AREVA

July 24, 2008

ATTN: Document Control Desk
Director, Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: Responses for Mixed Oxide Fresh Fuel Package License Amendment, Docket No. 71-9295 (TAC No. L24054)

This transmittal contains the responses to additional NRC comments provided to AREVA Federal Services LLC (AFS). These comments are a result of a requested license amendment to the MOX Fresh Fuel Package (USA/9295/B(U)F-96).

The comment responses are included in Attachment A. The SAR changes related to the responses are incorporated into Revison 7 of the SAR. One copy of replacement pages for Revision 7 of the SAR is provided. The page delete/insert instructions are included in Attachment B. Revision 7 of the entire SAR is also included electronically as a PDF file, as noted in Attachment C.

If you have any questions or comments regarding this submittal, please contact me at (253) 552-1326, or at fred.yapuncich@areva.com.

Sincerely,

Fred Yapuncich, Project Manager
AREVA Federal Services LLC

Enclosures: As Noted

cc: C. Staab, NRC
R. Clark, Shaw AREVA MOX Services
P. Mann, DOE
R. Migliore

Project File 35037.01.MOXX.6.2

NMSS01

Attachment A
Comment Responses

Criticality

Appendix B:

- B1.2-3 The AFS-B has plates on the outside of it. The AA433 did not. Is the overall package including the AFS-B still below the maximum weight limit?
Response: Yes, the overall package weight (including the AFS-B) is below the maximum weight. The AFS-B (and AFS-C) are designed so that the total package weight is below 14,260 pounds. Note that a fuel assembly weighs up to 1,580 pounds. A loaded AFS-B weighs up to 1,500 pounds (see Table B2.7-1) and a loaded AFS-C weighs up to 1,230 pounds (see Table C2.7-1).
Change to SAR: None

Appendix C:

-C1.1-1 The number of Exxon and PNL rods are increased. However, just as did the AA433, the AFS-C states that these are the maximum that will physically fit into the AFS-C. If the dimensions didn't change from AA433 to AFS-C, then how can more rods be added, and was this analyzed? Shouldn't the weight be different?
Response: The internal dimensions did change from the AA433 to the AFS-C, which is why the total number that will fit changed slightly. The weight of the AA433 is slightly different than the weight of the AFS-C. The criticality analysis conservatively ignored the AA433, so the analysis did not change for the AFS-C. The most reactive case modeled an excess of the number of rods that will fit in the AFS-C, so the original analysis remains bounding.
Change to SAR: None

-C1.2-2 Is there a distinct difference between a AFS-C and a dummy assembly, for the sake of inadvertently storing a AFS-C in place of a dummy assembly?
Response: Both the AFS-C and dummy fuel assembly are clearly labeled. Also, the dummy fuel assembly does not have a removable lid and therefore will look different than an AFS-C.
Change to SAR: None

-C1.2-3 Is the combined heat load of 80 = to the heat load for the Exxon cavity (80 watts) and the PNL cavity (30 watts)?
Response: There are four limits that must all be met: (1) The total package is limited to 240 watts, (2) the AFS-C is limited to 80 watts (total of Exxon and PNL cavities), (3) the Exxon cavity is limited to 80 watts, and (4) the PNL cavity is limited to 30 watts. For example, if there are 25 watts in the PNL cavity, then the Exxon cavity would be limited to 80 – 25 = 55 watts. If the PNL cavity is empty, then 80 watts could be present in the Exxon cavity. If the Exxon cavity is empty, the PNL cavity would be limited to 30 watts.
Change to SAR: None

-C6.1-2 Are the results in Table C6.1-1 still valid with an allowed increase in payload?
Response: Yes, the small increase in payload is bounded by the original analysis. In the most

reactive case, more rods were modeled than could actually fit.
Change to SAR: None

Structural

1) Section 1.0, page 1.1-1: last sentence in paragraph starting with *"Appendix A: Replacing up to three (3)….."* Please identify what "slightly damaged" means? Please defined "damaged fuel rod," and/or characterize/classify level of damage in fuel rods. This information is needed to determine compliance with 10CFR Part 71.33.

Response: The definition of damaged fuel is contained in Appendix A (see page A1.2-1), "Damaged fuel may be bent, scratched, or dented, but under no circumstances may exhibit cladding breach." "Slightly damaged" means the same as "damaged," and is stressing that damage is not severe (i.e., no cladding breach.)
Change to SAR: The definition of damaged fuel has been added to page 1.1-1 to clarify this definition, and as appropriate in A1.2.3.

2) Throughout the main-body of the SAR, sections of Appendices were referenced generically without providing the specific Appendix, (e.g.; "Appendix 1.4.2, *Packaging General Arrangement Drawing"* and "Appendix 2.12.3, *Certification Test Results,"* etc.) which creates some level of confusion since there are three (3) Appendices in revision 6 of SAR. Please state specific appendix when referenced in the main-body of SAR. This request is an editorial correction.

Response: All section headers, table numbers, figure numbers, and page numbers in the document are unique. For example, Appendix 1.4.2 is in the main SAR because there is no A, B, or C in the heading number. In this way, all appendices can be identified by the unique appendix number.
Change to SAR: None

3) Section A7.1, page A7-1: second paragraph: "light damaged rod" is defined as "bent, scratched, nicked, but under no circumstances shell exhibit cladding breach." How is/will the confirmation be made for no cladding breach condition for light damaged rods? This information is needed to determine compliance with 10CFR Part 71.33 and Subpart H.

Response: On page A7-1, it is stated that the "no cladding breach condition" is confirmed by visual inspection. The fuel manufacturer utilizes trained personnel to visually inspect their fuel assemblies and individual rods.
Change to SAR: Change "lightly" to "slightly" for consistency with the other definition of damaged fuel.

4) Section 2.6.5, on page 2.6-11: last sentence – shell outer diameter should read 29.62 inches per sheet 2 of 6 of Drawing 99088-20, Rev. 3. Please recalculate area (A_s) and Moment of Inertia (I_s) accordingly. This request is for recalculation/editorial correction.

Response: This observation is correct. As a fraction, the dimension would be 29-5/8-in. This dimension was rounded up in the analyses (29.63-in) and rounded down on the drawing (29.62-in). However, because the effect on the result is negligible, it is preferable to leave the SAR unchanged.
Change to SAR: None

5) Section 2.6.5, page 2.6-12: Equation for maximum moment (M_{max}) should read $M_{max} = 5{,}869(L_e) + w(L_e)^2/2$. Please recalculate maximum moment (M_{max}), stress (σ) and margin of safety (MS) accordingly. This request is for recalculation/editorial correction.

Response: Revised as suggested.
Change to SAR: This error has been corrected.

6) 6(a) Section B1.2.1, page B1.2-1, referring to Drawings 99008-60, sheet 1 of 2 and 2 of 2 for Item 7, which is a ¼ inch gusset-plate (item7) supporting Item 6: based on the write up in Sections B1.2.1, C1.2.1 and Section A of sheet 2 of Drawings 99008-60, 61 center to center dimension should read 15.35 inches.

Response: It is true that 153.5/10 = 15.35-in. However, since it is desired to show this dimension with a single decimal position (i.e., 0.x), the use of two decimal positions (i.e., 0.xx) would be inappropriate for this dimension. Therefore the 15.35-in. dimension is rounded down to 15.3-in. The difference (equal to 0.05-in.) does not have a significant effect on any calculation. Therefore we request that no change be made to this value.
Change to SAR: None

6(b) Unless otherwise gusset-plates are not placed (welded) intermittently staggered from one side to other, column A1 of Item 7 in "List of Material" table on sheet 1 of Drawing 99008-60 should read "18."

Response: This view is acknowledged to be somewhat confusing, since gussets are typically triangular in shape; however, in this case the triangle is void area and the gusset is the piece with the two notches on the bottom side. Therefore the number of gussets is appropriate for this configuration.
Change to SAR: Change "gusset plate" to "support plate" everywhere in Appendix B and C.

6(c) The side dimensions for triangle gusset-plate (Item 7 of Drawings 99008-60 and 61, Rev. 0) were listed as "7.0X3.25." Based on ratios of known dimensions from Section B on sheet 2 of 2 of Drawings 99008-60 and 61; the item 7 should read "2.0X2.0." These requests are for editorial correction, and compliance with 10CFR Part 71.111.

Response: As noted above, the support plate spans the inner width of the box. From Section B, the width of a support plate is approximately 6.9-in, and the height of a support plate is approximately 6.9 – 3.4 - 0.5 = 3.0-in. Note also that dimensions provided on a parts list are typically oversized and do not correspond exactly to the final machined dimensions to allow for machining tolerances.
Change to SAR: None

7) Sheet 2 of 2, Section A on Drawings 99008-60, 61, Rev. 0: Item 7 (¼ inch triangle gusset plates) is drawn as if the side is as long as width of the cavity. Please compare it to the Section B on the same page. This request is for clerical correction, and compliance with 10CFR Part 71.111.
Response: Please see replies to comments 6b and 6c.

8) Sections B2.7.1 and C2.7.1, Shelf Evaluation: It appears that the weight of securing

devises for fuel rods (if any) were not considered (e.g., clamps, straps, bolts, nuts, washers, spacers, channels, etc.) in impact pressure calculation. Margin of safety may be adversely affected at impact acceleration level of 180g. Please provide discussions why weights of other components were not considered. Please see the next RAI, whether reduction in allowable strength should apply for welded aluminum sections for this case also. This information is needed to determine compliance with 10CFR Part 53(e), Part 71.73, Part 71.107. Reword.

Response: The fuel rods and dunnage rods completely fill the cavity so that other securing devices are not required. Therefore, there are no other items whose weight is not considered. See comment #9 for a discussion of the reduction in aluminum strength as a result of welding.
Change to SAR: None.

9) Qualification of welds was not performed on the fuel rod containers under HAC conditions. Especially, qualifications of 3/8-inch partial groove weld would be a concern. The significant drawback for partial-penetration type of welds is that the opportunity to assure weld quality by non-destructive examinations (NDE) may be denied, and a cross-sectional discontinuity is created. The American Welding Society (AWS) D1.2 "Structural Welding Code – Aluminum" was referenced as the requirement for acceptance criteria for welds in notes 5 of Drawings 99008-60 and 61, Rev.0. One of the requirements in the AWS D1.2 code is the actual weld size shall be equal to or greater than the thickness of the base metal, if visual inspection were to be performed as acceptance criteria. There could be a significant difference between the strength of the heat-effected-zones (HAZ) and the strength of the unaffected sections of the welded aluminum components. Such losses in strength should be considered in designing welded aluminum structures per the ASW D1.2 code. Please provide justification for using a partial groove weld. Reduction in strength should also be considered in welded aluminum fuel rod container evaluations. This information is needed to determine compliance with 10CFR Part 55(e), Part 71.73 and Part 71.107.

Response: Section 2.3.5 of AWS D1.2 permits PJP (partial joint penetration) welds. Further, Section 3 addresses only qualification of weld procedures. Section 3.6.2, Item #8 specifies only the nature of the weld test specimen, not the specified joint. Sections 3.6.1 and 3.6.2, Item #5, specifically acknowledge PJP groove welds. The inspection criteria for visual inspection are found in Section 5.14, *Visual Inspection*. Therefore, it is the applicant's position that AWS D1.2 has been properly observed.

--(Strength reduction not taken in heat affected zones):

None of the welds used in the AFS-B and AFS-C are structural welds. The support plate welds are in compression, while the longitudinal 3/8-in welds, due to the support of the strongback, do not carry any primary loads because the AFS-B/AFS-C is securely attached in the strongback. As for the intermittent welds connecting the shelf to the body, it is intentionally omitted in the center of each 15.3-in long bay so as not to reduce the strength of the aluminum there, where the stresses are greatest (farthest from the support plates). This weld, as such, is never depended upon for structural integrity. To better justify that a reduction does not need to be taken in any structural analysis, the intermittent welds connecting the shelf to the body have been reduced from 8 inches long, centered on the support plates, to 2 inches long. To better clarify the configuration of the weld, it is shown as an intermittent weld, 2 inches long on 15.3-inch centers.

Change to SAR: Flag note 9 of drawings 99008-60 and -61, which is already shown for the weld, has been revised to state: "Center of each 2-inch long weld to coincide with plate (item 7)." The weld symbol has also been revised to indicate an intermittent weld, 2 inches long on 15.3-inch centers.

The following has been added to the third paragraph of Section B2.7.1, and to the paragraph entitled "Shelf Evaluation" in Section C2.7.1:

"Note that each weld between the shelf and the side plates is only 2-inches long, centered on each support plate, as shown in Section B of drawing 99008-60 [-61]. This weld is not structural, and serves only to compensate for any weld distortion which might occur from the two groove welds. As such, a strength reduction does not need to be considered, since the longer, unsupported length between support plates is far from any heat affected zone."

10) Page 2 of 2, Section B on Drawings 99008-60, 61, Rev. 0: typical 1/8" fillet weld symbol with three (3) legs is pointing to the wrong weld locations.

Response: Please see the responses to comments 6b and 6c.

11) Capacity of swivel hoist ring (item 9) was listed as 2,000 lbs in Drawings 99008-60 and 61, Rev. 0. It should be noted that minimum safety factor of three (3) against yielding is required per 10CFR Part 71.45. Please provide discussion why margin of safety of three (3) was not met.

Response: It is our understanding from the phone call that this comment refers to the aluminum threads of the AFS-B and AFS-C, and not to the swivel hoist ring itself. An analysis has been performed that demonstrates the aluminum threads meet a factor of safety of 3 against yielding and 5 against ultimate (ultimate is limiting). This analysis has been added to the SAR.
Change to SAR: The analysis has been added to Sections B2.4 and C2.4.

12)

12-1: Provide discussion/assurance that lifting and securing/closing devises (items 8, 9, 10, 11, 13 of Drawings 99008-60 and 61, Rev. 0) as designed will remain in place at times during normal conditions of transport and hypothetical accident conditions. Provide justification of torque values for bolts that will not breach the pressure boundary under all loading conditions as well as provide discussion of bolt torquing procedure(s).

Response 12-1: The rod box bolts are primarily locational in nature, since the box is retained in the strongback clamp arms. The bolts are retained from loosening using the aluminum washers, which are bent to hold the head. No specific bolt torquing procedure is required since the bolts only locate the lid and do not hold it in place during NCT or HAC. The rod box is not a pressure boundary.

The bolted joints in the rod box are adequately designed. The amount of material around the threaded holes is adequate by comparison to the design of standard nuts. For a 3/8-inch bolt, the nut is 9/16 inches across wrench flats, so the minimum thickness of the nut is equal to:

$$\left(\frac{9}{16}-\frac{3}{8}\right)\times\frac{1}{2}=0.094\text{ in}$$

The thickness of the material in the rod box wall section is equal to:

$$\left(\frac{3}{4}-\frac{3}{8}\right)\times\frac{1}{2}=0.188\text{ in}$$

Therefore, the thickness around the threaded hole in the rod box is twice as much as in a standard nut. Therefore, the joint design of the rod box is acceptable.

Change to SAR 12-1: None

12-2: Section 2.6.1.3.4 in the report refers to Table 4.2 of NUREG/CR-6007 as the source of nut factor (K), but they were listed in Table 4.1 in NUREG/CR-6007 (request for editorial correction).

Response 12-2: The SAR has been modified to note the correct table.
Change to SAR 12-2: Section 2.6.1.3.4 has been changed to read Table 4.1 instead of Table 4.2, as requested.

12-3: The values for nut factor (K) are experimentally derived constants. As a result, this experimental constant is subjected to wide variation, depending upon the specific condition under which it was measured. Even though, the lubricant type is often the dominating variable, it was advised to determine the actual nut factor on specific applications by testing. The value of 0.157 was used as the nut factor in the analytical hand calculations throughout the SAR. Please provide detailed discussion that the used nut factor is appropriate for this application. Please provide discussion on appropriateness of embedment, spacing, and edge distances of bolts used through out the assembly. This information is needed to determine compliance with 10CFR Part 55 and Part 71.107.

Response 12-3: The use of the bolt preload formula F = T/(kd) has been common practice for the analysis and sizing of bolts for many years. This formula depends on the nut factor, k. It has been acknowledged in the literature on bolts that the actual preload in a bolt can vary due to variation in k, which appears to depend heavily on the type of lubrication. Other factors affecting the preload force are the tightening method, the tightening speed, the operator skill, the bolt diameter and material, and perhaps other factors. If all of these variation factors are treated cumulatively, the calculated variation in preload force would spread over such a large range that a practical bolted joint design could not be achieved. However, bolted joints are used in every part of the nuclear industry, and experience demonstrates that these joints are safe and reliable.

The great majority of bolted joints in RAM packagings are tightened using a torque wrench. Examples include the 125-B (NRC docket 71-9200), the RH-TRU 72-B (NRC docket 71-9212), the RTG (DOE docket 71-9904), the T-3 (DOE docket 71-9132), the TN-FSV (NRC docket 71-9253), the NAC-LWT (NRC docket 71-9225), and the NAC-STC (NRC docket 71-9235). These examples represent a large variation in bolt surface finishes, platings, and lubrication (including no lubrication), as well as in other factors relating to the preload of the bolt. However, in spite of the wide parametric variation, they demonstrate that a reasoned approach to the design and analysis is more than adequate to ensure long-term reliability of the bolted joints.

Because so many factors can affect the actual bolt preload, and because these factors cannot be readily controlled, bolt analysis is not a precise science. Part of the successful application of the bolt preload formula [F = T/(kd)] is the use of judgment in the choice of input variables. The formula is widely and successfully used, yet it contains only one variable in the denominator, k, with which to capture all of the variation possible in the actual preload of a bolted joint. In general, it would require a more elaborate formula to properly account for all of the variables. However, the traditional formula has proven its ability in design calculations, and need not be abandoned. It is acceptable to continue to use the traditional formula by choosing an average value for k which accounts for the conditions which are expected to apply.

In the case of the MFFP, in which the bolts are lubricated, it is preferable to use the average nut factor for a variety of lubricants, since a particular lubricant has not been specified. It was chosen not to specify a particular lubricant, since during package operation, that exact lubricant may not be available. The drawing specifies that the lubricant be nickel-based and nuclear-grade. It is reasonable to assume that any lubricant meeting this specification will produce an acceptable preloaded joint, based on the broad experiences of RAM packaging listed above. For these reasons, it is acceptable to use the average nut factor of 0.157 in the preload calculations.

The burden of this discussion has been to show that, although the use of the preload formula with an average nut factor does not always capture all of the possible variation in preload, it is however an effective design approach. This is not only demonstrated by the successful history already alluded to, but by the actual experience of the MFFP, which was tested in full scale as described in Appendix 2.12.3 of the SAR. After numerous free drops and punctures, the MFFP prototypic certification unit was helium leak tight each time it was tested. Therefore, the closure bolts of the MFFP perform as designed.
Change to SAR 12-3: None

13) In Section 2.2.2 and in Sections A2.2, B2.2, C2.2 in Appendices A, B, C the applicant stated that *"materials of the transportation cask will not have significant chemical and galvanic reactions, and are not significantly affected by radiation, which was concluded from the previous use of similar materials without any incident."* In Section 8.2, the applicant states that *"the requirements of periodic maintenance program that includes pressure of MPPF, and leakage rate testing of penetrations and seals to ensure continued performance."* The applicant will visually inspect fabricated components of MPPF to ensure justification for continued operation. Slow developing material degradation mechanisms due to structural and/or metallurgical defects under normal service loading conditions are difficult to identify visually at initial stages. Immediately after that initial stage, growth/ propagation stages can develop in exponential levels. Regulations in 10CFR Part 71, Subpart H require that Type B packaging be designed, constructed and maintained under a certified quality assurance program – *"e.g.; Section 8.0 Quality Assurance of NUREG/CR-6007 states that "bolts should undergo acceptance testing prior to use that the tests should include both destructive and non-destructive testing," Section 8.0 of NUREG-1609 states about the requirements of periodic tests and replacements of components, and Section 2 of NUREG-1609-Supplement 1states that there can be significantly greater chemical and radiation effects in MOX-RAM packages than in LEU-RAM packages."* Please provide discussions to ensure the structural integrity for load bearing critical components of the packaging system will be in compliance with the regulatory requirements during its service life with a quality assurance/ maintenance program, which does not include periodic NDE techniques.

Response: Regarding the effects of radiation, the field from a fresh fuel MOX package is extremely weak when compared to spent fuel packagings, and no structural degradation is evident in those packages. As for periodic testing, we note that the containment boundary is pressure tested, followed by helium leakage rate testing, every five years. Helium leakage rate testing is performed on the containment seal at replacement. The bolts are visually inspected before each use. Bolts have been analyzed for fatigue in Section 2.1.2.2.2.1 and have a generous margin against fatigue failure. There are consequently numerous inspections of structural parts in the maintenance program.

Change to SAR: None

14) On Figures B2.7-1 and C2.7-1 "Gusset Plates" arrow is pointing to the cavity of the rod container. The arrow should point at the gusset plate. This request is for clerical correction.

Response: Correct as drawn, please see response to comments 6b and 6c.

15) Sections B8.2 and C8.2 state that "scheduled maintenance program is not required, and visual inspections are performed on fuel rod containers that, if required, repair and replacement shall be performed prior to use." Please provide discussions on how a discretionary maintenance application can ensure structural integrity of fuel rod containers. If a fuel rod container were to be declared damaged - is there a proper process of checking the integrity of unloaded fuel rods? This information is needed to determine for compliance with 10CFR Part 71.101.

Response: If a fuel rod container were damaged, it would not be loaded with fuel rods. If a fuel rod container is undamaged at loading, it would not become damaged during shipment because it is tightly secured in the strongback. In addition, detailed procedures outside the scope of the SAR will be used for loading and unloading the package. Further, the maintenance program is not discretionary. The SAR states that "damaged components shall be repaired or replaced prior to use."

Change to SAR: None.

We were hoping that we would be able to retrieve your SINDA/FLUINT input files. Our intention is to not review them as part of the amendment approval, but rather to have them for file.

Response: The input files were e-mailed directly to christopher.bajwa@nrc.gov.

Attachment B
Delete/Insert Instructions
Revision 7 of MFFP Safety Analysis Report

SAR Section	Delete Pages from Rev. 6	Insert Pages to Rev. 7
Cover and Spine, Vol. 1	Cover and spine, Vol. 1	Cover and spine, Vol. 1
Title page, Vol. 1	Title page, Vol. 1	Title page, Vol. 1
Table of Contents	xiii through xxii	xiii through xxii
Chapter 1	1.1-1 and 1.1-2	1.1-1 and 1.1-2
Chapter 2	2.6-7 and 2.6-8	2.6-7 and 2.6-8
	2.6-11 and 2.6-12	2.6-11 and 2.6-12
Cover and Spine, Vol. 2	Cover and spine, Vol. 2	Cover and spine, Vol. 2
Title page, Vol. 2	Title page, Vol. 2	Title page, Vol. 2
Chapter A1	A1.2-1 through A1.2-4	A1.2-1 through A1.2-4
Chapter A7	A7-1 and A7-2	A7-1 and A7-2
Chapter A8	A8-1 and A8-2	A8-1 and A8-2
Chapter B1	B1.2-1 and B1.2-2	B1.2-1 and B1.2-2
	B1.4-1 and B1.4-2	B1.4-1 and B1.4-2
	Drawing 99008-60, Rev. 0	Drawing 99008-60, Rev. 1
Chapter B2	B2-1 through B2-10	B2-1 through B2-12
Chapter C1	C1.2-1 and C1.2-2	C1.2-1 and C1.2-2
	C1.4-1 and C1.4-2	C1.4-1 and C1.4-2
	Drawing 99008-61, Rev. 0	Drawing 99008-61, Rev. 1
Chapter C2	C2-1 through C2-12	C2-1 through C2-14

Attachment C
Contents of Electronic Media

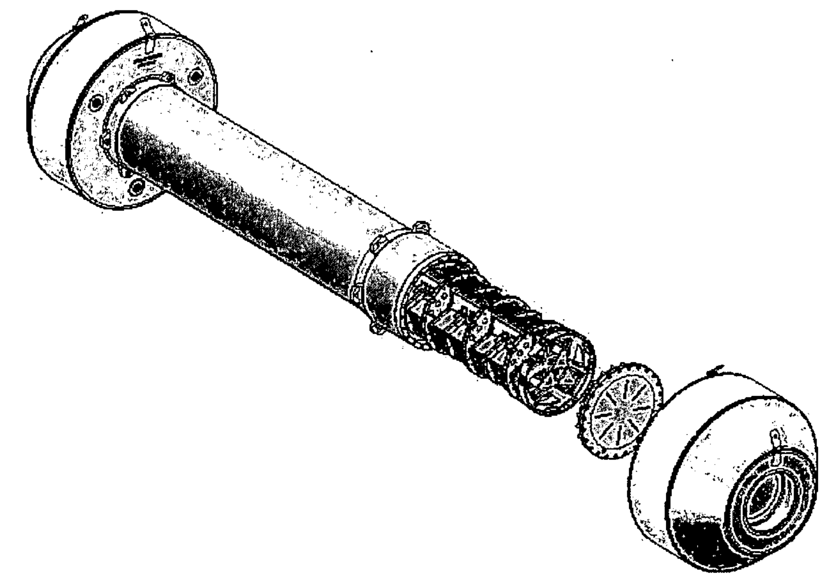
This submission is composed of both paper copies and electronic copies. The electronic copies are contained within an envelope labeled, "MFFP Docket 71-9295 Electronic Copy of Document." The envelope contains one compact disc of the following:

Title	Media Type	Contents
MOX Fresh Fuel Package Safety Analysis Report	CD-ROM	One file of the complete text of the submittal, including replacement pages: **001 MFFP SAR, Rev 7.PDF (876 pages, 31.774 MB)**

DOCKET 71-9295

AREVA

Mixed Oxide Fresh Fuel Package



Safety Analysis Report

Volume 1
Revision 7
July 2008

This page left intentionally blank.

A6.3.4 Demonstration of Maximum Reactivity A6.3-1

A6.4 Single Package Evaluation A6.4-1

A6.4.1 Single Package Configuration A6.4-1

A6.4.1.1 NCT Configuration A6.4-1

A6.4.1.2 HAC Configuration A6.4-1

A6.4.2 Single Package Results A6.4-2

A6.5 Evaluation of Package Arrays Under Normal Conditions of Transport A6.5-1

A6.6 Package Arrays Under Hypothetical Accident Conditions A6.6-1

A6.6.1 HAC Array Configuration A6.6-1

A6.6.2 HAC Array Results A6.6-1

A6.7 Fissile Material Packages for Air Transport A6.7-1

A6.8 Benchmark Evaluations A6.8-1

A6.9 Appendices A6.9-1

A6.9.1 Single Package Model A6.9.1-1

A6.9.2 Infinite Array Model A6.9.2-1

A7.0 PACKAGE OPERATIONS A7-1

A7.1 Package Loading A7-1

A7.2 Package Unloading A7-1

A7.3 Preparation of an Empty Package for Transport A7-1

A7.4 Preshipment Leakage Rate Test A7-1

A8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM A8-1

A8.1 Acceptance Tests A8-1

A8.1.1 Visual Inspections and Measurements A8-1

A8.1.2 Weld Inspections A8-1

A8.1.3 Structural and Pressure Tests A8-1

A8.1.4 Fabrication Leakage Rate Tests A8-1

A8.1.5 Component and Material Tests A8-1

A8.1.6 Shielding Tests A8-1

A8.1.7 Thermal Tests A8-1

A8.2 Maintenance Program A8-2

APPENDIX B: EXCESS MATERIAL ASSEMBLY AND AFS-B WITH MOX RODS

B1.0 GENERAL INFORMATION B1.1-1

B1.1 Introduction B1.1-1

B1.2 Package Description B1.2-1

B1.2.1 Packaging B1.2-1

B1.2.2 Containment System B1.2-1

B1.2.3 Contents of Packaging B1.2-2

B1.2.3.1 Radionuclide Inventory B1.2-2

B1.2.3.2 Maximum Payload Weight B1.2-2

B1.2.3.3 Maximum Decay Heat B1.2-3

B1.2.3.4 Maximum Pressure Buildup B1.2-3

B1.2.4 Operational Features B1.2-3

B1.3 General Requirements for All Packages B1.3-1

B1.4 Appendices B1.4-1

B1.4.1 Nomenclature B1.4-1

B1.4.2 Packaging General Arrangement Drawings B1.4-1

B2.0 STRUCTURAL EVALUATION B2-1

B2.1 Structural Design B2-1

B2.1.1 Discussion B2-1

B2.1.2 Design Criteria B2-1

B2.1.3 Weights and Center of Gravity B2-2

B2.2 Materials B2-2

B2.3 Fabrication and Examination B2-3

B2.4 Lifting and Tie-down Standards for All Packages B2-3

B2.5 General Considerations B2-4

B2.6 Normal Conditions of Transport B2-4

B2.6.1 Heat B2-4

B2.6.1.1 Differential Thermal Expansion B2-4

B2.6.2 Cold B2-5

B2.6.3 Reduced External Pressure B2-5

B2.6.4 Increased External Pressure B2-5

B2.6.5 Vibration and Shock B2-5

B2.6.6 Water Spray B2-5
B2.6.7 Free Drop B2-5
B2.6.8 Corner Drop B2-5
B2.6.9 Compression B2-5
B2.6.10 Penetration B2-6

B2.7 Hypothetical Accident Conditions B2-6
B2.7.1 Free Drop B2-6
B2.7.2 Crush B2-9
B2.7.3 Puncture B2-9
B2.7.4 Thermal B2-9
B2.7.4.1 Summary of Pressures and Temperatures B2-9
B2.7.4.2 Differential Thermal Expansion B2-10
B2.7.4.3 Stress Calculations B2-10
B2.7.5 Immersion – Fissile Material B2-10
B2.7.6 Immersion – All Packages B2-10
B2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A_2) B2-10
B2.7.8 Summary of Damage B2-10

B2.8 Accident Conditions for Air Transport of Plutonium B2-10

B2.9 Accident Conditions for Fissile Material Packages for Air Transport B2-10

B2.10 Special Form B2-11

B2.11 Fuel Rods B2-11

B2.12 Appendices B2-11

B3.0 THERMAL EVALUATION B3.1-1

B3.1 Description of Thermal Design B3.1-1
B3.1.1 Design Features B3.1-1
B3.1.2 Content's Decay Heat B3.1-1
B3.1.3 Summary of Temperatures B3.1-1
B3.1.4 Summary of Maximum Pressures B3.1-2

B3.2 Material Properties and Component Specifications B3.2-1
B3.2.1 Material Properties B3.2-1
B3.2.2 Component Specifications B3.2-1

B3.3 General Considerations B3.3-1
B3.3.1 Evaluations by Analysis B3.3-1
B3.3.1.1 NCT Analytical Model B3.3-1

B3.3.1.2 HAC Analytical Model B3.3-5
B3.3.2 Evaluation by Test B3.3-5
B3.3.3 Margins of Safety B3.3-6

B3.4 Thermal Evaluation for Normal Conditions of Transport B3.4-1
B3.4.1 Heat and Cold B3.4-1
B3.4.1.1 Heat B3.4-1
B3.4.1.2 Cold B3.4-1
B3.4.2 Maximum Normal Operating Pressure B3.4-2
B3.4.3 Maximum Thermal Stresses B3.4-3
B3.4.4 Evaluation of Package Performance for Normal Conditions of Transport B3.4-3

B3.5 Thermal Evaluation under Hypothetical Accident Conditions B3.5-1
B3.5.1 Initial Conditions B3.5-1
B3.5.2 Fire Test Conditions B3.5-1
B3.5.2.1 Analytical Model B3.5-1
B3.5.3 Maximum Temperatures and Pressures B3.5-1
B3.5.3.1 Maximum Temperatures B3.5-1
B3.5.3.2 Maximum Pressures B3.5-2
B3.5.4 Accident Conditions for Fissile Material Packages for Air Transport B3.5-2
B3.5.5 Evaluation of Package Performance for Accident Conditions of Transport B3.5-3

B3.6 Appendices B3.6.1-1
B3.6.1 Computer Analysis Results B3.6.1-1

B4.0 CONTAINMENT B4-1

B5.0 SHIELDING B5-1

B6.0 CRITICALITY EVALUATION B6.1-1

B6.1 Description of Criticality Design B6.1-1
B6.1.1 Design Features Important for Criticality B6.1-1
B6.1.2 Summary Table of Criticality Evaluation B6.1-1
B6.1.3 Criticality Safety Index B6.1-2

B6.2 Fissile Material Contents B6.2-1

B6.3 General Considerations B6.3-1
B6.3.1 Model Configuration B6.3-1
B6.3.1.1 Contents Model B6.3-1

B6.3.1.2 Packaging Model B6.3-1
B6.3.2 Material Properties B6.3-1
B6.3.3 Computer Codes and Cross-Section Libraries B6.3-1
B6.3.4 Demonstration of Maximum Reactivity B6.3-1

B6.4 Single Package Evaluation B6.4-1
B6.4.1 Single Package Configuration B6.4-1
B6.4.1.1 NCT Configuration B6.4-1
B6.4.1.2 HAC Configuration B6.4-1
B6.4.2 Single Package Results B6.4-3

B6.5 Evaluation of Package Arrays Under Normal Conditions of Transport B6.5-1

B6.6 Package Arrays Under Hypothetical Accident Conditions B6.6-1
B6.6.1 HAC Array Configuration B6.6-1
B6.6.2 HAC Array Results B6.6-1

B6.7 Fissile Material Packages for Air Transport B6.7-1

B6.8 Benchmark Evaluations B6.8-1

B6.9 Appendices B6.9-1
B6.9.1 Single Package Model B6.9.1-1
B6.9.2 Infinite Array Model B6.9.2-1

B7.0 PACKAGE OPERATIONS B7-1

B7.1 Package Loading B7-1

B7.2 Package Unloading B7-1

B7.3 Preparation of an Empty Package for Transport B7-1

B7.4 Preshipment Leakage Rate Test B7-2

B8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM B8-1

B8.1 Acceptance Tests B8-1
B8.1.1 Visual Inspections and Measurements B8-1
B8.1.2 Weld Inspections B8-1
B8.1.3 Structural and Pressure Tests B8-1
B8.1.4 Fabrication Leakage Rate Tests B8-1
B8.1.5 Component and Material Tests B8-1
B8.1.6 Shielding Tests B8-1
B8.1.7 Thermal Tests B8-1

B8.2 Maintenance Program B8-2

APPENDIX C: AFS-C WITH TA-18 MOX RODS

C1.0 GENERAL INFORMATION **C1.1-1**

C1.1 Introduction **C1.1-1**

C1.2 Package Description **C1.2-1**

C1.2.1 Packaging C1.2-1
C1.2.2 Containment System C1.2-2
C1.2.3 Contents of Packaging C1.2-2
C1.2.3.1 Radionuclide Inventory C1.2-2
C1.2.3.2 Maximum Payload Weight C1.2-2
C1.2.3.3 Maximum Decay Heat C1.2-3
C1.2.3.4 Maximum Pressure Buildup C1.2-3
C1.2.4 Operational Features C1.2-3

C1.3 General Requirements for All Packages **C1.3-1**

C1.4 Appendices **C1.4-1**

C1.4.1 Nomenclature C1.4-1
C1.4.2 Packaging General Arrangement Drawings C1.4-1

C2.0 STRUCTURAL EVALUATION **C2-1**

C2.1 Structural Design **C2-1**

C2.1.1 Discussion C2-1
C2.1.2 Design Criteria C2-1
C2.1.3 Weights and Center of Gravity C2-2

C2.2 Materials **C2-2**

C2.3 Fabrication and Examination **C2-3**

C2.4 Lifting and Tie-down Standards for All Packages **C2-3**

C2.5 General Considerations **C2-4**

C2.6 Normal Conditions of Transport **C2-4**

C2.6.1 Heat C2-4
C2.6.1.1 Differential Thermal Expansion C2-4
C2.6.2 Cold C2-5
C2.6.3 Reduced External Pressure C2-5
C2.6.4 Increased External Pressure C2-5
C2.6.5 Vibration and Shock C2-5
C2.6.6 Water Spray C2-5

C2.6.7 Free Drop....C2-5
C2.6.8 Corner Drop....C2-5
C2.6.9 Compression....C2-5
C2.6.10 Penetration....C2-6

C2.7 Hypothetical Accident Conditions.... C2-6
C2.7.1 Free Drop....C2-6
C2.7.2 Crush....C2-11
C2.7.3 Puncture....C2-11
C2.7.4 Thermal....C2-12
C2.7.4.1 Summary of Pressures and Temperatures....C2-12
C2.7.4.2 Differential Thermal Expansion....C2-12
C2.7.4.3 Stress Calculations....C2-12
C2.7.5 Immersion – Fissile Material....C2-12
C2.7.6 Immersion – All Packages....C2-12
C2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A_2)....C2-12
C2.7.8 Summary of Damage....C2-12

C2.8 Accident Conditions for Air Transport of Plutonium.... C2-13

C2.9 Accident Conditions for Fissile Material Packages for Air Transport.... C2-13

C2.10 Special Form.... C2-13

C2.11 Fuel Rods.... C2-13

C2.12 Appendices.... C2-13

C3.0 THERMAL EVALUATION.... C3.1-1

C3.1 Description of Thermal Design.... C3.1-1
C3.1.1 Design Features....C3.1-1
C3.1.2 Content's Decay Heat....C3.1-1
C3.1.3 Summary of Temperatures....C3.1-2
C3.1.4 Summary of Maximum Pressures....C3.1-2

C3.2 Material Properties and Component Specifications.... C3.2-1
C3.2.1 Material Properties....C3.2-1
C3.2.2 Component Specifications....C3.2-1

C3.3 General Considerations.... C3.3-1
C3.3.1 Evaluations by Analysis....C3.3-1
C3.3.1.1 NCT Analytical Model....C3.3-1
C3.3.1.2 HAC Analytical Model....C3.3-5

C3.3.2 Evaluation by Test C3.3-6
C3.3.3 Margins of Safety C3.3-6

C3.4 Thermal Evaluation for Normal Conditions of Transport C3.4-1
C3.4.1 Heat and Cold C3.4-1
C3.4.1.1 Heat C3.4-1
C3.4.1.2 Cold C3.4-2
C3.4.2 Maximum Normal Operating Pressure C3.4-2
C3.4.3 Maximum Thermal Stresses C3.4-4
C3.4.4 Evaluation of Package Performance for Normal Conditions of Transport C3.4-4

C3.5 Thermal Evaluation under Hypothetical Accident Conditions C3.5-1
C3.5.1 Initial Conditions C3.5-1
C3.5.2 Fire Test Conditions C3.5-1
C3.5.2.1 Analytical Model C3.5-1
C3.5.3 Maximum Temperatures and Pressures C3.5-1
C3.5.3.1 Maximum Temperatures C3.5-1
C3.5.3.2 Maximum Pressures C3.5-2
C3.5.4 Accident Conditions for Fissile Material Packages for Air Transport C3.5-2
C3.5.5 Evaluation of Package Performance for Accident Conditions of Transport C3.5-3

C3.6 Appendices C3.6.1-1
C3.6.1 Computer Analysis Results C3.6.1-1

C4.0 CONTAINMENT C4-1

C5.0 SHIELDING C5-1

C6.0 CRITICALITY EVALUATION C6.1-1

C6.1 Description of Criticality Design C6.1-1
C6.1.1 Design Features Important for Criticality C6.1-1
C6.1.2 Summary Table of Criticality Evaluation C6.1-1
C6.1.3 Criticality Safety Index C6.1-2

C6.2 Fissile Material Contents C6.2-1

C6.3 General Considerations C6.3-1
C6.3.1 Model Configuration C6.3-1
C6.3.1.1 Contents Model C6.3-1
C6.3.1.2 Packaging Model C6.3-1
C6.3.2 Material Properties C6.3-1

C6.3.3 Computer Codes and Cross-Section Libraries C6.3-1
C6.3.4 Demonstration of Maximum Reactivity C6.3-2

C6.4 Single Package Evaluation C6.4-1
C6.4.1 Single Package Configuration C6.4-1
C6.4.1.1 NCT Configuration C6.4-1
C6.4.1.2 HAC Configuration C6.4-1
C6.4.2 Single Package Results C6.4-6

C6.5 Evaluation of Package Arrays Under Normal Conditions of Transport...... C6.5-1
C6.5.1 NCT Array Configuration C6.5-1
C6.5.2 NCT Array Results C6.5-1

C6.6 Package Arrays Under Hypothetical Accident Conditions........................... C6.6-1
C6.6.1 HAC Array Configuration C6.6-1
C6.6.2 HAC Array Results C6.6-2

C6.7 Fissile Material Packages for Air Transport... C6.7-1

C6.8 Benchmark Evaluations C6.8-1

C6.9 Appendices C6.9-1
C6.9.1 Single Package Model C6.9.1-1
C6.9.2 Infinite Array Model C6.9.2-1

C7.0 PACKAGE OPERATIONS C7-1

C7.1 Package Loading C7-1

C7.2 Package Unloading C7-1

C7.3 Preparation of an Empty Package for Transport.. C7-2

C7.4 Preshipment Leakage Rate Test... C7-2

C8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM C8-1

C8.1 Acceptance Tests C8-1
C8.1.1 Visual Inspections and Meausrements C8-1
C8.1.2 Weld Inspections C8-1
C8.1.3 Structural and Pressure Tests C8-1
C8.1.4 Fabrication Leakage Rate Tests C8-1
C8.1.5 Component and Material Tests... C8-1
C8.1.6 Shielding Tests C8-1
C8.1.7 Thermal Tests C8-1

C8.2 Maintenance Program C8-2

This page left intentionally blank.

1.0 GENERAL INFORMATION

This chapter of the Mixed Oxide Fresh Fuel Package (MFFP) Safety Analysis Report (SAR) presents a general introduction and description of the package. The MFFP is utilized for transport of mixed oxide (MOX) fresh fuel assemblies in accordance with the requirements of 10 CFR 71[1] and 49 CFR 173[2]. The major components of the packaging system are shown in Figure 1.1-1. The containment boundary is identified in Figure 1.1-2. Additional figures and schematics are presented in support of the discussion within this chapter. Terminology used throughout this SAR is presented in Section 1.4.1, *Nomenclature*. General arrangement drawings of the packaging are provided in Appendix 1.4.2, *Packaging General Arrangement Drawings*.

The main body of the SAR provides the analysis for the contents of three (3) intact fuel assemblies. Three Appendices have been added to the main SAR to address three additional contents:

> **Appendix A:** Replacing up to three (3) standard fuel assemblies with Areva Rod Box 17 (ARB-17) containers. Each ARB-17 may contain up to 17 standard MOX fuel rods. The fuel rods may be undamaged or slightly damaged. Slightly damaged rods are defined as rods that may be bent, scratched, or dented, but under no circumstances exhibit cladding breach.
>
> **Appendix B:** Contents of up to one (1) AFS-B rod container, and one (1) Excess Material Assembly (EMA). The AFS-B may contain up to 175 standard MOX fuel rods. For transportation purposes, the EMA is equivalent to a MOX fuel assembly.
>
> **Appendix C:** Contents of up to three (3) AFS-C rod containers containing two types of rods currently stored at Los Alamos Technical Area 18 (TA-18), Exxon rods and Pacific Northwest Laboratory (PNL) rods. TA-18 rods are MOX rods but are not the same as standard MOX rods. Each AFS-C may contain up to 116 Exxon rods and 69 PNL rods.

Each Appendix has eight chapters and follows the same format as the main body of the SAR, referring to the main body of the SAR for information common to both.

1.1 Introduction

The Mixed Oxide Fresh Fuel Package, Model: **MFFP**, is designed to transport fresh MOX pressurized water reactor (PWR) reactor fuel assemblies. The packaging is designed to provide a safe means of transporting up to three fresh MOX PWR fuel assemblies, with or without burnable poison rod assemblies (BPRAs) installed.

This SAR contains the information required to conclusively demonstrate that when the MFFP is subjected to the applicable tests described in Subpart F of 10 CFR 71, the applicable requirements of Subpart E of 10 CFR 71 have been met. A combination of analytical and full-scale prototypic testing is used to demonstrate that the MFFP satisfies these requirements. A full-scale, prototypic certification test unit (CTU) was subjected to a series of hypothetical

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Materials*, Final Rule, 01-26-04.

[2] Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), *Shippers-General Requirements for Shipments and Packagings*, Final Rule, 01-26-04.

accident condition (HAC) free and puncture drop tests. A detailed discussion of the CTU and certification tests is provided in Appendix 2.12.3, *Certification Test Results*. These tests, coupled with supplementary analytical evaluations, conclusively demonstrated the leaktight[3] containment boundary integrity and criticality control performance of the MFFP.

Based on the shielding and criticality assessments provided in Chapter 5.0, *Shielding Evaluation*, and Chapter 6.0, *Criticality Evaluation*, the Criticality Safety Index (CSI) for the MFFP is zero (0.0), and the Transport Index (TI) is determined at the time of shipment.

Authorization is sought for shipment of the MFFP by all modes of conveyance, except for aircraft, as a Type B(U)F package per the definitions delineated in 10 CFR §71.4.

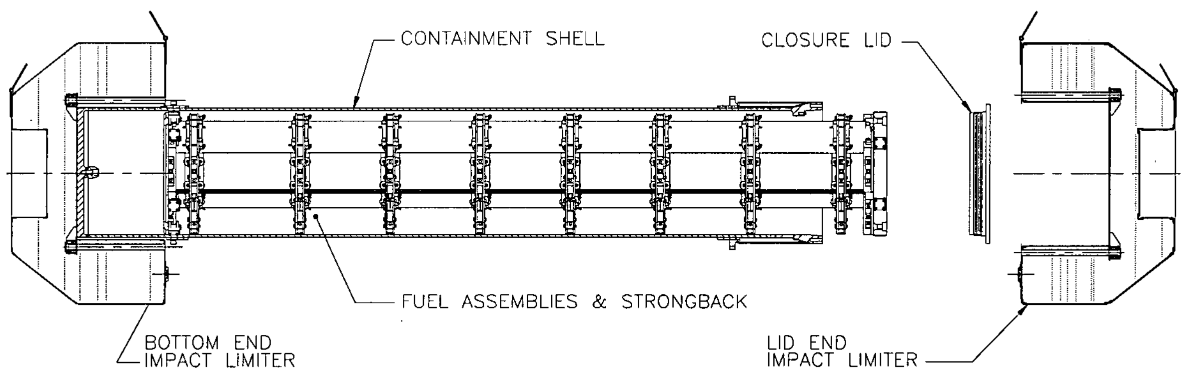


Figure 1.1-1 – Major MFFP Components

[3] Leaktight is defined as 1×10^{-7} standard cubic centimeters per second (scc/s), or less, air leakage per ANSI N14.5-1997, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*, American National Standards Institute, (ANSI), Inc

2.6.1.3.4 Closure Bolt Evaluation

The closure bolts are tightened to a maximum of 220 lb_f-ft torque (minimum torque is 175 lb_f-ft). From Subsection 4.2 of NUREG/CR-6007[5], the maximum non-prying tensile force per bolt due to preload, Fa_{max}, is found from:

$$Fa_{max} = \frac{Q_{max}}{(K)(Db)} = \frac{12(220)}{(0.157)(0.75)} = 22{,}420\ lb_f$$

where Q_{max} = 220 lb_f-ft is the maximum applied closure bolt preload, K= 0.157 is the nut factor (based the average K for lubricated bolts from Table 4.1 of NUREG/CR-6007), and Db=0.75 inches is the closure bolt nominal diameter. The closure lid has a step located at the bolt circle diameter which precludes prying forces.

The maximum residual torsion is 50% of the applied torsion:

$$Mtr = 0.5(Q_{max})\ 0.5(12 \times 220) = 1{,}320\ in\text{-}lb_f$$

From Subsection 4.4 of NUREG/CR-6007, utilizing appropriate temperature dependent material properties from Section 2.2.1, *Material Properties and Specifications*, the maximum non-prying tensile force per bolt, Fa, due to pressure loads are based on the following formula:

$$Fa = \frac{\pi(Dlg)^2(Pli - Plo)}{4Nb} = \frac{\pi(28.97)^2(39.7 - 14.7)}{4 \cdot 24} = 687\ lb_f$$

where Dlg = 28.97 inches is the closure lid diameter at the location of gasket load reaction (i.e., the O-ring seal diameter), Pli = 39.7 psia is the pressure inside the closure lid, Plo = 14.7 psia is the pressure outside the closure lid, and Nb = 24 is the total number of closure bolts.

The bolt diameter used for stress calculations is based on the stress diameter of the closure bolts, i.e., Dba = 0.653 inches[6]. The closure bolt tensile stress, Sba, is defined as:

$$Sba = (1.2732)\frac{\sum Fa}{Dba^2} = (1.2732)\frac{22{,}420 + 687}{0.653^2} = 68{,}994\ psi$$

From Table 2.1-1, for NCT the allowable average tensile stress is $S_m = (2/3)S_y$. The allowable tensile stress is therefore 73,187 psi at a conservative temperature of 160 °F, from Table 2.6-1. The corresponding margin of safety on average tensile stress, $\sigma_{t\text{-ave}}$, is:

$$MS_{\sigma_{t\text{-ave}}} = \frac{73{,}187}{68{,}994} - 1.0 = +0.06$$

While the temperature of the closure bolts and the closure lid are essentially identical in all cases, a thermally induced load is applied to the bolts since the thermal expansion coefficient of the ASTM A564, Grade 630 Condition H1100, alloy steel closure bolts and Type XM-19 stainless steel closure lid differ. From Subsection 4.5 of NUREG/CR-6007, utilizing appropriate

---

[5] G.C. Mok, L.E. Fischer, S.T. Hsu, *Stress Analysis of Closure Bolts for Shipping Casks*, NUREG/CR-6007, UCRL-ED-110637, U.S. Nuclear Regulatory Commission, April 1992

[6] From Table 5.1 of NUREG/CR-6007: Dba = Db - 0.9743 p, where Db is the nominal diameter of the closure bolt and p is the pitch = 0.1 inches per thread.

temperature dependent material properties from Section 2.2.1, *Material Properties and Specifications*, the maximum non-prying tensile force per bolt due to thermal differential expansion of the closure bolt and the closure lid is based on the following formula:

$$Fa_{therm} = \left(\frac{\pi}{4}\right)(Db)^2(Eb)[(al)(Tl)-(ab)(Tb)]$$

$$Fa_{therm} = \left(\frac{\pi}{4}\right)(0.75)^2\left(28.8\times10^6\right)\left[\left(8.4\times10^{-6}\right)(90)-\left(5.5\times10^{-6}\right)(90)\right] = 3{,}321\ lb_f$$

where Db is the bolt diameter, Eb = 28.8 × 10^6 psi is the elastic modulus of the closure bolt material, al = 8.4 × 10^{-6} in/in/°F is the thermal expansion coefficient of the closure lid material, ab = 5.5 × 10^{-6} in/in/°F is the thermal expansion coefficient of the closure bolt material, Tl = 90 °F is the temperature change of the closure lid from a reference temperature of 70 °F, and Tb = 90 °F is the temperature change of the closure bolt from a reference temperature of 70 °F.

The closure bolt thermal stress, Sb_{therm}, is defined as:

$$Sb_{therm} = (1.2732)\frac{\sum Fa}{Dba^2} = (1.2732)\frac{3{,}321}{0.653^2} = 9{,}916\ psi$$

The closure bolt shear stress due to torsion, Sbt, is defined as:

$$Sbt = (5.093)\frac{\sum Mt}{Dba^3} = (5.093)\frac{1{,}320}{0.653^3} = 24{,}144\ psi$$

Finally, the maximum closure bolt stress intensity, Sbi, is defined as:

$$Sbi = \sqrt{(Sba + Sb_{therm})^2 + 4Sbt^2} = \sqrt{(68{,}994+9{,}916)^2 + 4(24{,}144)^2} = 92{,}512\ psi$$

Note that there are no applied shear stresses since the shear load is carried by the closure lid.

For tension-plus-residual torsion, and closure bolts having a minimum ultimate stress, S_u, greater than 100,000 psi, the maximum stress intensity is $1.35S_m$. The allowable stress intensity is 98,802 psi and the corresponding margin of safety on average tensile + residual torsion stress (σ+τ) is:

$$MS_{(\sigma+\tau)} = \frac{98{,}802}{92{,}512} - 1.0 = +0.07$$

2.6.1.3.5 Strongback Securement Bolts

The three 1/2-13UNC socket head cap screws (SHCS) that secure the strongback into the body are tightened to a maximum of 75 lb_f-ft torque (minimum torque is 70 lb_f-ft). Since these SHCS only react normal transportation forces (not regulatory NCT forces), the preload is the only applied load to be evaluated. The maximum tensile force per bolt due to preload, Fa_{max}, is found from:

$$Fa_{max} = \frac{Q_{max}}{(K)(Db)} = \frac{12(75)}{(0.157)(0.50)} = 11{,}465\ lb_f$$

where Q_{max} = 75 lb_f-ft is the maximum applied closure bolt preload, K= 0.157 is the nut factor, and Db=0.50 inches is the SHCS nominal diameter.

2.6.5 Vibration and Shock

The effects of vibration normally incident to transport are shown to be insignificant. Draft ANSI N14.23[9] identifies peak truck trailer vibration inputs. Table 2 of ANSI N14.23 shows peak vibration accelerations of a trailer bed as a function of package and tie-down system natural frequency. For the frequency range 0 to 5 Hz, and conservatively assuming a light package, Table 2 of ANSI N14.23 gives peak accelerations (99% level) of 2*g* in the vertical direction, and 0.1*g* in both the lateral and longitudinal directions. All other frequency ranges give significantly lower acceleration levels. Further, due to package symmetry, the vertical load of ±2*g* governs the ±0.1*g* in the lateral and longitudinal directions.

Design fatigue curves are taken from Figure I-9.2.2 and Table I-9.2.2 of the ASME Code[10], Section III, Appendix I for the Type XM-19 stainless steel shell material, from which the allowable amplitude, S_a, of the alternating stress component (1/2 of the alternating stress range) as a function of number of loading cycles may be obtained. Table I-9.2.2 extends the fatigue allowable data to the endurance limit, which is used in the fatigue assessment of transportation vibration. The allowable amplitude, S_a, from Table I-9.2.2 for Type XM-19 stainless steel shell material at 10^{11} cycles is 13,600 psi. This value is adjusted based on the ratio of room temperature elastic modulus of 28.3×10^6 psi, which is the basis for Table I-9.2.2, and the elastic modulus at 160 °F, 27.8×10^6 psi from Table 2.6-1, as follows:

$$S_a = 13{,}600\left[\frac{27.8(10^6)}{28.3(10^6)}\right] = 13{,}360 \text{ psi}$$

An analysis of the MFFP shows that fatigue of the containment boundary is not of concern. The body can be modeled as a simply supported beam, with concentrated loads at each end, supported by the cradles of the transport skid, and with a distributed load equal only to the weight of the shell. The load at each end is equal to the sum of the weight of the impact limiter, body end structure, and one-half of the weight of the loaded strongback (since the strongback weight is supported by the strongback endplates, the strongback and payload weight is applied to the body at the ends). The beam model of the MFFP is shown in Figure 2.6-1.

The cross-sectional area of the shell is:

$$A_s = \frac{\pi}{4}\left(d_o^2 - d_i^2\right) = 51.59 \text{ in}^2$$

and the area moment of inertia is:

$$I_s = \frac{\pi}{64}\left(d_o^4 - d_i^4\right) = 5{,}450 \text{ in}^4$$

where d_o is the shell outer diameter of 29.63 inches and d_i is the inner diameter of 28.5 inches. For a material density of 0.29 lb_m/in^3, the distributed weight of the shell is w = 15 lb_m/in. For an

[9] ANSI N14.23, *Design Basis for Resistance to Shock and Vibration of Radioactive Material Packages Greater Than One Ton in Truck Transport*, 1980, American National Standards Institute, Inc. (ANSI).

[10] ASME Code, Subsection III, Division 1 Appendices, Appendix I, *Design Stress Intensity Values, Allowable Stresses, Material Properties, and Design Fatigue Curves*, Figure I-9.2.2, *Design Fatigue Curve for Austenitic Steels, Nickel-Chromium-Iron Alloy, Nickel-Iron-Chromium Alloy, and Nickel-Copper Alloy for $S_a \leq 28.2$ ksi, for Temperatures not Exceeding 800 °F*, and Table I-9.2.2, *Tabulated Values of S_a, ksi, from Figure I-9.2.2*.

overall length of shell of 168.2[11] inches, the total shell weight is 168.2 × 15 = 2,523 pounds. The maximum gross weight of the MFFP is 14,260 pounds. The remaining weight, which is divided equally between each end, is 14,260 - 2,523 = 11,737 pounds, or 5,869 pounds per end. The reaction (under static, 1*g* conditions) at each cradle support is 14,260/2 = 7,130 pounds. The maximum bending moment, which occurs at the skid cradle support, is:

$$M_{max} = 5{,}869(L_e) + w\frac{L_e^{\ 2}}{2} = 190{,}730\ lb_f - in$$

where L_e = 31.25 inches (the distance from the end to the cradle support centerline). The shell bending stress is:

$$\sigma = \frac{Mc}{I_s} = \frac{190{,}730(14.82)}{5{,}450} = 519\ psi$$

where c = 29.63/2 = 14.82 inches. Multiplying the stress by a factor of 2 to account for the ±2*g* alternating load condition results in a conservative fatigue stress amplitude of 2 × 519 = 1,038 psi. This stress is considerably less than the minimum value of the fatigue limit found above to be 13,360 psi. The margin of safety is:

$$MS = \frac{13{,}360}{1{,}038} - 1.0 = +11.9$$

2.6.6 Water Spray

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

2.6.7 Free Drop

Because the maximum gross weight of the MFFP is 14,260 pounds, a three-foot free drop is required per 10 CFR §71.71(c)(7). The MFFP is designed to withstand the effects of a 30-foot HAC free drop, while maintaining leaktight containment and criticality control of the payload. However, the NCT free drop is from a height of 3 feet, which represents a potential energy of impact of only 10% that of the 30-foot hypothetical accident condition (HAC) free drop tests. HAC free drop performance of the containment boundary and strongback was demonstrated to be within acceptable limits by full-scale testing of the MFFP certification test unit (CTU), as discussed in Appendix 2.12.3, *Certification Test Results*. Leakage rate testing following certification testing demonstrated the ability of the MFFP to maintain leaktight (i.e., 1.0×10^{-7} standard cubic centimeters per second (scc/sec), air) containment boundary integrity. Therefore, the requirements of 10 CFR §71.71(c)(7) are met.

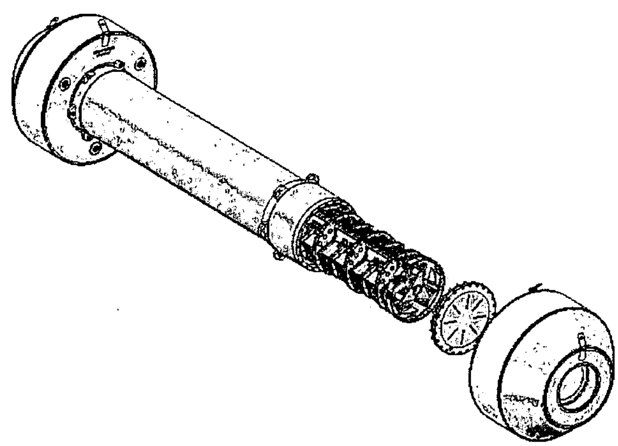
[11] The actual length is 168.45 inches instead of 168.2 inches. Because the difference is small and would not affect the results significantly, the analysis is not revised.

DOCKET 71-9295

AREVA

Mixed Oxide Fresh Fuel Package

Appendix A: ARB-17
Appendix B: AFS-B with 175 MOX rods and Excess Material Assembly
Appendix C: AFS-C with TA-18 MOX Rods



Safety Analysis Report

Volume 2
Revision 7
July 2008

This page left intentionally blank.

A1.2 Package Description

General arrangement drawings of the packaging are provided in Section 1.4.2, *Packaging General Arrangement Drawings*. The addition of the ARB-17 does not alter these packaging drawings because the ARB-17 is included with the contents.

A1.2.1 Packaging

The packaging description is unchanged from the description provided in Section 1.2.1, *Packaging*.

A1.2.2 Containment System

The containment system description is unchanged from the description provided in Section 1.2.2, *Containment System*.

A1.2.3 Contents of Packaging

The MFFP may carry up to three (3) ARB-17 containers. The ARB-17 itself is part of the contents and not part of the packaging. For shipping less than a total of three fuel assemblies and ARB-17 containers, non-fuel dummy fuel assemblies are utilized in the unoccupied strongback locations to balance the weight. Any combination of ARB-17, standard fuel assembly, and dummy fuel assembly is acceptable (e.g., 1 ARB-17 and 2 fuel assemblies; 1 ARB-17, 1 fuel assembly, and 1 dummy fuel assembly; 3 ARB-17s, etc.). The physical size and weight of the dummy fuel assemblies are nominally the same as the MK-BW/MOX1 17 × 17 design. The physical fuel rod parameters provided in Table 1.2-1 and nuclear design parameters provided in Table 1.2-2 are applicable to fuel rods in the ARB-17.

A sketch of the ARB-17 is provided in Figure A1.2-1. The exterior enclosure of the ARB-17 consists of 0.75 inch thick stainless steel side walls with a 1.5 inch thick stainless steel top end closure plate and a 0.75 inch thick stainless steel bottom end closure plate. The outside envelope of the ARB-17 is 8.43 inches square by 159.85 inches long (not including the swivel hoist ring). A swivel hoist ring is mounted to the top of the ARB-17 to facilitate vertical handling.

Each ARB-17 may contain up to 17 MOX fuel rods, which may be either undamaged, slightly damaged, or a combination of both (e.g., 9 undamaged and 8 slightly damaged). Slightly damaged fuel rods may be bent, scratched, or dented, but under no circumstances may exhibit cladding breach. A 2-inch, Schedule 40 pipe mounted with pipe clamps against one wall of the ARB-17 is used to transport both undamaged or slightly damaged fuel rods. Slightly damaged fuel rods may be transported within this pipe only if the bending in the fuel rod is minor. Examples of allowable ARB-17 loading are illustrated in Figure A1.2-2.

A Buna-N rubber pad is used at the top of the fuel support pipe to cushion the ends of the fuel rods. To limit movement of the fuel rods during shipment, stainless steel dunnage rods are used as needed to fill the remaining void within the fuel support pipe (the pipe component may fit a maximum of 22 fuel and dunnage rods). Each undamaged fuel rod is inserted into a polypropylene sleeve that is 0.004 inches thick and ≤ 2 inches in circumference (diameter ≤ 0.637 inches) to prevent scratching of the cladding.

Slightly damaged fuel rods with bending that precludes shipment in the fuel support pipe are clamped in the C-channel within the ARB-17. Any unused space is filled with stainless steel dunnage rods, as needed. Fuel rods exhibiting cladding breach are not acceptable for transportation in an ARB-17. Use of polypropylene sleeves for the slightly damaged rods is optional.

A1.2.3.1 Radionuclide Inventory

The nuclear parameters for the ARB-17 rods are unchanged from those provided in Table 1.2-2.

A1.2.3.2 Maximum Payload Weight

A conservative weight of approximately 1,525 pounds may be determined for the ARB-17 by assuming 17 slightly damaged fuel rods in the C-channel and 22 stainless steel dunnage rods in the pipe component. This weight is bounded by the 1,580 pound weight of a fuel assembly (including a BPRA). The maximum MFFP payload weight for a payload containing an ARB-17 (i.e., two fuel assemblies and one ARB-17) is 4,685 pounds. Therefore, the maximum payload weight is bounded by the value of 4,740 pounds provided in Section 1.2.3.2, *Maximum Payload Weight.*

A1.2.3.3 Maximum Decay Heat

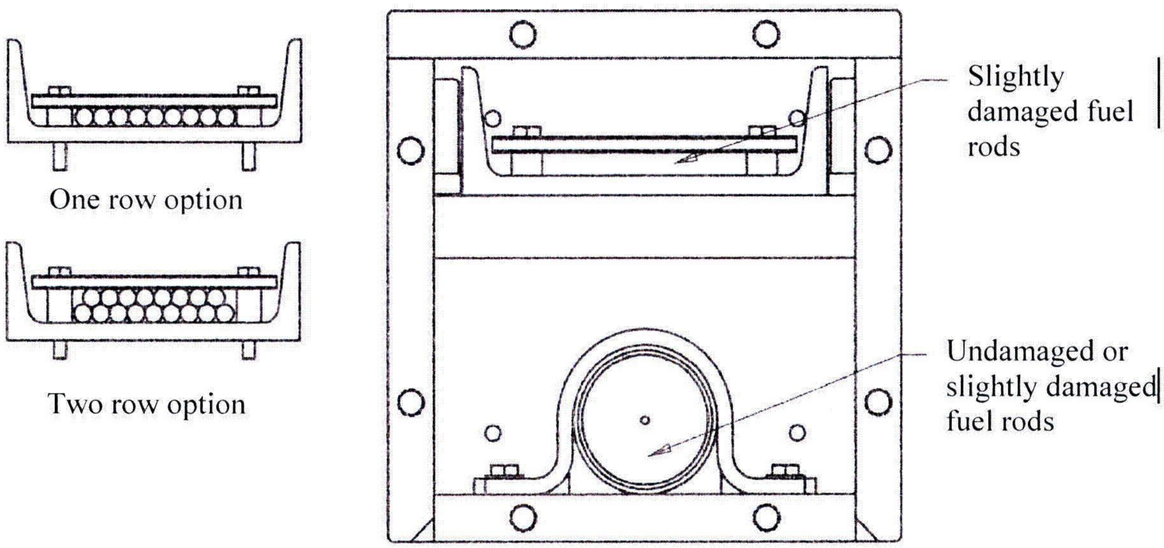
The maximum decay heat of an ARB-17 is 17/264*80 = 5.15 watts, which is bounded by the 80 watt decay heat of a standard fuel assembly. The maximum MFFP decay heat for a payload containing an ARB-17 (i.e., two fuel assemblies and one ARB-17) is 165 watts. This maximum heat load is bounded by the 240 watts provided in Section 1.2.3.3, *Maximum Decay Heat.*

A1.2.3.4 Maximum Pressure Buildup

The maximum normal operating pressure (MNOP) of the MFFP transporting one or more ARB-17 rod containers is bounded by the 10 psig value provided in Section 1.2.3.4, Maximum *Pressure Buildup.*

A1.2.4 Operational Features

Operating procedures and instructions for loading, unloading, and preparing an empty MFFP for transport with the ARB-17 are provided in Chapter A7.0, *Package Operations.*



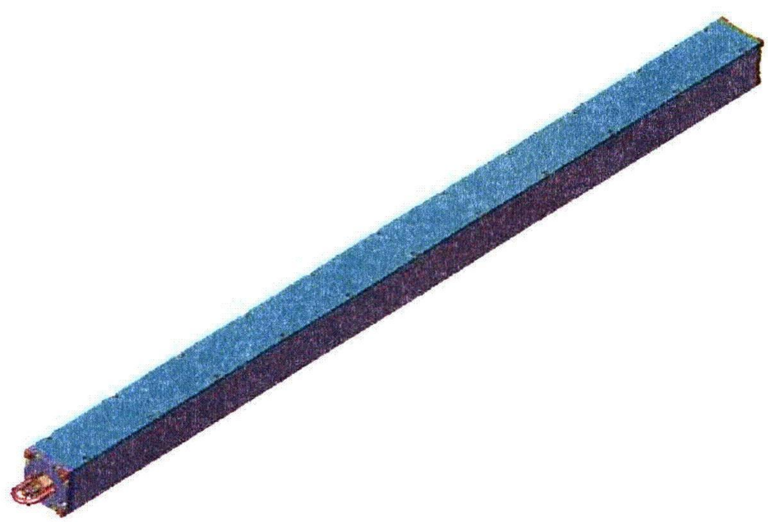
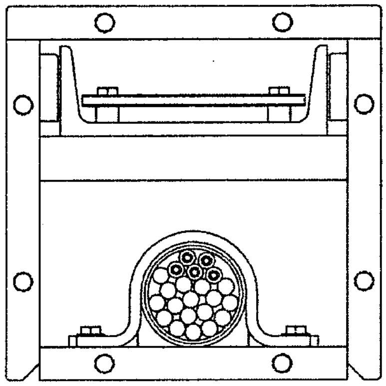
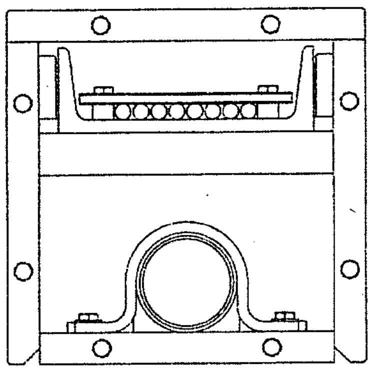


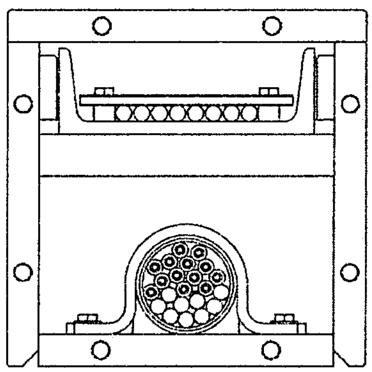
Figure A1.2-1 – ARB-17 Sketches



Example 1: 17 fresh fuel rods and 5 dunnage rods, empty C-channel



Example 2: 8 slightly damaged fuel rods in C-channel, empty pipe component



Example 3: 8 slightly damaged rods in C-channel, 9 fresh fuel rods and 13 dunnage rods in pipe component

Figure A1.2-2 – ARB-17 Sample Loadings

A7.0 PACKAGE OPERATIONS

A7.1 Package Loading

The package loading operations are the same as the operations for fuel assembly loading described in Chapter 7.1, *Package Loading*. The ARB-17 is handled in the same manner as a fuel assembly.

The ARB-17 may contain fuel rods that are slightly damaged. These damaged rods may be bent, scratched, or nicked, but under no circumstances shall exhibit cladding breach. The structural integrity of these fuel rods must be confirmed by visual inspection prior to loading in the ARB-17.

A7.2 Package Unloading

The package unloading operations are the same as the operations for fuel assembly unloading described in Chapter 7.2, *Package Unloading*. The ARB-17 is handled in the same manner as a fuel assembly.

A7.3 Preparation of an Empty Package for Transport

Previously used and empty MFFPs shall be prepared and transported per the requirements of 49 CFR §173.428[1].

A7.4 Preshipment Leakage Rate Test

The preshipment leakage rate test is the same as described in Section 7.4, *Preshipment Leakage Rate Test*.

---

[1] Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), *Shippers–General Requirements for Shipments and Packagings*, 10-01-06 Edition.

This page left intentionally blank.

A8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

A8.1 Acceptance Tests

Per the requirements of 10 CFR §71.85[1], this section discusses the inspections and tests to be performed prior to first use of the ARB-17 rod container.

A8.1.1 Visual Inspections and Measurements

Each ARB-17 rod container shall be examined in accordance with the requirements delineated on the applicable fabrication drawing.

A8.1.2 Weld Inspections

All welds shall be inspected to the requirements delineated on the applicable fabrication drawing.

A8.1.3 Structural and Pressure Tests

The ARB-17 rod container does not require any lifting device load tests or pressure tests.

A8.1.4 Fabrication Leakage Rate Tests

The ARB-17 rod container does not require any leakage rate tests.

A8.1.5 Component and Material Tests

The ARB-17 rod container does not require any component or material tests.

A8.1.6 Shielding Tests

The ARB-17 rod container does not require any shielding tests.

A8.1.7 Thermal Tests

The ARB-17 rod container does not require any thermal tests.

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 01-01-06 Edition.

A8.2 Maintenance Program

The ARB-17 rod container does not require a scheduled maintenance program. The parts which are routinely handled during use (the body, the lid, and the lid fasteners) are visually inspected prior to use. Damaged components shall be repaired or replaced prior to use.

B1.2 Package Description

General arrangement drawings of the packaging are provided in Section 1.4.2, *Packaging General Arrangement Drawings*. The addition of the AFS-B and EMA does not alter these packaging drawings. A drawing of the AFS-B rod container is given in Section B1.4.2, *Packaging General Arrangement Drawings*.

B1.2.1 Packaging

The MFFP packaging description is unchanged from the description provided in Section 1.2.1, *Packaging*. The AFS-B rod container is designed to hold up to 175 MOX fuel rods of the type used in the MOX fuel assemblies. The container has outer cross sectional dimensions of 8.4 inches square, a length from bottom to top of 159.9 inches, and an overall length (to the lift ring bolt head) of 161.2 inches. The primary material of construction of the container is ASTM 6061-T651 aluminum alloy. The two side walls, the bottom plate, and the lid are all ¾ inches thick. The side plates are attached to the bottom plate with two longitudinal, 3/8-inch groove welds. The lid is attached with twenty-two (22) zinc-plated, 3/8-16 UNC, SAE J429 Grade 8, hex head cap screws. The two square end pieces are made of solid aluminum alloy, and each are attached to the container with eight (8) zinc-plated SAE J429 3/8-16 UNC hex head cap screws made of Grade 8 alloy steel. The lower square end piece is 2.4 inches thick and the upper square end piece is 3.0 inches thick. Each bolt is secured in place using a thin stainless steel lock tab. Two of the eight bolts on each end go horizontally into the lid, in addition to the 22 cap screws on the top of the lid.

Inside the container is a ½-inch thick shelf, made of the same aluminum alloy, which fits into ¼-inch deep grooves in each side wall. The shelf is supported by ¼-inch thick aluminum support plates on 15.3-inch centers. The region between the shelf and the lid is the rod cavity, which is 6.9 inches wide, 3.4 inches deep, and 153.5 inches long. The support plates and the shelf are located with intermittent 1/8-inch fillet welds, none of which are load bearing. Along the inside of the two side plates are two, 2.1-inch wide grooves, 0.4 inches deep. These grooves accommodate the bulkheads used in the AFS-C rod container, but they have no function in the AFS-B container. The components of the AFS-B feature numerous small holes that ensure the AFS-B will not hold pressure.

The lid is lifted by means of two, ¼-20 UNC threaded holes in the lid. The holes are located such that at least half of the hole is blocked by the top of the sidewall, which prevents an overly-long lifting bolt from possibly damaging any fuel rods. The container is lifted from its top end using a swivel hoist ring. All threaded holes may optionally be fitted with helical-coil thread inserts. The label 'AFS-B' is painted prominently on both sides of the container. The AFS-B is finished with a clear anodize treatment.

An external view of the AFS-B rod container is given in Figure B1.2-1. An internal cross sectional view is given in Figure B2.7-1.

B1.2.2 Containment System

The containment system description is unchanged from the description provided in Section 1.2.2, *Containment System*.

B1.2.3 Contents of Packaging

The MFFP may simultaneously transport one (1) AFS-B containing up to 175 standard MOX fuel rods, and one (1) EMA. The 175 fuel rod limit is a geometrical limit based on the size of the cavity, assuming the fuel rods are packed in a hexagonal lattice. If necessary, for a payload of fewer than 175 rods, aluminum or stainless steel dunnage rods are used to take up the remaining space. A non-fuel dummy assembly is utilized in the unoccupied strongback location. The physical size and weight of the non-fuel dummy assemblies are nominally the same as the MK-BW/MOX1 17 × 17 design. Alternately, the AFS-B may be transported separately with two dummy fuel assemblies per strongback, and the EMA may be transported in lieu of a standard fuel assembly.

Because the AFS-B with 175 fuel rods is more reactive that a MOX fuel assembly, it is not acceptable to transport more than one (1) AFS-B per MFFP. Also, the AFS-B cannot be combined in a shipment with more than (1) EMA or standard fuel assembly. For transportation purposes, an EMA and a standard MOX fuel assembly may be considered interchangeable. Examples of acceptable and unacceptable loading configurations are summarized below:

Acceptable Loading Configurations	Unacceptable Loading Configurations
1 AFS-B, 1 EMA/fuel assembly, 1 dummy	1 AFS-B, 2 EMAs/fuel assemblies
1 AFS-B, 2 dummies	2 AFS-Bs, 1 dummy
Any combination of fuel assemblies, EMAs, and dummy fuel assemblies	3 AFS-Bs

The physical parameters for a fuel rod provided in Table 1.2-1 and nuclear design parameters provided in Table 1.2-2 are applicable to rods in the AFS-B. These parameters are also applicable to the EMA, with the exceptions that the OD of the fuel pellets may be out of tolerance (nominal pellet diameter = 0.323 inch), and the weight percent Pu-238 exceeds the 0.05 wt.% limit specified in Table 1.2-2 (EMA fuel rods have Pu-238/Pu as high as 0.19 wt.%). Pu-238 is a neutronic poison and is neglected in the criticality analysis, so there is no safety concern associated with this value being outside of the tolerance. Minor fluctuations of the fuel pellet OD are also negligible.

B1.2.3.1 Radionuclide Inventory

The nuclear parameters for the AFS-B rods are unchanged from those provided in Table 1.2-2. As noted above, the rods in the EMA do not meet the performance specifications of a standard fuel rod, although the differences are minor and without safety significance.

B1.2.3.2 Maximum Payload Weight

The loaded AFS-B has a payload weight of approximately 1,500 pounds. The EMA, which weighs approximately the same as a standard MOX fuel assembly and will not be loaded with a burnable poison rod assembly (BPRA), weighs less than the 1,580 pound design weight of a fuel assembly loaded with a BPRA. The combined payload weight of the AFS-B, EMA, and dummy fuel assembly is therefore bounded by the value of 4,740 pounds provided in Section 1.2.3.2, *Maximum Payload Weight*.

B1.4 Appendices

B1.4.1 Nomenclature

The nomenclature list from Section 1.4.1, *Nomenclature*, is applicable. Additional nomenclature listed below.

AFS-B – Container used to transport up to 175 standard MOX fuel rods. The AFS-B interfaces with the strongback in the same manner as a fuel assembly.

Excess Material Assembly (EMA) – Fuel assembly comprised of 264 fuel rods that do not necessarily meet the performance requirements of a standard MOX fuel rod. An EMA has the same outer dimensions and visual appearance of a standard fuel assembly.

B1.4.2 Packaging General Arrangement Drawings

The general arrangement drawings of the body, strongback, and impact limiters are unchanged from those provided in Section 1.4.2, *Packaging General Arrangement Drawings*. The following AFS-B drawing is included in this section:

- 99008-60, Rev. 1, 2 sheets, *AFS-B Assembly*

This page left intentionally blank.

Figure Withheld Under 10 CFR 2.390

AREVA

AREVA Federal Services LLC
Packaging Projects
Tacoma, WA 98402

AFS-B ASSEMBLY
SAR DRAWING

SCALE: 1:5	WT. ~ LBS
REV: 1	SHEET 1 OF 2
DWG SIZE D	DWG NO. 99008-60
	CADFILE: 99008601.SLDDRW

Figure Withheld Under 10 CFR 2.390

REV: 1	SHEET 2 OF 2
DWG NO. 99008-60	

B2.0 STRUCTURAL EVALUATION

This chapter of Appendix B provides a structural evaluation of the MFFP when transporting one (1) AFS-B rod container and one (1) Excess Material Assembly (EMA). As these items fill only two of the three available strongback locations, the third strongback location is filled with a dummy fuel assembly. Alternately, the AFS-B may be transported separately with two dummy fuel assemblies per strongback, and the EMA may be transported in lieu of a standard fuel assembly. It is demonstrated that all quantities of interest are bounded by the analyses presented in Chapter 2.0, *Structural Evaluation*.

B2.1 Structural Design

B2.1.1 Discussion

A comprehensive discussion of the MFFP design and standard configuration is provided in Section 1.2, *Package Description*. The MFFP drawings show the detailed geometry of the package, as well as the dimensions, tolerances, materials, and fabrication requirements, and are provided in Appendix 1.4.2, *Packaging General Arrangement Drawings*.

A physical description of the AFS-B rod container is provided in Section B1.2.3, *Contents of Packaging*, and is shown in the drawings in Appendix B1.4.2, *Packaging General Arrangement Drawings*. The AFS-B container is a robust box designed to provide confinement of individual fuel rods under all conditions of transport. The AFS-B container has the same external boundary dimensions as a standard MOX fuel assembly, and thus is loaded, mounted, and unloaded from the strongback in the same manner as a fuel assembly. The structural evaluations and testing performed as part of the original license activities adequately characterize the performance of the MFFP with this payload.

The EMA is structurally identical to a MOX fuel assembly, and its structural response will be the same as a MOX fuel assembly described in Chapter 2.0, *Structural Evaluation*. Therefore, no additional structural evaluations are necessary for this item.

B2.1.2 Design Criteria

The MFFP design criteria are unchanged from those provided in Section 2.1.2, *Design Criteria*. The design criteria for the AFS-B rod container are based on the functional requirement that the rod container confine the rods inside the container boundary under all NCT and HAC. Because the AFS-B rod container is transported within the MFFP strongback, it is protected from gross distortion by the fuel control structure (FCS). As shown in Section 2.12.5, *Fuel Control Structure Evaluation*, the FCS provides a limit to any reconfiguration of the fuel assembly which could occur as a result of the worst case HAC event. The MOX fuel assembly consists of a larger number of rods (264) than is contained in the AFS-B rod container (175). In addition, the rods in the MOX fuel assembly are unconfined by any structure other than the FCS, whereas fuel rods in the AFS-B rod container are confined within a container having significant structure. Therefore, gross distortion of the fuel rods or of the AFS-B container, or escape of the fuel rods from the container, will not occur.

To enhance criticality safety by preventing the potential for damage to the fuel rods in the HAC free drop impact event, the AFS-B rod container is designed to minimize the relative motion of the rods under impact conditions. To accomplish this, the AFS-B rod container is designed to limit the "rattle space" of the fuel rods (including any dummy rods as necessary) to less than approximately one half rod diameter.

The only component of the AFS-B container which is not supported externally by the strongback or FCS is the internal shelf. To ensure that the "rattle space" available to the rods cannot increase as a result of the free drop impact event, the internal shelf is designed to have a primary bending stress less than the yield point of the shelf material at NCT maximum temperature.

B2.1.3 Weights and Center of Gravity

The loaded weight of the AFS-B, conservatively assuming 175 fuel rods, is bounded by 1,500 pounds, which is 5% less than the gross weight of 1,580 pounds for a fuel assembly or dummy fuel assembly. Because the EMA will not contain a burnable poison rod assembly (BPRA), the EMA weight is bounded by the 1,580 pound design weight of the combined fuel assembly and BPRA. Therefore, the weight of the MFFP when transporting one (1) AFS-B, one (1) EMA, and one (1) dummy fuel assembly is bounded by the weights given in Section 2.1.3, *Weights and Center of Gravity*, for transport of MOX fuel assemblies.

The longitudinal center of gravity (CG) of the package is essentially unchanged from that reported in Section 2.1.3, *Weights and Center of Gravity*, or 103.7 inches from the bottom end impact limiter.

B2.2 Materials

The AFS-B is constructed primarily of ASTM B209, 6061-T651 aluminum plate material. The lid and ends are attached with SAE J429 zinc-plated hex head cap screws made from Grade 8 material. A stainless steel swivel hoist ring is included for lifting. No non-metallic materials are used in the AFS-B. These materials do not result in any chemical or galvanic reactions, and are not significantly affected by radiation. The material properties for the aluminum material at 70 and 200 °F needed for calculations are given in Table B2.2-1, and are taken from the ASME B&PV Code,[1] as noted. Note that although there is limited welding of the 6061 material, welding is not used in regions where the material properties of unwelded material are used in stress analysis.

[1] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, Materials, Part D, Properties, 2001 Edition, 2002 and 2003 Addenda.

Table B2.2-1 - Material Properties of ASTM B209 6061-T651 Aluminum Alloy

Temperature, °F	Yield Strength, psi	Ultimate Strength, psi	Coefficient of Thermal Expansion, 10^{-6} in/in/°F
70	35,000①	42,000①	-
200	33,700②	-	13.0③

Notes:
①Yield and ultimate strength at 70 °F from ASME B&PV Code, Section II, Part B, SB-209.
②Yield strength at 200 °F from ASME B&PV Code, Section II, Part D, Table Y-1.
③Coefficient of thermal expansion from ASME B&PV Code, Section II, Part D, Table TE-2.

B2.3 Fabrication and Examination

The AFS-B rod container is fabricated to the requirements of the drawing shown in Appendix B1.4.2, *Packaging General Arrangement Drawings*. The materials of construction are specified to either ASTM or SAE standards. The rod container is inspected to the dimensional requirements of the drawing. Welds are visually inspected to the AWS D1.2[2] welding code.

B2.4 Lifting and Tie-down Standards for All Packages

Because the gross weight of the MFFP is lower when transporting the AFS-B rod container and EMA compared to three (3) fuel assemblies, this section is unchanged from Section 2.4, *Lifting and Tie-down Standards for All Packages*, in regards to the package itself.

The AFS-B uses a 5/8-11 UNC swivel hoist ring for handling. The thread depth for this swivel hoist ring bolt is 1.28-in. The minimum required thread depth may be computed by the following equation:

$$L_i = \frac{A_t \times S_t}{A_i \times S_i}, \text{ where}$$

A_t is the tensile stress area of the 5/8-11 UNC bolt (0.2201 in^2)

S_t is the allowable ultimate tensile strength for the 5/8-11 UNC bolt (170,000/5 = 34,000 psi)[3]

A_i is the internal aluminum thread stripping area per inch length (1.4255 in^2/in-length)

S_i is the governing allowable shear strength of the aluminum thread (0.6 x 42,000/5 = 5,040 psi using ultimate strength). Note that this value bounds the value obtained using the yield strength (0.6 x 35,000/3 = 7,000 psi). Material properties are at 70 °F.

The minimum length of aluminum thread to develop the full tensile strength of the external thread is then:

---

[2] ANSI/AWS D1.2, *Structural Welding Code – Aluminum*, American Welding Society (AWS).

[3] Conservatively high tensile strength obtained from ASTM A574, *Standard Specification for Alloy Steel Socket-Head Cap Screws*. Actual tensile strength of swivel hoist ring bolt will be equal to or less than this value.

$$L_i = \frac{(0.2201)(34{,}000)}{(1.4255)(5{,}040)} = 1.0416 \text{ in}$$

As this length is less than the 1.28-in thread depth of the swivel hoist ring bolt, tear out of the aluminum threads is not a concern. The governing factor is therefore the swivel hoist ring bolt, and the performance of this item is ensured by the rated capacity of the swivel hoist ring. Note that an optional 300 series insert may also be used, which would further increase the conservatism.

B2.5 General Considerations

The AFS-B rod container is evaluated by reasoned argument and by analysis in the following sections. In addition, the results and conclusions of Section 2.5, *General Considerations*, remain unchanged.

B2.6 Normal Conditions of Transport

B2.6.1 Heat

It is demonstrated in Section B3.4, *Thermal Evaluation for Normal Conditions of Transport*, that under NCT, all MFFP component temperatures associated with the AFS-B payload are bounded by the standard three (3) fuel assembly payload. Therefore, all associated pressure and thermal stresses are bounded by the values presented in Section 2.6.1, *Heat*. For the AFS-B rod container, the bounding temperature of the sidewalls and the internal shelf is 200 °F. Since the AFS-B is vented, it cannot retain pressure.

B2.6.1.1 Differential Thermal Expansion

The evaluation of differential thermal expansion given in Section 2.6.1.2, *Differential Thermal Expansion*, is not affected by use of the AFS-B rod container. An additional evaluation of the differential thermal expansion between the strongback and the AFS-B container will now be made.

From Section 2.6.1.2, *Differential Thermal Expansion*, the design temperature of the strongback is T_{SB} = 180 °F, and the coefficient of thermal expansion for the strongback material is $\alpha_{SB} = 8.8 \times 10^{-6}$ in/in/°F. As stated above, the bounding temperature for the AFS-B container is $T_{AFS\text{-}B}$ = 200 °F, and from Table B2.2-1, the coefficient of thermal expansion is $\alpha_{AFS\text{-}B} = 13.0 \times 10^{-6}$ in/in/°F. The overall length of the container is L = 159.9 inches. The reference temperature is 70 °F. The differential thermal growth of the rod container and the strongback is:

$$\delta = \alpha_{AFS-B}(L)(T_{AFS-B} - 70) - \alpha_{SB}(L)(T_{SB} - 70) = 0.115 \text{ inches}$$

This calculation conservatively assumes that the entire length of the two components is at the respective peak temperatures, and thus overestimates the relative thermal expansion. To prevent axial interference of the AFS-B container with the strongback, the clamp pads will be set with a clearance to the end of the AFS-B container. As stated in Section B7.1, *Package Loading*, the ¾-10 clamp pad screw will be backed out a minimum of one turn from the position of contact, ensuring a minimum axial clearance between the AFS-B container and the strongback of 0.1 inches at the reference temperature. This is adequate to ensure that the thermal expansion force is negligible or non-existent considering the conservatism of the evaluation above.

B2.6.2 Cold

This section is unchanged from Section 2.6.2, *Cold.*

B2.6.3 Reduced External Pressure

This section is unchanged from Section 2.6.3, *Reduced External Pressure.*

B2.6.4 Increased External Pressure

This section is unchanged from Section 2.6.4, *Increased External Pressure.*

B2.6.5 Vibration and Shock

The vibration normally incident to transportation will have no effect on the AFS-B rod container. The AFS-B container is installed and retained in the same manner as a MOX fuel assembly. The spring loaded clamp arms which hold the container in place will significantly dampen any vibrational loads which could come from the cask body. Furthermore, any fatigue cracks which might occur from vibration, which are too small to be noted during a visual inspection, would have no effect on the ability of the AFS-B to perform its function of confining the rods in a HAC free drop impact. Therefore, vibration and shock are not of concern for the AFS-B rod container.

B2.6.6 Water Spray

This section is unchanged from Section 2.6.6, *Water Spray.*

B2.6.7 Free Drop

Because a loaded AFS-B is slightly lighter than a fuel assembly (including BPRA), the response of the MFFP to a free drop would be essentially the same when compared to the standard payload.

Since the AFS-B rod container is shown to confine the fuel rods in a HAC free drop impact (see Section B2.7.1), its performance will be acceptable for the NCT free drop event.

B2.6.8 Corner Drop

This section is unchanged from Section 2.6.8, *Corner Drop.*

B2.6.9 Compression

This section is unchanged from Section 2.6.9, *Compression.*

B2.6.10 Penetration

This section is unchanged from Section 2.6.10, *Penetration.*

B2.7 Hypothetical Accident Conditions

B2.7.1 Free Drop

The functional criteria of the AFS-B rod container is to confine the fuel rods in the worst-case HAC free drop event. As an additional enhancement to criticality safety, the container should also restrict the relative movement of the rods to minimize the potential for damage to the fuel rods.

The MFFP strongback, including the fuel control structure (FCS), is designed to maintain a complete MOX fuel assembly in a subcritical configuration during the governing free drop event. Using physical test (see Appendix 2.12.3, *Certification Test Results*) and calculations (see Appendix 2.12.5, *Fuel Control Structure Evaluation*), it has been demonstrated that *a*) the fuel rods do not break or fragment, and *b*) the strongback and FCS are capable of confining the rods within a defined geometry. As stated in Section B1.2, *Package Description*, the AFS-B rod container consists of a completely enclosed structure made of 6061-T651 aluminum plates of ¾-inch nominal thickness. The lid of the container is attached using 22, 3/8-inch diameter bolts. The container has the same boundary dimensions as the MOX fuel assembly, and is mounted in the strongback in the same manner. As such, the AFS-B container represents an added level of confinement for the fuel rods, beyond that provided by the strongback and FCS. For this reason, confinement of the fuel rods by the AFS-B container is ensured. Table B2.7-1 presents added detail which supports this conclusion. As stated in Section B2.1.2, *Design Criteria*, the rod movement in an impact is restricted to a maximum of approximately one-half of a rod diameter.

The rod cavity inside the AFS-B container is formed by the ¾-inch thick lid plate, the two ¾-inch thick side plates, thick end plates (minimum thickness of 2.4 inches), and a ½-inch thick shelf plate. The shelf plate is located in longitudinal, ¼-inch deep grooves on the inside face of each ¾-inch thick side plate, and supported against the bottom plate by support plates at 15.3-inch intervals. Note that each weld between the shelf and the side plates is only 2-inches long, centered on each support plate, as shown in Section B of drawing 99008-60. This weld is not structural, and serves only to compensate for any weld distortion which might occur from the two groove welds. As such, a strength reduction does not need to be considered, since the longer, unsupported length between support plates is far from any heat affected zone. Figure B2.7-1 shows a cross section of the AFS-B container. To demonstrate that the rod cavity maintains its internal geometric integrity in the worst-case free drop impact, the following evaluation is performed. The internal geometric integrity assures that the "rattle space" inside the container is minimized to prevent any possible damage to the rods. However, any loss of the rod container contents is precluded by the rod container primary structure, as discussed above. In the following, it is assumed that the impact occurs with the shelf oriented horizontally with the container lid side up. This orientation governs over all others where some component of the rod load is directed toward the thick sidewalls of the container.

In this evaluation, any support from the support plates beneath the shelf will be conservatively neglected. The shelf is then a plate, simply supported on its two long sides, and free on its two short sides. A governing impact of 180g is taken from Section 2.12.5.2, *Conditions Analyzed*, for the maximum slapdown impact. From Table 2.12.5-1, the fuel rod weight is 5.33 lb each, and the length is L_r = 152.4 inches. From Figure B2.7-1, the internal width of the cavity is b = 6.9 inches. For 175 rods, the total weight of rods is therefore W = 175 × 5.33 = 933 lb. Since the rods rest on an area bounded by the rod length and the cavity width, the impact pressure on the shelf is:

$$q = \frac{Wg}{L_r b} = 159.7 \text{ psi}$$

A formula from Roark,[4] Table 26, Case 1a, is used. Even though this formula assumes simple support on the narrow ends as well as the sides, the maximum stress at the center of the plate, which is more than 10 plate-widths distant from the ends, will not be materially affected. The length of the shelf is L_S = 153.5 inches. The ratio a/b is 153.5/6.9 = 22.2, from which β = 0.75. The maximum stress at the center of the plate is found from:

$$\sigma = \frac{\beta q b^2}{t^2} = 22{,}810 \text{ psi}$$

where t = 0.5 inches, and the other quantities are as defined above. From Table B2.2-1, the yield strength of the shelf material at the bounding temperature of 200 °F is 33,700 psi. The margin of safety against yield of the shelf is:

$$MS = \frac{33{,}700}{22{,}810} - 1 = +0.48$$

Since the shelf does not yield, the "rattle space" available for the rods does not increase as a result of the slapdown free drop event. Other impact orientations would place lower loadings on the shelf. Thus, the AFS-B rod container supports the geometry assumptions made in the criticality analysis of Chapter 6, *Criticality Evaluation.*

[4] Young, W. C., *Roark's Formulas for Stress and Strain*, Sixth Edition, McGraw-Hill, 1989.

Table B2.7-1 – Comparison of the MOX Fuel Assembly and the AFS-B Rod Container in the MFFP Strongback

MOX Fuel Assembly	AFS-B Rod Container	Conclusion
Strongback clamps on fuel grids	Strongback clamps on container	AFS-B lid is both bolted in place and clamped in place by the strongback
Max weight of 1,580 lb	Max weight of 1,500 lb	AFS-B applies lower inertia loads to the strongback in free drop impact events
264 rods	175 rods	Lighter payload in AFS-B
Rods self-supporting over span between clamp arms	Rods fully supported by thick walls and bolted lid of container	AFS-B eliminates rod bending loads
Rods can move axially a limited amount	Rods are confined by thick, bolted end structures	AFS-B confines rods axially
Rod lateral buckling is controlled by strongback and FCS	Rod lateral buckling is controlled by strongback and FCS, plus: 1. restricted free space inside container 2. rods supported by thick walls of container	AFS-B adds a significant layer of rod support to that existing in the basic strongback/FCS

Figure Withheld Under 10 CFR 2.390

Figure B2.7-1 – AFS-B Rod Container Cross Section View

B2.7.2 Crush

This section is unchanged from Section 2.7.2, *Crush*.

B2.7.3 Puncture

The weight of the MFFP containing an AFS-B rod container and EMA is bounded by the weight of the MFFP with a payload of three (3) standard fuel assemblies. Therefore, the system response to a puncture is bounded by the discussion presented in Section 2.7.3, *Puncture*.

B2.7.4 Thermal

B2.7.4.1 Summary of Pressures and Temperatures

Package pressures and temperatures due to the HAC thermal event are presented in Section B3.5.3, *Maximum Temperatures and Pressures*. MFFP strongback and shell temperatures under HAC associated with the AFS-B payload are bounded by the standard three (3) fuel assembly payload. From Section B3.5.3.2, *Maximum Pressures*, the maximum internal pressure during the HAC thermal event is 117.1 psig. This pressure is bounded by the 130 psig pressure used in Section 2.7.4, *Thermal*.

B2.7.4.2 Differential Thermal Expansion

This section is unchanged from Section 2.7.4.2, *Differential Thermal Expansion*, as the MFFP strongback and shell temperatures under HAC associated with the AFS-B payload are bounded by the standard three (3) fuel assembly payload.

B2.7.4.3 Stress Calculations

As discussed in Section B2.7.4.1, *Summary of Pressures and Temperatures*, a conservative maximum internal pressure of 117.1 psig is calculated for the HAC thermal event. This pressure is lower than the 130 psig pressure used in Section 2.7.4.3, *Stress Calculations*. Therefore, the stresses calculated in Section 2.7.4.3 conservatively bound the stresses resulting from the payload evaluated in this Appendix.

B2.7.5 Immersion – Fissile Material

This section is unchanged from Section 2.7.5, *Immersion – Fissile Material*. In addition, since each separate cavity of the AFS-B container is vented, full flooding of all cavities by water in the immersion test is assured.

B2.7.6 Immersion – All Packages

This section is unchanged from Section 2.7.6, *Immersion – All Packages*.

B2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A_2)

This section is unchanged from Section 2.7.7, *Deep Water Immersion Test*.

B2.7.8 Summary of Damage

The AFS-B rod container maintains its structural integrity and functionality in the worst-case HAC free drop event, which bounds the loadings of all other HAC events on the container. Since the AFS-B rod container is mounted in the same way as a MOX fuel assembly but weighs less, the response of the MFFP to drop and puncture accidents is unchanged when using the AFS-B. Therefore, the AFS-B is acceptable for use as a payload container.

B2.8 Accident Conditions for Air Transport of Plutonium

This section does not apply for the MFFP, since air transport is not claimed.

B2.9 Accident Conditions for Fissile Material Packages for Air Transport

This section does not apply for the MFFP, since air transport is not claimed.

B2.10 Special Form

This section does not apply for the MFFP, since special form is not claimed.

B2.11 Fuel Rods

This section does not apply for the MFFP, since containment by the fuel rod cladding is not claimed.

B2.12 Appendices

There are no appendices to Chapter B2.0. The applicability of the appendices to Chapter 2, *Structural Evaluation*, is given in Table B2.12-1.

Table B2.12-1 – Applicability of Section 2.12 Appendices to the AFS-B Payload

Appendix	Applicability
2.12.1, Impact Limiter Evaluation	As the weight of the AFS-B is bounded by the weight of a fuel assembly, the impact limiter evaluation from Section 2.12.1 remains bounding.
2.12.2, Certification Test Plan	Unchanged from Section 2.12.2
2.12.3, Certification Test Results	Unchanged from Section 2.12.3
2.12.4, Engineering Test Results	Unchanged from Section 2.12.4
2.12.5, Fuel Control Structural Evaluation	As the weight of the AFS-B is bounded by the weight of a fuel assembly, and because it is more structurally robust than a fuel assembly, the fuel control structural evaluation from Section 2.12.5 remains bounding.
2.12.6, CASKDROP Computer Program	Unchanged from Section 2.12.6
2.12.7, Impact Limiter Weld Joint Test Results	Unchanged from Section 2.12.7
2.12.8, Effect of Bounding Weight on Package Structural Responses	As the weight of the AFS-B is bounded by the weight of a fuel assembly, the package structural responses evaluation from Section 2.12.8 remains bounding.

This page left intentionally blank.

C1.2 Package Description

General arrangement drawings of the packaging are provided in Section 1.4.2, *Packaging General Arrangement Drawings*. The addition of the AFS-C does not alter these packaging drawings. A drawing of the AFS-C rod container is given in Section C1.4.2, *Packaging General Arrangement Drawings*.

C1.2.1 Packaging

The MFFP packaging description is unchanged from the description provided in Section 1.2.1, *Packaging*. The AFS-C rod container is designed to hold up to 116 Exxon fuel rods, up to 69 PNL fuel rods, or both quantities together. The container has outer cross sectional dimensions of 8.4 inches square, a length from bottom to top of 159.9 inches, and an overall length (to the lift ring bolt head) of 161.2 inches. The primary material of construction of the container is ASTM 6061-T651 aluminum alloy. The two side walls, the bottom plate, and the lid are all ¾ inches thick. The side plates are attached to the bottom plate with two longitudinal, 3/8-inch groove welds. The lid is attached with twenty-two (22) zinc-plated, 3/8-16 UNC, SAE J429 Grade 8, hex head cap screws. The two square end pieces are made of solid aluminum alloy, and each are attached to the container with eight (8) zinc-plated SAE J429 3/8-16 UNC hex head cap screws made of Grade 8 alloy steel. The lower square end piece is 2.4 inches thick and the upper square end piece is 3.0 inches thick. Each bolt is secured in place using a thin stainless steel lock tab. Two of the eight bolts on each end go horizontally into the lid, in addition to the 22 cap screws on the top of the lid.

Inside the container is a ½-inch thick shelf, made of the same aluminum alloy, which fits into ¼-inch deep grooves in each side wall. The shelf is supported by ¼-inch thick aluminum support plates on 15.3-inch centers. The support plates and the shelf are located with intermittent 1/8-inch fillet welds, none of which are load bearing. Along the inside of the two side plates are two, 2.1-inch wide grooves, 0.4 inches deep. Each groove holds a 2-inch thick plate of the same aluminum alloy, which serve as bulkheads. The two bulkheads form rod cavities on each end of the container: a 78.3-inch long cavity for Exxon rods at the lower end and a 37.7-inch long cavity for the PNL rods at the top end. The cavity located between the two bulkheads is empty. Both rod cavities are 6.9 inches wide and 3.4 inches deep. The components of the AFS-C feature numerous small holes that ensure flooding or draining of water from its various cavities.

The lid is lifted by means of two, ¼-20 UNC threaded holes in the lid. The holes are located such that at least half of the hole is blocked by the top of the sidewall, which prevents an overly-long lifting bolt from possibly damaging any fuel rods. The container is lifted from its top end using a swivel hoist ring. All threaded holes may optionally be fitted with helical-coil thread inserts. The label 'AFS-C' is painted prominently on both sides of the container. The AFS-C is finished with a clear anodize treatment.

An external view of the AFS-C rod container is given in Figure C1.2-1. An internal cross sectional view is given in Figure C2.7-1, and views of a typical bulkhead in Figure C2.7-2.

C1.2.2 Containment System

The containment system description is unchanged from the description provided in Section 1.2.2, *Containment System*.

C1.2.3 Contents of Packaging

The MFFP may transport up to three (3) AFS-C rod containers, each containing up to 116 Exxon rods, up to 69 PNL rods, or both quantities together. These limits are based upon the number of rods that will fit within the AFS-C inner cavity, although less rods may be necessary in order to meet the decay heat limit for the package. The actual quantity of rods transported will be limited by either the physical space (i.e., the quantities listed above), or by the decay heat limit of 240 Watts total in the MFFP (see Section C1.2.3.3, *Maximum Decay Heat.*) If necessary, for a payload of fewer than the maximum quantities of rods, aluminum or stainless steel dunnage rods are used to take up the remaining space. For shipping less than a total of three (3) AFS-C containers, non-fuel dummy assemblies are utilized in the unoccupied strongback locations. The physical size and weight of the non-fuel dummy assemblies are nominally the same as the MK-BW/MOX1 17 × 17 design.

The physical parameters for the Exxon and PNL fuel rods are provided in Table C1.2-1. The Exxon rods are well characterized. However, known data for the PNL rods are limited to rod OD, rod length, average plutonium mass, and average plutonium isotopics. No records are available for a number of other PNL rod characteristics, such as pellet OD, active fuel height, and maximum plutonium mass. Data listed as "assumed" in Table C1.2-1 represent the most reactive estimated values determined in Chapter C6.0, *Criticality Analysis*, and are considered bounding. In the criticality analysis, the Exxon rods are conservatively limited to 65 g Pu per rod, and the PNL rods are conservatively limited to 42 g Pu per rod.

C1.2.3.1 Radionuclide Inventory

The average fuel rod isotopics for the Exxon and PNL rods as of 1980 are provided in Table C1.2-2. As these values are averages, these values are not necessarily bounding for criticality purposes. The bounding isotopics used for criticality are discussed in detail in Chapter C6.0, *Criticality Analysis*. Because the values in Table C1.2-2 are 1980 vintage, and Pu-241 has a half life of 14.35 years, the Pu-241 content of the actual rods will be less that the values provided here because most of the Pu-241 will have decayed to Am-241.

C1.2.3.2 Maximum Payload Weight

The weight of a single loaded AFS-C containing 116 Exxon and 69 PNL rods is approximately 1,230 pounds. This weight is bounded by the 1,580 pound weight of a standard fuel assembly (with BPRA). Three loaded AFS-C containers would weigh approximately 3,690 pounds. Therefore, the maximum payload weight is bounded by the value of 4,740 pounds provided in Section 1.2.3.2, *Maximum Payload Weight.*

C1.4 Appendices

C1.4.1 Nomenclature

The nomenclature list from Section 1.4.1, *Nomenclature*, is applicable. Additional nomenclature listed below.

AFS-C – Container used to transport up to 116 Exxon rods and 69 PNL rods. The AFS-C interfaces with the strongback in the same manner as a fuel assembly.

Exxon Rod – A type of MOX fuel rod with a length of approximately 77.3-in.

Pacific Northwest Laboratory (PNL) Rod – A type of MOX fuel rod with a length of approximately 36.6-in.

Los Alamos Technical Area 18 (TA-18) – Building at Los Alamos National Laboratory that currently stores the Exxon and PNL rods.

C1.4.2 Packaging General Arrangement Drawings

The general arrangement drawings of the body, strongback, and impact limiters are unchanged from those provided in Section 1.4.2, *Packaging General Arrangement Drawings*. The following AFS-C drawing is included in this section:

- 99008-61, Rev. 1, 2 sheets, *AFS-C Assembly*

This page left intentionally blank.

Figure Withheld Under 10 CFR 2.390

AREVA

AREVA Federal Services LLC
Packaging Projects
Tacoma, WA 98402

AFS-C ASSEMBLY
SAR DRAWING

SCALE: 1:5	WT. ~ LBS
REV: 1	SHEET 1 OF 2
DWG SIZE D	DWG NO. 99008-61
	CADFILE: 99008611.SLDDRW

Figure Withheld Under 10 CFR 2.390

REV: 1	SHEET 2 OF 2
DWG NO. 99008-61	

C2.0 STRUCTURAL EVALUATION

This chapter of Appendix C provides a structural evaluation of the MFFP when transporting up to three (3) AFS-C rod containers containing Los Alamos Technical Area 18 (TA-18) MOX fuel rods. Two types of TA-18 fuel rods are available, Exxon Nuclear (Exxon) and Pacific Northwest Laboratory (PNL). Because these rods have different outer diameters and lengths, they will be segregated longitudinally within the AFS-C cavity. The AFS-C may transport up to 116 Exxon rods and 69 PNL rods. The maximum number of rods is limited by the cavity size of the AFS-C. It is demonstrated that all quantities of interest are bounded by the analyses presented in Chapter 2.0, *Structural Evaluation*.

C2.1 Structural Design

C2.1.1 Discussion

A comprehensive discussion of the MFFP design and standard configuration is provided in Section 1.2, *Package Description*. The MFFP drawings show the detailed geometry of the package, as well as the dimension, tolerances, materials, and fabrication requirements, and are provided in Appendix 1.4.2, *Packaging General Arrangement Drawings*. A physical description of the AFS-C is provided in Section B1.2.3, *Contents of Packaging*. The following discussion is limited to the AFS-C.

A physical description of the AFS-C rod container is provided in Section C1.2.3, *Contents of Packaging*, and is shown in the drawings in Appendix C1.4.2, *Packaging General Arrangement Drawings*. The AFS-C container is a robust box designed to provide confinement of the fuel rods under all conditions of transport. The AFS-C container has the same external boundary dimensions as a standard MOX fuel assembly, and thus is loaded, mounted, and unloaded from the strongback in the same manner as a fuel assembly. The structural evaluations and testing performed as part of the original license activities adequately characterize the performance of the MFFP with this payload.

C2.1.2 Design Criteria

The MFFP design criteria are unchanged from those provided in Section 2.1.2, *Design Criteria*. The design criteria for the AFS-C rod container are based on the functional requirement that the rod container confine the rods inside the container boundary under all NCT and HAC. Because the AFS-C rod container is transported within the MFFP strongback, it is protected from gross distortion by the fuel control structure (FCS). As shown in Section 2.12.5, *Fuel Control Structure Evaluation*, the FCS provides a limit to any reconfiguration of the fuel assembly which could occur as a result of the worst case HAC event. The MOX fuel assembly consists of a larger number of rods (264) than is contained in the AFS-C rod container (up to 116 Exxon rods and 69 PNL rods). In addition, the rods in the MOX fuel assembly are unconfined by any structure other than the FCS, whereas fuel rods in the AFS-C rod container are confined within a container having significant structure. Therefore, gross distortion of the fuel rods or of the AFS-C container, or escape of the fuel rods or fuel rod fragments from the container, are not of concern.

To enhance criticality safety by preventing the potential for damage to the fuel rods in the HAC free drop impact event, the AFS-C rod container is designed to minimize the relative motion of the rods under impact conditions. To accomplish this, the AFS-C rod container is designed to limit the "rattle space" of the fuel rods (including any dummy rods as necessary) to less than approximately one half rod diameter.

The only components of the AFS-C container which are not supported externally by the strongback or FCS are the internal shelf and rod cavity bulkheads. To ensure that the "rattle space" available to the rods cannot increase as a result of the free drop impact event, these components are designed to have a primary bending stress less than the yield point of their material at NCT maximum temperature.

C2.1.3 Weights and Center of Gravity

The loaded weight of the AFS-C, conservatively assuming 116 Exxon and 69 PNL rods, is bounded by 1,230 pounds, which is 22% less than the gross weight of 1,580 pounds for a fuel assembly (including a BPRA). Therefore, the weight of the MFFP when transporting one or more AFS-C containers is bounded by the weights given in Section 2.1.3, *Weights and Center of Gravity*, for transport of MOX fuel assemblies.

When transporting both Exxon and PNL fuel rods, the weight is nearly balanced in the AFS-C container, and the center of gravity of the overall MFFP is essentially unchanged from the case of the standard MOX fuel assembly payload, where it is located 103.7 inches from the end of the bottom impact limiter. When transporting AFS-C containers with only Exxon rods, the center of gravity of the MFFP will be shifted approximately 3 inches toward the closed end, compared to the standard MOX fuel payload. When transporting AFS-C containers with only PNL rods, the center of gravity of the MFFP will be shifted approximately 1.5 inches toward the lid end, compared to the standard MOX payload. These shifts of c.g. are small relative to the overall length of the MFFP of approximately 200 inches, and will not have a significant effect on lifting, tiedown, or HAC response of the package.

C2.2 Materials

The AFS-C is constructed primarily of ASTM B209, 6061-T651 aluminum plate material. The lid and ends are attached with bolts made from SAE J429 Grade 8 material. A stainless steel swivel hoist ring is included for lifting. No non-metallic materials are used in the AFS-C. These materials do not result in any chemical or galvanic reactions, and are not significantly affected by radiation. The material properties for the aluminum material at 70 and 200 °F needed for calculations are given in Table C2.2-1, and were taken from the ASME B&PV Code,[1] as noted. Note that although there is limited welding of the 6061 material, welding is not used in regions where the material properties are used in stress analysis.

[1] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, Materials, Part D, Properties, 2001 Edition, 2002 and 2003 Addenda.

Table C2.2-1 - Material Properties of ASTM B209 6061-T651 Aluminum Alloy

Temperature, °F	Yield Strength, psi	Ultimate Strength, psi	Coefficient of Thermal Expansion, 10^{-6} in/in/°F
70	35,000①	42,000①	-
200	33,700②	-	13.0③

Notes:
①Yield and ultimate strength at 70 °F from ASME B&PV Code, Section II, Part B, SB-209.
②Yield strength at 200 °F from ASME B&PV Code, Section II, Part D, Table Y-1.
③Coefficient of thermal expansion from ASME B&PV Code, Section II, Part D, Table TE-2.

C2.3 Fabrication and Examination

The AFS-C rod container is fabricated to the requirements of the drawings shown in Appendix C1.4.2, *Packaging General Arrangement Drawings.* The materials of construction are specified to either ASTM or SAE standards. The rod container is inspected to the dimensional requirements of the drawing. Welds are visually inspected to the AWS D1.2[2] welding code.

C2.4 Lifting and Tie-down Standards for All Packages

Because the gross weight of the MFFP is lower when transporting an AFS-C rod container, this section is unchanged from Section 2.4, *Lifting and Tie-down Standards for All Packages*, in regards to the package itself.

The AFS-B uses a 5/8-11 UNC swivel hoist ring for handling. The thread depth for this swivel hoist ring bolt is 1.28-in. The minimum required thread depth may be computed by the following equation:

$$L_i = \frac{A_t \times S_t}{A_i \times S_i}, \text{ where}$$

A_t is the tensile stress area of the 5/8-11 UNC bolt (0.2201 in^2)

S_t is the allowable ultimate tensile strength for the 5/8-11 UNC bolt (170,000/5 = 34,000 psi)[3]

A_i is the internal aluminum thread stripping area per inch length (1.4255 in^2/in-length)

S_i is the governing allowable shear strength of the aluminum thread (0.6 x 42,000/5 = 5,040 psi using ultimate strength). Note that this value bounds the value obtained using the yield strength (0.6 x 35,000/3 = 7,000 psi). Material properties are at 70 °F.

The minimum length of aluminum thread to develop the full tensile strength of the external thread is then:

[2] ANSI/AWS D1.2, *Structural Welding Code – Aluminum*, American Welding Society (AWS).

[3] Conservatively high tensile strength obtained from ASTM A574, *Standard Specification for Alloy Steel Socket-Head Cap Screws.* Actual tensile strength of swivel hoist ring bolt will be equal to or less than this value.

$$L_i = \frac{(0.2201)(34{,}000)}{(1.4255)(5{,}040)} = 1.0416 \text{ in}$$

As this length is less than the 1.28-in thread depth of the swivel hoist ring bolt, tear out of the aluminum threads is not a concern. The governing factor is therefore the swivel hoist ring bolt, and the performance of this item is ensured by the rated capacity of the swivel hoist ring. Note that an optional 300 series insert may also be used, which would further increase the conservatism.

C2.5 General Considerations

The AFS-C rod container is evaluated by reasoned argument and by analysis in the following sections. In addition, the results and conclusions of Section 2.5, *General Considerations*, remain unchanged.

C2.6 Normal Conditions of Transport

C2.6.1 Heat

It is demonstrated in Section C3.4, *Thermal Evaluation for Normal Conditions of Transport*, that under NCT the MFFP strongback and shell temperatures associated with the AFS-C payload are bounded by the standard three (3) fuel assembly payload. Therefore, all associated pressure and thermal stresses are bounded by the values presented in Section 2.6.1, *Heat*. For the AFS-C rod container, the bounding temperature of the sidewalls and the internal shelf is 200 °F. Since the AFS-C is vented, it cannot retain pressure.

C2.6.1.1 Differential Thermal Expansion

The evaluation of differential thermal expansion given in Section 2.6.1.2, *Differential Thermal Expansion*, is not affected by use of the AFS-C rod container. An additional evaluation of the differential thermal expansion between the strongback and the AFS-C container will now be made.

From Section 2.6.1.2, *Differential Thermal Expansion*, the design temperature of the strongback is T_{SB} = 180 °F, and the coefficient of thermal expansion for the strongback material is $\alpha_{SB} = 8.8 \times 10^{-6}$ in/in/°F. As stated above, the bounding temperature for the AFS-C container is $T_{AFS\text{-}C}$ = 200 °F, and from Table C2.2-1, the coefficient of thermal expansion is $\alpha_{AFS\text{-}C} = 13.0 \times 10^{-6}$ in/in/°F. The overall length of the container is L = 159.9 inches. The reference temperature is 70 °F. The differential thermal growth of the rod container and the strongback is:

$$\delta = \alpha_{AFS-C}(L)(T_{AFS-C} - 70) - \alpha_{SB}(L)(T_{SB} - 70) = 0.115 \text{ inches}$$

This calculation conservatively assumes that the entire length of the two components is at the respective peak temperatures, and thus overestimates the relative thermal expansion. To prevent axial interference of the AFS-C container with the strongback, the clamp pads will be set with a clearance to the end of the AFS-C container. As stated in Section C7.1, *Package Loading,* the ¾-10 clamp pad screw will be backed out a minimum of one turn from the position of contact, ensuring a minimum axial clearance between the AFS-C container and the strongback of 0.1

inches at the reference temperature. This is adequate to ensure that the thermal expansion force is negligible or non-existent considering the conservatism of the evaluation above.

C2.6.2 Cold

This section is unchanged from Section 2.6.2, *Cold.*

C2.6.3 Reduced External Pressure

This section is unchanged from Section 2.6.3, *Reduced External Pressure.*

C2.6.4 Increased External Pressure

This section is unchanged from Section 2.6.4, *Increased External Pressure.*

C2.6.5 Vibration and Shock

The vibration normally incident to transportation will have no effect on the AFS-C rod container. The AFS-C container is installed and retained in the same manner as a MOX fuel assembly. The spring loaded clamp arms which hold the container in place will significantly dampen any vibrational loads which could come from the cask body. Furthermore, any fatigue cracks which might occur from vibration, which are too small to be noted during a visual inspection, would have no effect on the ability of the AFS-C to perform its function of confining the rods in a HAC free drop impact. Therefore, vibration and shock are not of concern for the AFS-C rod container.

C2.6.6 Water Spray

This section is unchanged from Section 2.6.6, *Water Spray.*

C2.6.7 Free Drop

Because a loaded AFS-C is lighter than a fuel assembly (including BPRA), the response of the MFFP to a free drop would be essentially the same when compared to the standard payload.

Since the AFS-C rod container is shown to confine the fuel rods in a HAC free drop impact (see Section C2.7.1), its performance will be acceptable for the NCT free drop event.

C2.6.8 Corner Drop

This section is unchanged from Section 2.6.8, *Corner Drop.*

C2.6.9 Compression

This section is unchanged from Section 2.6.9, *Compression.*

C2.6.10 Penetration

This section is unchanged from Section 2.6.10, *Penetration.*

C2.7 Hypothetical Accident Conditions

C2.7.1 Free Drop

The functional criteria of the AFS-C rod container is to confine the Exxon and PNNL fuel rods in the worst-case HAC free drop event. As an additional enhancement to criticality safety, the container should also restrict the relative movement of the rods to minimize the potential for damage to the fuel rods.

The MFFP strongback, including the fuel control structure (FCS), is designed to maintain a complete MOX fuel assembly in a subcritical configuration during the governing free drop event. Using physical test (see Appendix 2.12.3, *Certification Test Results*) and calculations (see Appendix 2.12.5, *Fuel Control Structure Evaluation*), it has been demonstrated that *a*) the fuel rods do not break or fragment, and *b*) the strongback and FCS are capable of confining the rods within a defined geometry. As stated in Section C1.2, *Package Description*, the AFS-C rod container consists of a completely enclosed structure made of 6061-T651 aluminum plates of ¾-inch nominal thickness. The lid of the container is attached using 22, 3/8-inch diameter bolts. The container has the same boundary dimensions as the MOX fuel assembly, and is mounted in the strongback in the same way. As such, the AFS-C container represents an added level of confinement for the fuel rods, beyond that provided by the strongback and FCS. For this reason, confinement of the fuel rods by the AFS-C container is ensured. Table C2.7-1 presents added detail which supports this conclusion. As stated in Section C2.1.2, *Design Criteria*, the movement of rods in an impact is restricted to a maximum of approximately one-half of a rod diameter.

The rod cavities inside the AFS-C container are formed by the ¾-inch thick lid plate, the two ¾-inch thick side plates, the ½-inch thick shelf plate, the thick end plates (minimum thickness of 2.4 inches), and the two, 2-inch thick bulkhead plates. The Exxon rod cavity is located at one end of the container and is 78.3 inches long, and the PNL rod cavity is located at the other end, and is 37.7 inches long. The shelf plate is located in longitudinal, ¼-inch deep grooves on the inside face of each ¾-inch thick side plate, and supported against the bottom plate by support plates at 15.3-inch intervals. Figure C2.7-1 shows a cross section of the AFS-C container. The bulkhead plates are located in 0.4-inch deep grooves on the inside face of each side plate. Figure C2.7-2 shows a typical cross section view of a bulkhead plate. The bulkhead plate spans the distance between the two side plates, and closes off one end of each rod cavity. To demonstrate that the rod cavity maintains its internal geometric integrity in the worst-case free drop impact, the following evaluations are performed. The internal geometric integrity assures that the "rattle space" inside the container is minimized to prevent any possible damage to the rods. However, any loss of the rod container contents is precluded by the rod container primary structure, as discussed above.

Shelf Evaluation. In the following, it is assumed that the impact occurs with the shelf oriented horizontally with the container lid side up. This orientation governs over all others where some component of the rod load is directed toward the thick sidewalls of the container. Any support from the support plates beneath the shelf is conservatively neglected. The shelf is then a plate, simply supported on its two long sides, and free on its two short sides. A governing impact of

180g is taken from Section 2.12.5.2, *Conditions Analyzed*, for the maximum slapdown impact. The loading from the weight of the fuel rods will be taken from the governing case of either the Exxon or PNL rods. Note that each weld between the shelf and the side plates is only 2-inches long, centered on each support plate, as shown in Section B of drawing 99008-61. This weld is not structural, and serves only to compensate for any weld distortion which might occur from the two groove welds. As such, a strength reduction does not need to be considered, since the longer, unsupported length between support plates is far from any heat affected zone.

From Table C1.2-1, the Exxon fuel rod weight is 4 lb each, and the length is $L_{Ex} = 77.3$ inches. From the same table, the PNL fuel rod weight is 3.3 lb each, and the length is $L_{PNL} = 36.6$ inches. From Figure C2.7-1, the internal width of the cavity is b = 6.9 inches. For 116 Exxon rods, the total weight is $W_{Ex} = 116 \times 4 = 464$ lb. The total weight of the PNL rods is $W_{PNL} = 69 \times 3.3 = 228$ lb. Since the rods rest on an area bounded by the rod length and the cavity width, the impact pressure on the shelf is:

$$q = \frac{W_{Ex}g}{L_{Ex}b} = 156.6 \text{ psi for Exxon rods}$$

$$q = \frac{W_{PNL}g}{L_{PNL}b} = 162.5 \text{ psi for PNL rods}$$

Therefore the governing load is q = 162.5 psi, which will conservatively be assumed to apply to the entire shelf, rather than just the area beneath the PNL rods. A formula from Roark,[4] Table 26, Case 1a, is used. Even though this formula assumes simple support on the narrow ends as well as the sides, the maximum stress at the center of the plate, which is more than 10 plate-widths distant from the ends, will not be materially affected. The length of the shelf is $L_s = 153.5$ inches. The ratio a/b is 153.5/6.9 = 22.2, from which $\beta = 0.75$. The maximum stress at the center of the plate is found from:

$$\sigma = \frac{\beta q b^2}{t^2} = 23{,}210 \text{ psi}$$

where t = 0.5 inches, and the other quantities are as defined above. From Table C2.2-1, the yield strength of the shelf material at the bounding temperature of 200 °F is 33,700 psi. The margin of safety against yield of the shelf is:

$$MS = \frac{33{,}700}{23{,}210} - 1 = +0.45$$

Since the shelf does not yield, the "rattle space" available for the rods does not increase as a result of the slapdown free drop event. Other impact orientations would place lower loadings on the shelf.

Bulkhead Evaluation. In this evaluation, stresses associated with the bulkhead are demonstrated to remain below the yield point of the aluminum alloy material in the worst case end drop impact of 120g, taken from Section 2.12.5.2, *Conditions Analyzed*. The governing weight is that of the Exxon fuel rods, having a maximum weight of $W_{Ex} = 464$ lb. The bulkhead is modeled as a beam, simply supported at each side plate, for a span of L = 6.9 inches, and a width (see Figure C2.7-2) of

---

[4] Young, W. C., *Roark's Formulas for Stress and Strain*, Sixth Edition, McGraw-Hill, 1989.

b = 3.3 inches, assuming a 0.1-in total gap. (Note that the nomenclature has been partially redefined so as to be consistent with common textbook formulas.) The moment of inertia is:

$$I = \frac{bh^3}{12} = 2.2 \text{ in}^4$$

where h = 2 inches. The c-distance is h/2 = 1 inch. The loading per inch of length of the beam is:

$$w = \frac{W_{Ex}g}{L} = 8069.6 \text{ lb/in}$$

where g = 120 for the end drop impact. The bending moment is:

$$M = \frac{wL^2}{8} = 48{,}024 \text{ in} - \text{lb}$$

The bending stress is:

$$\sigma = \frac{Mc}{I} = 21{,}829 \text{ psi}$$

From Table C2.2-1, the yield strength of the bulkhead material at the bounding temperature of 200 °F is 33,700 psi. The margin of safety against bending yield of the bulkhead is:

$$MS = \frac{33{,}700}{21{,}829} - 1 = +0.54$$

The bearing stress on the two grooves in the side plates which support the bulkhead is equal to:

$$\sigma_b = \frac{F}{A} = \frac{W_{Ex}g}{2bt_g} = 27{,}214 \text{ psi}$$

where a value of t_g = 5/16 (0.31) inches is conservatively used for the 3/8 (0.4) inches deep groove in the side plate. Conservatively, this bearing stress will be compared to the tensile yield strength, even though bearing stress is commonly permitted to reach a much higher value. The margin of safety on bearing yield is:

$$MS = \frac{33{,}700}{26{,}953} - 1 = +0.25$$

The groove edge which supports the bulkhead is subject to a shearing load on a plane oriented at 45° to the plane of the bulkhead. The shear area per groove is:

$$A_s = t_g b\sqrt{2} = 1.45 \text{ in}^2$$

The shear stress is:

$$\tau = \frac{W_{Ex}g}{2A_s} = 19{,}200 \text{ psi}$$

The shear yield strength is equal to 0.6 times the tensile yield strength. The margin of safety is:

$$MS = \frac{(0.6)33{,}700}{19{,}200} - 1 = +0.05$$

Note that in all of these calculations, the yield point of the material is conservatively chosen as a stress criteria, even though the HAC event is classified as a Service Level D loading condition by Regulatory Guide 7.6.[5] Since neither the shelf nor the bulkhead experience yield in the governing slapdown or end drop impacts, the "rattle space" available for the rods does not increase as a result of the worst case free drop event. Thus, the AFS-C rod container supports the geometry assumptions made in the criticality analysis of Chapter 6, *Criticality Evaluation.*

Table C2.7-1 Comparison of the MOX Fuel Assembly and the AFS-C Rod Container in the MFFP Strongback

MOX Fuel Assembly	AFS-C Rod Container	Conclusion
Strongback clamps on fuel grids	Strongback clamps on container	AFS-C lid is both bolted in place and clamped in place by the strongback
Max weight of 1,580 lb	Max weight of 1,230 lb	Lighter payload in AFS-C, which applies lower inertia loads to the strongback in free drop impact events
264 rods	116 Exxon plus 69 PNL (185) rods	Fewer rods in AFS-C
Rods self-supporting over span between clamp arms	Rods supported by thick walls and bolted lid of container	AFS-C eliminates rod bending loads
Rods can move axially a limited amount	Rods are confined by thick, bolted end structures	AFS-C confines rods axially
Rod lateral buckling is controlled by strongback and FCS	Rod lateral buckling is controlled by strongback and FCS, plus: 1. restricted free space inside container 2. rods supported by thick walls of container 3. rods are shorter than MOX rods	AFS-C adds a significant layer of rod support to that existing in the basic strongback/FCS

[5] U.S. Nuclear Regulatory Commission, Regulatory Guide 7.6, *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels*, Revision 1, March 1978.

Figure Withheld Under 10 CFR 2.390

Figure C2.7-1 AFS-C Rod Container Cross Section View

Figure Withheld Under 10 CFR 2.390

Figure C2.7-2 AFS-C Rod Container Bulkhead Views

C2.7.2 Crush

This section is unchanged from Section 2.7.2, *Crush*.

C2.7.3 Puncture

The weight of the MFFP containing up to three AFS-C rod containers is bounded by the weight of the MFFP with a payload of three (3) standard fuel assemblies. Therefore, the system response to a puncture is bounded by the discussion presented in Section 2.7.3, *Puncture*.

C2.7.4 Thermal

C2.7.4.1 Summary of Pressures and Temperatures

Package pressures and temperatures due to the HAC thermal event are presented in Section C3.5.3, *Maximum Temperatures and Pressures*. MFFP strongback and shell temperatures under HAC associated with the AFS-C payload are essentially the same as the standard three (3) fuel assembly payload. From Section C3.5.3.2, *Maximum Pressures*, the maximum internal pressure during the HAC thermal event is 121.4 psig, with the package initially at atmospheric pressure. This pressure is bounded by the 130 psig pressure used in Section 2.7.4, *Thermal*.

C2.7.4.2 Differential Thermal Expansion

This section is unchanged from Section 2.7.4.2, *Differential Thermal Expansion*, as the MFFP strongback and shell temperatures under HAC associated with the AFS-C payload are essentially the same as the standard three (3) fuel assembly payload.

C2.7.4.3 Stress Calculations

As discussed in Section C2.7.4.1, *Summary of Pressures and Temperatures*, a conservative maximum internal pressure of 121.4 psig is calculated for the HAC thermal event. This pressure is lower than the 130 psig pressure used in Section 2.7.4.3, *Stress Calculations*. Therefore, the stresses calculated in Section 2.7.4.3 conservatively bound the stresses resulting from the payload evaluated in this Appendix.

C2.7.5 Immersion – Fissile Material

This section is unchanged from Section 2.7.5, *Immersion – Fissile Material*.

C2.7.6 Immersion – All Packages

This section is unchanged from Section 2.7.6, *Immersion – All Packages*.

C2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A_2)

This section is unchanged from Section 2.7.7, *Deep Water Immersion Test*.

C2.7.8 Summary of Damage

The AFS-C rod container maintains its structural integrity and functionality in the worst-case HAC free drop event, which bounds the loadings of all other HAC events on the container. Since the AFS-C rod container is mounted in the same way as a MOX fuel assembly but weighs less, the response of the MFFP to drop and puncture accidents is unchanged when using the AFS-C. Therefore, the AFS-C is acceptable for use as a payload container.

C2.8 Accident Conditions for Air Transport of Plutonium

This section does not apply for the MFFP, since air transport is not claimed.

C2.9 Accident Conditions for Fissile Material Packages for Air Transport

This section does not apply for the MFFP, since air transport is not claimed.

C2.10 Special Form

This section does not apply for the MFFP, since special form is not claimed.

C2.11 Fuel Rods

This section does not apply for the MFFP, since containment by the fuel rod cladding is not claimed.

C2.12 Appendices

There are no appendices to Chapter C2.0. The applicability of the appendices to Chapter 2, *Structural Evaluation*, is given in Table C2.12-1.

Table C2.12-1 – Applicability of Section 2.12 Appendices to the AFS-C Payload

Appendix	Applicability
2.12.1, Impact Limiter Evaluation	As the weight of the AFS-C is bounded by the weight of a fuel assembly, the impact limiter evaluation from Section 2.12.1 remains bounding.
2.12.2, Certification Test Plan	Unchanged from Section 2.12.2
2.12.3, Certification Test Results	Unchanged from Section 2.12.3
2.12.4, Engineering Test Results	Unchanged from Section 2.12.4
2.12.5, Fuel Control Structural Evaluation	As the weight of the AFS-C is bounded by the weight of a fuel assembly, and because it is more structurally robust than a fuel assembly, the fuel control structural evaluation from Section 2.12.5 remains bounding.
2.12.6, CASKDROP Computer Program	Unchanged from Section 2.12.6
2.12.7, Impact Limiter Weld Joint Test Results	Unchanged from Section 2.12.7
2.12.8, Effect of Bounding Weight on Package Structural Responses	As the weight of the AFS-C is bounded by the weight of a fuel assembly, the package structural responses evaluation from Section 2.12.8 remains bounding.

This page left intentionally blank.