02

The following table summarizes the thermal strain and the thermal growth in the cladding and pellets with a temperature change from 20°C to 800°C ($\Delta T = 780°C, T = 1{,}073\,K$). All dimensions are expressed in inches.

Table 2 - 7 Thermal Expansion at 800°C

	Strain at 800°C $\left(\frac{\Delta D}{D}\right)$	Thermal Expansion at 800°C $\left(\frac{\Delta D}{D}\right)D$	Dimension at 800°C $D+\left(\frac{\Delta D}{D}\right)D$
Pellet OD	8.08×10^{-3}	2.76×10^{-3}	0.3441
Clading ID	5.77×10^{-3}	2.01×10^{-3}	0.3500

This results in a radial gap at 800°C of:

$$g_{800} = \frac{0.3500 - 0.3441}{2} = 0.0030 \cdot in$$

2.6.1.3 Stress Calculations

Since the temperatures and pressures generated under normal conditions of transport are well below the design conditions for the boiling water reactor fuel no specific calculations were performed for the fuel containment.

2.6.1.4 Comparison with Allowable Stresses

The normal conditions of transport conditions are well below the operating conditions of the fuel no comparison to allowable stresses was performed.

2.6.2 Cold

The NCT cold condition consists of exposing the RAJ-II packaging to a steady-state ambient temperature of -40 °F. Insulation and payload internal decay heat are assumed to be zero. These conditions will result in a uniform temperature throughout the package of -40 F. With no internal heat load (i.e., no contents to produce heat), the net pressure differential will only be reduced from the initial conditions at loading.

For the containment, the principal structural concern due to the NCT cold condition is the effect of the differential expansion of the fuel to the zirconium alloy tube. During the cool-down from 20 °C to -40 °C, the tube could shrink onto the fuel because of difference in the thermal expansion coefficient. However, the clearance between the fuel and the cladding is such that even if the fuel did not shrink, there would still be clearance. Differential thermal expansion stresses are negligible in the package for three reasons: 1) the temperature distribution throughout the entire package is relatively uniform, 2) the package is fabricated from only one type of structural material, and 3) the package is not radially or axially constrained.

Brittle fracture at -40 °F is addressed in Section 2.1.2.4.1.

2.6.3 Reduced External Pressure

The effect of a reduced external pressure of 25 kPa (3.5 psia) per 10 CFR 71.71(c)(3) is negligible for the RAJ-II packaging. The RAJ-II package contains no pressure-tight seal and therefore cannot develop differential pressure. Therefore, the reduced external pressure requirement of 3.5 psia delineated in 10 CFR 71.71(c)(3) will have no effect on the package. Compared with the 1.115 MPa (161.7 psia) internal pressure in the fuel rods, a reduced external pressure of 3.5 psia will have a negligible effect on the fuel rods.

2.6.4 Increased External Pressure

The RAJ-II package contains no pressure-tight seal and, therefore, cannot develop differential pressure. Therefore, the increased external pressure requirement of 140 kPa (20 psia) delineated in 10 CFR 71.71(c)(4) will have no effect on the package. The pressure-tight cladding of the fuel rods is designed for much higher pressures in its normal service in a reactor and is not affected by the slight increase in external pressure.

The containment is provided by the cladding tubes of the fuel. These tubes, designed for the conditions in an operating reactor, have the capability of withstanding the increased external pressure. The failure mode of radial buckling is not a plausible failure mode since the fuel pellets would prevent any significant deformation due to external pressure.

2.6.5 Vibration

The RAJ-II packaging contains an internal shock mount system and, therefore, cannot develop significant vibratory stresses for the package's internal structures. Therefore, vibration normally incident to transportation, as delineated in 10 CFR 71.71(c)(5), will have a negligible effect on the package. Due to concerns of possibly damaging the fuel so it cannot be installed in a reactor after transport, extreme care is taken in packaging the fuel using cushioning material and vibration isolation systems. These systems also ensure that the fuel containment boundary also remains uncompromised. The welded structure of the light weight RAJ-II package is unaffected by vibration. However, after each use the packaging is visually examined for any potential damage.

2.6.6 Water Spray

The materials of construction of the RAJ-II package are such that the water spray test identified in 10 CFR 71.71(c)(6) will have a negligible effect on the package.

For the above reasons, testing must include impact orientations that affect the lid and stability of the walls of the containers. In general, the energy absorbing capabilities of the RAJ-II are governed by the deformation of the stainless steel and impregnated paper honeycomb that is not significantly affected by temperature.

Appendices 2.12.1 and 2.12.2 provide a comprehensive report of the certification test process and results. Discussions specific to CTU test orientations for free drop and puncture, including initial test conditions, are also provided.

The RAJ-II package has undergone extensive testing during its development. Testing has included 1.2-meter (4-foot) drops on the end in the vertical orientation and the lid in the horizontal orientation. The package has been also dropped from 9 meters in the same orientation demonstrating that the damage from the 1.2-meter (4-foot) drops has little consequence on the performance of the package in 9-meter (30-foot) drop. Based on these preliminary tests it was determined that the worst case orientation for the 9-meter (30-foot) drop test would be slap-down on the lid. The lid down drop demonstrated that the vibration isolation frame bolts would fail allowing the inner container to come in contact with the paper honeycomb in the lid and partially crush the honeycomb. It was expected that the slap-down orientation would maximize the crush of this material minimizing the separation distance between the fuel assemblies in the post accident condition.

A single "worst-case" 9-meter (30-foot) free drop is required by 10 CFR 71.73(c)(1). Based on the above discussion and experience with other long slender packages similar to the RAJ-II, a 15 degree slap-down on the lid was chosen for the 9-meter (30-foot) drop. Following that drop, a 25 degree oblique puncture drop on the damaged lid was performed. See Figure 2-13, Figure 2-14 and Appendix 2.12.1.

Other free drop orientations that were tested include vertical end and bottom corner. These tests demonstrated that the RAJ-II package contains the fuel assemblies without breaching the fuel cladding (containment boundary).

2.7.1.1 End Drop

9-meter (30-foot) end free drops were performed on GNF-J CTU 1J and GNF-A CTU 2. The orientation was selected with the lower end of the fuel down to maximize the damage since the expansion springs in the fuel rods are located in the upper end. This orientation maximized the damage to the energy absorbing wood in the end of the RAJ-II and maximized the axial loading on the fuel assembly. Both tests resulted in deformations of the fuel but were within the limits evaluated in the criticality evaluation in Section 6.0. Following the GNF-A tests, the fuel rods were demonstrated to maintain containment after the free and puncture drops, thus maintaining its containment boundary integrity. Although this orientation caused the most severe damage to the fuel, the damage was well within the structural limits for the fuel and package.

2.7.1.2 Side Drop

No side drop testing was performed in this certification sequence. A side drop test was done in previous testing of the package. That testing resulted in the inner container holding frame top bolts failing and allowing the inner container to come in contact with the outer lid. The inner package showed little damage and the fuel was not deformed. It was judged that the slapdown and the horizontal drop tests bounded the side drop orientation.

2.7.1.3 Corner Drop

A 9-meter (30-foot) free drop on the OC body bottom corner was performed on GNF-J CTU 1J. The impact point previously sustained damage due to 0.3-meter (1-foot) and 1.2-meter (4-foot) free drops. The resultant cumulative deformation was approximately 163 mm (6 inches). There was no loss of contents or significant structural damage to the OC as a result of this free drop. The maximum recorded impact acceleration was 203g. Refer to Appendix 2.12.2 for complete details of the corner free drop.

2.7.1.4 Oblique Drops

An orientation of 15 degrees from horizontal was tested with GNF-A CTU 1. Additional information regarding the selection of this angle is provided in Supplement 1, "Clarifications on the RAJ-II Selection of Slapdown and Puncture Orientations". The IC holding frame was plastically deformed and only a portion of the bolts failed. Neither the fuel nor the IC were not significantly damaged. The damage sustained was bounded by the assumptions utilized in the criticality and thermal evaluations. The fuel was leak tested after the test and was demonstrated to have maintained containment boundary. Refer to Appendix 2.12.1 for complete details of the 15-degree oblique free drop.

2.7.1.5 Horizontal Drop

A 9-meter (30-foot) horizontal free drop on the OC lid was performed on GNF-J CTU 2J. The impact results in a maximum deformation of 19 mm (0.8 inch), which occurred in the OC lid. The side wall of the OC body bulged approximately 19 mm (0.8 inches). Some localized weld failure of OC lid flange/OC lid interface occurred where the bolster angles attach to the lid. None of the OC lid bolts failed as a result of the impact. There was no loss of contents as a result of the free drop. The maximum recorded impact acceleration was 146g. Refer to Appendix 2.12.2 for complete details of the horizontal free drop.

2.7.1.6 Summary of Results

Successful HAC free drop testing of the test units indicates that the various RAJ-II packaging design features are adequately designed to withstand the HAC 30-foot free drop event. The most important result of the testing program was the demonstrated ability of the fuel to remain undamaged and hence maintain its containment capability as defined by ANSI N14.5.

The RAJ-II also maintained its basic geometry required for nuclear criticality safety. Observed permanent deformations of the RAJ-II packaging were less than those assumed for the criticality evaluation.

The GNF-A mock-up fuel assembly rods were leakage rate tested after the conclusion of the testing and were demonstrated to be leaktight, as defined in ANSI N14.5.

A comprehensive summary of free drop test results are provided in Appendices 2.12.1 and 2.12.2.

2.7.2 Crush

Subpart F of 10 CFR 71 requires performing a dynamic crush test in accordance with the requirements of 10 CFR 71.73(c)(2). Since the RAJ-II package weight exceeds 500 kg (1,100 pounds), the dynamic crush test is not required.

2.7.3 Puncture

Subpart F of 10 CFR 71 requires performing a puncture test in accordance with the requirements of 10 CFR 71.73(c)(3). The puncture test involves a 1-meter (40-inch) free drop of a package onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 150 mm (6 inches) in diameter, with the top surface horizontal and its edge rounded to a radius of not more than 6 millimeter (0.25 inch). The package is to be oriented in a position for which maximum damage will occur. The length of the bar used was approximately 1.5 meters (60 inches). The ability of the RAJ-II package to adequately withstand this specified puncture drop condition is demonstrated via testing of the full-scale RAJ-II CTUs.

To properly select a worst-case package orientation for the puncture drop event, items that could potentially compromise containment integrity and/or criticality safety of the RAJ-II package must be clearly identified. For the RAJ-II package design, the foremost item to be addressed is the ability of the containment to remain leak-tight. Shielding integrity is not a controlling case for the reasons described in Chapter 5.0. Criticality safety is conservatively evaluated based on measured physical damage to the outer container walls as described in Section 6.0.

Previous testing has shown that the 1-meter drop onto the puncture bar did not penetrate the outer wall or damage the fuel. Based on this previous testing and other experience, an oblique and horizontal puncture drop orientations centered over the fuel were chosen as the most damaging.

Appendices 2.12.1 and 2.12.2 provide a comprehensive report of the certification test process and results. Discussions specific to the configuration and orientation of the test unit are provided.

The "worst-case" puncture drop as required by 10 CFR 71.73(c)(3) was performed on the package with the lid down and 25 degrees from horizontal. The angle was chosen based on experience with other packages and the RAJ-II. Additional information regarding the selection of this angle is provided in Supplement 1, "Clarifications on the RAJ-II Selection of Slapdown and Puncture Orientations". The puncture bar was aimed at the CG of package to maximize the energy imparted to the package.

The puncture pin did not penetrate the outer container. It deformed the lid inward and it contacted the inner container lid and deformed it a small amount. The outer lid total deformation was less than 12 cm (4.7 inches) and the inner container lid deformed less than 5 cm (2.0 inches).

2.7.4 Thermal

Thermal testing of the GNF-J CTU 2J was performed following the free drop and puncture drop tests (refer to Appendix 2.12.2). Although there was no failure of the containment boundary due to the thermal testing, the thermal evaluation of the RAJ-II package for the HAC heat condition as presented in Section 3.0, demonstrates the regulatory compliance to 10 CFR 71.73(c)(4).. Because the RAJ-II package does not contain pressure-tight seals, the HAC pressure for the OC and the IC is zero. The fuel assembly exhibits negligible decay heat.

2.7.4.1 Summary of Pressures and Temperatures

The maximum predicted HAC temperature for the fuel assembly is 921 K (1,198 °F) during the fire event. The fuel rods are designed to withstand a minimum temperature of 1,073 K (1,475 °F) without bursting. This has been demonstrated by heating representative fuel rods to this temperature for over 30 minutes. This heating resulted in rupture pressures in the excess of 3.6 MPa (520 psi). The pressure due to the accident conditions does not exceed 3.5 MPa (508 psig). Summary of pressures and related stresses are provided in Section 3.0.

2.7.4.2 Differential Thermal Expansion

The fuel cladding is not restricted by the packaging and hence can not develop any significant differential thermal expansion stresses. The packaging itself is made of the same metal (austenitic stainless steel) eliminating any significant stresses due to differential thermal expansion.

2.7.4.3 Stress Calculations

Stress calculations for the controlling hoop stress for the fuel cladding that provides containment is provided in Section 3.0.

2.7.4.4 Comparison with Allowable Stresses

The allowable stress used in the analysis in Section 3.0 is based on empirical data from burst tests performed on fuel rods when heated to 800 °C and above. The allowed fuel cladding configurations for the RAJ-II have a positive margin of safety based on stresses required to fail the fuel in the test.

Table 2 - 11 Testing Summary

Test	CTU	Orientation with horizontal	Exterior damage	Interior damage	Fuel
9-meter (30-foot) lid down	1	15°	Minor deformation on both ends.	No bolts broken on the frame or the lids. Significant deformation to inner container and internal clamp frame. Reduction of spacing between outside of package and fuel to about 4 inches.	Minimal damage to the fuel assemblies. Some twist to the assembly. No real damage to the fuel rods. The fuel was demonstrated to have a leak rate of less than 1 $\times 10^{-7}$ atm-cc/s after the testing.
1-meter (40 in) lid down over cg	1	25°	Did not penetrate outer wall	Outer wall contacted inner container. Section 2.12 Figure 2-39 through 2-42 show some damage to the inner container, however, this damage is conservatively modeled in the HAC criticality analyses in Section 6.0 and is not sufficient to allow fuel to leak from the container.	The fuel appeared not to be affected by this test. Passed helium leak test.
9-meter (30-foot) lower end	2	90°	Localized damage on impact end.	Major crushing of the wood at the end of the inner package and breaking of the inner wall of the inner container on the impacted end. The outer wall was damaged but did not fail completely.	Fuel was bent and separated from end fittings. Fuel spacers were damaged. Fuel rods had no significant damage. Fuel bending was influenced by the movement of the weight added to the fuel cavity. Post drop leak test giving a He leak rate of 5.5×10^{-6} atm-cc/s demonstrated that containment had been maintained.

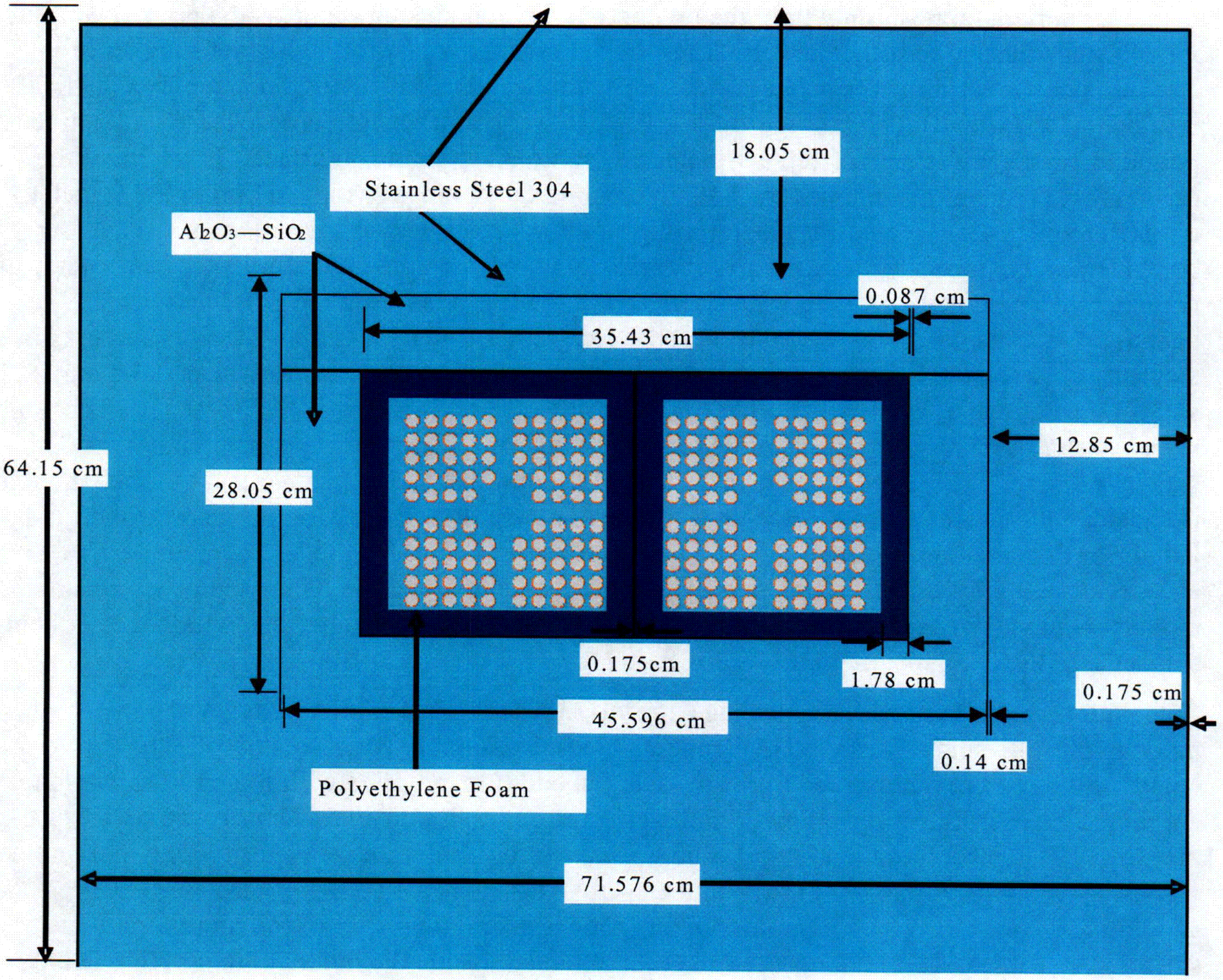

Figure 6-5 RAJ-II Container Cross-Section Normal Conditions of Transport Model

6.3.1.1.2 Single Package Hypothetical Accident Condition Model

The RAJ-II HAC model inner container dimensions are shown in Figure 6-7 and Figure 6-8. The container deformation modeled for the RAJ-II HAC model includes the damage incurred from the 9-meter drop onto an unyielding surface as well as conservative factors. The RAJ-II inner container length is conservatively reduced by 8.1 cm to bound the damage incurred from the 9-meter drop onto an unyielding surface. The alumina silicate insulation is assumed to remain in place, since scoping calculations proved it to be a better reflector than water for the worst case moderator conditions considered in the HAC model. The polyethylene foam, present in the normal model, is assumed to burn away when exposed to an external fire. As a result, the fuel assemblies are assumed to freely move within the respective compartment resulting in a worst case orientation. The rubber vibro-isolating devices are also assumed to melt when exposed to an external fire, allowing the inner container to shift downward about 2.54 cm. However, scoping calculations reveal no increase in reactivity by moving the inner container; therefore, the

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inner container is positioned within the outer container as shown in Figure 6-8. The inner container horizontal position within the outer container remains the same as the normal condition model, since the stainless steel fixture assemblies remained intact following the 9-meter drop. The outer container dimensions are shown in Figure 6-6 RAJ-II Outer Container Hypothetical Accident Condition Modeland Figure 6-8. The outer container length is reduced by 4.7 cm to bound the damage sustained from a 9-meter drop onto an unyielding surface. In addition, the outer container height is reduced by 2.4 cm to bound the damage sustained during the 9-meter drop (Reference 1). No credit is taken for the structural steel between the inner and outer containers. The honeycomb shock absorbers, located between the inner and outer containers, are not explicitly modeled. Instead, water is placed in the space between the inner and outer containers, and its density is varied from 0.0 – 1.0 g/cm^3. The honeycomb shock absorbers have a density between 0.04 and 0.08 g/cm^3. The hydrogen number densities for water (1.0 g/cm^3) and for the honeycomb shock absorber (0.08 g/cm^3) are 6.677x10^{-2} and 2.973x10^{-3} atoms/b*cm, respectively. As a result, water is more effective at thermalizing neutrons than the honeycomb shock absorbers. Therefore, the use of water at 1.0 g/cm^3 between the inner and outer containers is considered a conservative replacement for the honeycomb shock absorbers. The reduction in length for the inner and outer containers, the reduction in height for the outer container, the absence of polyethylene foam, the presence of the insulation, and the fuel assembly freedom of movement are consistent with the physical condition of the RAJ-II shipping container after being subjected to the tests specified in 10 CFR Part 71.

Calculations performed with the package array HAC model determine the fuel assembly modeling for the single package HAC model. No fuel assembly structures outside the active length of the rod are represented in the models. In addition, no grids within the rod active length are represented. Neglecting external/internal grid structure is considered conservative because the structure displaces moderator and/or removes neutrons by radiative capture. The maximum pellet enrichment and maximum fuel lattice average enrichment is 5.0 wt% U-235. The gadolinia content of any gadolinia-urania fuel rods is taken to be 75% of the minimum value specified in Table 6-1. The fuel assemblies are modeled inside the inner container, in one of seven orientations shown in Figure 6-9 RAJ-II Hypothetical Accident Condition Model with Fuel Assembly Orientation 1 through Figure 6-15 RAJ-II Hypothetical Accident Condition Model with Fuel Assembly Orientation 7. The worst case orientation is chosen for each fuel assembly design considered for transport and used in subsequent calculations. Fuel damage sustained during the 9-meter (30 foot) drop test is simulated as a change in fuel rod pitch along the full axial length of each fuel assembly considered for transport. Based on the fuel damage sustained in the RAJ-II shipping container drop test (Reference 1), a 10% reduction in fuel rod pitch over the full length of each fuel assembly, or a 4.1% increase in fuel rod pitch over the full length of each fuel assembly, is determined to be conservative. Both un-channeled (Figure 6-9 through Figure 6-15) and channeled fuel assemblies (Figure 6-16) are considered in the worst case orientation, subjected to the worst case fuel damage, and the most reactive configuration is chosen for subsequent calculations.

The fuel damage sustained during the 9-meter drop test is bounded by performing a fuel parameter sensitivity study and creating a worst case fuel assembly for each fuel design. The sensitivity study results determine the fuel parameter ranges for the fuel assembly loading criteria shown in Table 6-1. The ranges are broad enough to accommodate future fuel assembly design changes. The fuel rod pitch, fuel pellet outer diameter, fuel rod clad inner and outer

Supplement 1

Clarifications on the RAJ-II Selection of Slapdown and Puncture Orientations

Slapdown

The selection of the 15 degree impact angle for the 9 meter drop test is based on the orientation that would do the most damage to the fuel and the package. The vertical drop bounds the case of drops with high angles of impact. The slapdown drop is designed to attack the package in two ways. For long slender packages the interest is in the bending or bowing of the package during impact. The second concern is the high impact of the secondary end that could excessively damage the package exposing the fuel for the ensuing thermal test or by locally damaging the fuel. It is possible using a dynamic computer model to determine the worst-case orientation. This was done with the PacTec proprietary program SLAPDOWN (similar to the program by the same name created by Sandia National Laboratories), which calculates the impact accelerations in a package during a slapdown event. The inputs to the program consist of the package geometry and mass properties, as well as the impact crush behavior of the ends of the package which strike the ground. In a slapdown event, one end of the package strikes first (the primary end) and the other strikes second (the secondary end). The crush properties are input as force-deflection curves for each end of the package. Since these properties are not known, nor can they be readily calculated, a range of crush force-deflection behavior was investigated. In this way, the dependence of impact orientation angle on peak accelerations can be reliably determined. The basis of comparison was the secondary impact acceleration at the far end of the package, in Gs, vs. the primary impact angle.

The calculation parameters are given in the following table. The SLAPDOWN program models the package as a rigid rod with springs at each end. The mass moment of inertia was found by assuming the mass was uniformly distributed over the volume of the package. In a manner similar to the WE-1 fresh fuel package (NRC Docket 71-9289), five different linear spring rates were compared: $k = 5(10^5)$ lb/in, $1(10^6)$ lb/in, $1.5(10^6)$ lb/in, $2.5(10^6)$ lb/in, and $5(10^6)$ lb/in. These spring rates were chosen to bound the actual behavior of the package during impact. Since the package has similar construction at each end, both primary and secondary springs were modeled with the same spring rate. The springs were non-conservative, in that they unloaded at the uniform rate of $1(10^7)$ lb/in. Friction with the ground was assumed to be negligible.

Slapdown Parameters for RAJ-II Package

Parameter	Value	Parameter	Value
Length, in	199.5	Center of Gravity location	Central
Width, in	28.4	Weight, lb	3,559
Height, in	25.3	Mass moment, in-lb-s^2	31,040

The secondary impact at the far end of the package was evaluated at primary impact angles between 15° and 40°, in increments of 5°, for each of the crush spring rates chosen. In each case, the secondary impact was greatest at a primary impact angle of 35° (it was virtually identical for 30° and 35° at the highest spring rate of $5(10^6)$ lb/in). However, the dependence on impact angle was extremely weak. As shown by the table below, the greatest difference between the maximum secondary impact and the impact at 15° is no more than 2.5%. For higher spring stiffness, the difference is even lower. Therefore, there is no significant difference in package performance in the slapdown free drop test between the worst-case primary angle of 35° and the actual angle used of 15°.

Slapdown Results for RAJ-II Package

Spring rate of crush, lb/in	Secondary impact for primary θ = 15º (g)	Secondary impact for primary θ = 35º (g)	Δ%
$5(10^5)$	316	324	2.5
$1(10^6)$	450	461	2.4
$1.5(10^6)$	555	567	2.1
$2.5(10^6)$	724	739	2.0
$5(10^6)$	1,043	1,062	1.8

Similar analysis performed for the WE-1 package which has similar geometry, demonstrated that the bounding case for the secondary impact was the 15 degree orientation. Recent testing for licensing of the Westinghouse Traveler package (Docket No 71-9297) for PWR fuel was done at 14.7 degrees. Both of these packages have similar geometry to the RAJ-II. They all are relatively slender and handle 1-2 fuel assemblies.

Puncture

The most likely scenario to penetrate the protective outer box provided the basis for selecting the puncture impact angle of 25°. The postulated worst case damage from the puncture test is penetrating both the skin of the outer box and also the skin of the inner box. This would have both the possibility of physically damaging the fuel and also compromising the thermal protection during the fire event. Since the early 1980's it has been recognized that the oblique puncture where the shell is attacked by the ¼ in radius edge of the puncture bar is the most likely to penetrate and tear the skin of the package. Due to the complex nature of the regulatory puncture event, there is no generally accepted computational technique that can readily determine puncture response as a function of test parameters such as orientation angle. Therefore, the worst case orientation used must be derived from experience and general usage. To evaluate this, a review of the oblique puncture tests performed for several licensed packages was made. Emphasis was placed on the orientation angles used for punctures on the more featureless regions of the packages, which corresponds to the RAJ-II test in question. Other puncture test orientations are often dictated by the shape and location of the specific features they are trying to test. Since these orientations can vary widely, they were generally ignored in the survey. The results constitute the generally accepted industry practice concerning the worst-case puncture orientation in cases where a specific structural feature (gap, port, etc.) is not involved. Consistent with the RAJ-II, the packages compared all feature relatively thin shell thicknesses (in contrast to, for example, heavy wall spent fuel packages). The packages compared below are the TRUPACT-II, the HalfPACT, the TNF-XI, and the NPC.

Because of the relatively light weight of the RAJ-II it was recognized that to maximize the puncture damage the bar had to strike near the CG to keep the package from rolling off the bar and not imparting energy into the shell.

Supplement 1

Clarifications on the RAJ-II Selection of Slapdown and Puncture Orientations

TRUPACT-II (NRC Docket 71-9218)

The discussion of puncture testing in Section 2.7 of the TRUPACT-II SAR states that oblique angles are the most challenging, and that the worst case angle is greater than 20°. The puncture testing orientations used in certification test units 1 – 3 is graphically shown in Figures 2.10.3-4 through 2.10.3-6 of Revision 20 of the SAR. A large number of puncture tests were performed, most of which were crafted to test a particular feature or a potential weakness. The ones most relevant to the RAJ-II were tests 7 on CTU #1 and test R on CTU #2, where in both cases the relatively smooth side of the package was tested at an oblique angle to the puncture bar, with the bar axis in line with the c.g. of the package. For CTU #1 test 7, the oblique angle was 28°, and for CTU #2 test R, the angle was 23°. Both preliminary testing for this package and actual certification testing demonstrated that the steeper angles just allowed the puncture bar to slide along the surface and not penetrate the skin.

HalfPACT (NRC Docket 71-9279)

The puncture testing orientations used in the engineering test unit and in the certification test unit are graphically shown in Figures 2.10.3-9 and 2.10.3-10, respectively, of Revision 3 of the HalfPACT SAR. As for the TRUPACT-II, several puncture tests were performed, but their orientation was dictated by the desire to test package features, such as the shell thickness transition, while maintaining the center of gravity of the package in line with the puncture bar axis. The consequence is that the angles used were somewhat smaller compared to other packages. Tests 5 and 6 of the CTU were oriented at 16° and 23° to the package surface, respectively.

TNF-XI (NRC Docket 71-9301)

As discussed in the TNF-XI SAR, during the preliminary tests, several punctures at angles of 0° (perpendicular to the surface), 25°, and 45° were performed. In the qualification tests, many of the same tests were repeated, but not the 45° orientation tests, since the damage in these tests was less than for the smaller angles. Therefore, the primary qualification puncture tests were performed at the oblique angle of 25°, besides the perpendicular tests at 0°.

NPC (NRC Docket 71-9294)

As for the TRUPACT-II, most of the puncture tests of the New Powder Container (NPC) were aimed at special package external features such as the lid gap. However, two punctures were performed on relatively featureless regions of the outer surface: puncture drop #12, directly on the package side at 0°, and puncture drop #14, on the package lid, having an oblique angle of 24°.

In conclusion, the oblique puncture angles used during certification testing for the packages examined in this survey varied between 23° and 28°, not counting one of the tests on the HalfPACT, where an angle of 16° was used. (The oblique angles observed were 16°, 23°, 23°, 24°, 25°, and 28°.) Each test was considered to be the worst case, or potentially worst case, condition. Therefore, the angle of 25° used for the RAJ-II testing compares favorably with the practice of a wide range of recently licensed packages.