71-9270

NAC INTERNATIONAL

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March 31, 2004

U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852-2738

Attn: Document Control Desk

Subject: Submittal of a Request for an Amendment of Certificate of Compliance (CoC) No. 9270 for the UMS® Universal Transport Cask to Incorporate Various Update Information

Docket No. 71-9270

Reference:
1. Model No. UMS Universal Transport Cask Package, Certificate of Compliance (CoC) No. 9270, Revision 0, U.S. Nuclear Regulatory Commission (NRC), October 31, 2002
2. Safety Analysis Report for the NAC UMS® Universal Transport Cask, Revision 1, NAC International, December 2002

NAC International (NAC) herewith submits a request for approval of an Amendment to Reference 1 to incorporate various update information to make the UMS® Transport Cask documentation consistent with that of the UMS® Storage System.

This submittal includes eight copies of Revision UMST-04A changed pages for Reference 2 [NAC-UMS® Transport Cask Safety Analysis Report (SAR)]. The changed pages incorporate the requested amendment noted above. Consistent with NAC administrative practice, this proposed revision is numbered to uniquely identify the applicable changed pages. Revision bars mark the SAR text changes (on Revision UMST-04A pages) that are proposed in this submittal. Upon final approval, the changed pages will be reformatted, assigned the next appropriate revision number, and incorporated into the NAC UMS® Universal Transport Cask SAR.

Reference 2 changed pages have been updated to document that no restriction is placed on the loading of fuel assembly types into a particular UMS® canister class. Throughout the document, where appropriate, the term "BORAL" has been replaced with "neutron absorber." Also, to avoid any conflict of terminologies with the ASME code, the term "backing ring" has been replaced with "spacer ring" where appropriate. The Maine Yankee fuel can description has been updated and appropriate calculations have been revised to demonstrate adequacy of the design configurations while applying a conservative approach. A table has been added to Chapter 2, which contains the major physical design parameters of the Maine Yankee fuel cans.

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Changes incorporated in Chapters 1 and 2 of Reference 2 include stress calculation results for PWR canister shield lid and structural lid reduced weld sizes. Also, these chapters have been revised to reflect minor material changes to components.

Chapters 1, 3 and 5 have been revised to update the high burnup fuel definition and to add a table (Chapter 3) summarizing the thermal characteristics of METAMIC neutron absorber.

Chapter 7 has been revised to remove references made to "threaded plugs" and to add a note allowing the use of one or more shims when installing the structural lid to assure that the lid is flush with or slightly protrudes above the canister shell.

In this amendment request, 17 license drawings have been updated to their current revisions. Changes made to these license drawings are summarized in Attachment 1 (List of Drawing Changes) to this letter. In addition, two new license drawings are included in this submittal – 412-501 and 412-502 – to define the two Main Yankee fuel can configurations.

NAC hereby requests approval of the changes contained in UMST-04A. Approval of this amendment request will make the UMS Transport Cask application consistent with the current version of the UMS Storage FSAR.

If you have any comments or questions, please contact me on my direct line at (678) 328-1321.

Sincerely,

T C Thompson

Thomas C. Thompson
Director, Licensing
Engineering

Attachment 1, List of Drawing Changes

Enclosure

CC: John Niles (MY) w/o Enclosure
Glenn Michael (APS) w/o Enclosure
Keith Waldrop (Duke) w/o Enclosure

NAC INTERNATIONAL

U.S. Nuclear Regulatory Commission
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ATTACHMENT 1

NAC-UMS TRANSPORT SAR, REV. UMST-04A

LIST OF DRAWING CHANGES

Drawing 790-500, Revision 4 – Assembly, Universal Transport Cask, Overpack, NAC-UMS®

- Add new Item # 16 Trunnion Cap, per drawing 790-505.
- Revise drawing to show installation of trunnion caps in place of secondary trunnions, as an alternative assembly.
- Add note that secondary trunnions are not installed during transport.
- Revise Note 8 added per DCR 790-000-4A to be Delta Note 8 and read: "Trunnion Cap (Item 16) to be installed in place of Secondary Trunnion (Item 7) during transport."
- Sheet 1, Zone F6-5: Add balloon callout for Item 16 between balloons 7 and 8, and apply Delta Note 8 to Items 7 and 16.
- Remove alternate assembly callout (added per DCR 790-500-2A).
- Revise graphics to show new primary trunnion (added per DCR 790-505-1B).
- BOM, Item 4: Material: IS: St. Stl.; WAS: 316 St. Stl.
- BOM, Item 11: Remove material callout.
- BOM, Item 15: Material: IS: St. Stl.; WAS: 18-8 St. Stl.
- BOM: Add Item 17, Quantity, Assy –99: 1, Name: O-Ring, Material: Viton, Spec.: Coml, Description: Parker #3-908 V747-75.
- Add balloon callout for Item 17 next to Item 4 balloon, Sheet 2, Zone: B7.
- BOM, Item 6: Material: IS) St. Stl.; WAS: 303 St. Stl.

Drawing 790-505, Revision 2 – Lifting Trunnion, NAC-UMS®

- Add new Item 5, Trunnion Cap, to be installed on cask when secondary trunnion is not used. Cap is identical to Item No. 1, except trunnion section to be removed. Trunnion cap to be installed with secondary trunnion bolts.
- Revise Item 5 (added per DCR 790-005-3A) material to be 304 St. Stl., and the Spec. to be ASTM A479.
- Revise Item 2 detail.

Drawing 790-571, Revision 3 – Bottom Weldment, Fuel Basket, 56 Element BWR, NAC-UMS®

- Change dimension, Zone D7: IS) 22.0; WAS: 21.9.

Drawing 790-575, Revision 10 — BWR Fuel Tube, NAC-UMS®

- Change dimension, Zone D1: IS: 6.00; WAS: 5.97.
- Show original fabrication of Detail D-D.
- Update borders to current.

- Items 3 and 4 IS: "Neutron Absorber" and update Item/Assembly names and notes accordingly; WAS: Neutron Poison
- Replace material in BOM: IS: Boral/Metamic; WAS: Boral

Drawing 790-581, Revision 8 – PWR Fuel Tube, NAC-UMS®

- Items 4, 5, and 6: IS: Neutron Absorber; WAS: Neutron Poison and update Item/Assembly names and notes accordingly.
- Replace material in BOM: IS: Boral/Metamic; WAS: Boral.
- Change dimension, Sheet 1, Detail A-A, Zone B7: IS: .34) TYP; WAS: (.43 TYP).
- Change dimension, Sheet 1, Detail A-A, Zone B7: IS: (.18) TYP; WAS: (.23) TYP.
- Change dimension, Sheet 1, Detail A-A, Zone B7: IS: .16 1 Edge Each Side Typ; WAS: .2 1 Edge Each Side Typ.
- Update drawing borders.
- Show original fabrication of Detail D-D.
- On Sheet 1, in Zone D-5, revise the note in the tail of the weld symbol: IS: PAW, LBW, or GTAW, Both Sides, TYP; WAS: PAW or GTAW, Both Sides, TYP.
- On Sheet 1, in Detail A-A, revise the note in the tail of the weld symbol: IS: PAW, LBW or GTAW, Both Sides, TYP; WAS: PAW or GTAW, both Sides, TYP.
- On Sheet 1, in Detail A-A, add a note marker for Delta Note 5 to the welding symbol.
- Add a Delta Note 5 as follows: "Alternatively, cladding may be attached to tube via a continuous weld."
- On Sheet 1, revise Detail D-D (Alternate Fabrication) by deleting the 1/32-inch fillet weld which has a 2 inch length on 8 inch intervals on the far side of the flange (Item 10).
- On Sheet 1, revise dimension in Zone A7: IS: .16+ .12, -.07 ONE SIDE TYP; WAS: .16 ONE SIDE TYP.
- Sheet 1, Zone D7: Revise reference dimension: IS: (8.8) TYP; WAS: (8.80) TYP.

Drawing 790-582, Revision 11 — Shell Weldment, Canister, NAC-UMS®

- Add Delta Note 7 as follows: Tolerances applied to localized areas of shell diameter are .24"/.18". Localized areas being flatspots, bulges, etc... At no point shall there be any interference between the interfacing components and the shell.
- Add Delta Note 7 graphic symbol at Drawing Zone C7, adjacent to shell weldment diameter of 67.06" ± .12".
- Revise Delta Note 4 as follows: Tolerances applied to localized areas of shell diameter are +.18"/-.24". Localized areas being flatspots, bulges, etc... At no point shall there be any interference between the interfacing components and the shell.
- Revise Delta Note 4 as follows: "Tolerance applied to localized areas of shell diameter are +.21"/-.24". Localized areas..."

- Increase the depth of the bevel on the top of the shell: IS: .9 +.1/-.2; WAS: .8.
- Add a detail for an optional sump in the Bottom Plate, BOM Item #6.
- DCR 790-582-8A should refer to Delta Note 7, not Delta Note 4.
- Sheet 1 and 2, Zone E7, add Delta Note 6 to full penetration, double-V groove joint weld for TSC shell longitudinal seam as follows:
  Alternate weld joint allowed provided the following criteria are satisfied:
  1. Alternate weld joint achieves complete joint penetration.
  2. Alternate weld joint meets all requirements of Section III, Subsection NB.
  3. Alternate weld joint is approved by NAC.
- The change made on DEC 790-582-9A should have added Delta Note 8, however the description of change had listed to add Delta Note 6.
- Revise Delta Note 2 as follows: WAS: For ASSY-99, 96, 95 Angle is 35° ± 5° for ass6 –98, 97 angle is 40° ± 5°. Engrave Stripe 1.0 Wide x .03 deep and fill with weather resistant yellow paint. IS: Optional Engraved Stripe - For ASSY-99, 96, 95 Angle is 35° ± 5° for ASSY –98, 97 angle is 40° ± 5°. Engrave Stripe 1.0 Wide x .03 deep and fill with weather resistant yellow paint.

<u>Drawing 790-583, Revision 7 – Assembly, Drain Tube, Canister, Duke-McGuire, NAC-UMS®</u>

- Add a Delta Note: When the optional Sump shown on Drawing 790-582 is used these dimensions shall be:
  165.9 –6
  175.0 –5
  176.4 –4
  181.2 –3
  182.6 –2
- Add Delta Note callout to the length dimensions in Zone D4.
- Add Delta Note to state "Item 1 (Nipple) can be substituted with Snap-Tite # SVHN16-16-EMV with Viton seals."
- Add Delta to Part #1,Sheet 1 of 1.
- Add Delta Note 2 as follows: "Item 7, alternate seals are: "Viton" Parker 3-916V0884-75 & "EPDMP Parker 3-916E0893-80.
- Add Delta Note 2 to Item 7 in BOM and in field of drawing.
- Add a new Note as follows: "As an option, Item 1 may be rebuild to install Viton or EPDM seals. Replacement seals are installed in accordance with manufacturer's instructions using Snap-Tite Kit numbers H-16-55-E and H-16-59-E for EPDM seals and Kit H-16-55-V and H-16-59-V for Viton seals. Item 1 is re-assembled using a torque value of 100 +10/-0 foot-lbs.
- Revise Delta Note 1 on drawing 790-583 to read as follows. IS: When the optional sump shown on drawing 790-582 is used these dimensions shall be: (165.9) –5; (175.0) –6; (176.4) –7; (181.2) –8; (182.6) -9 WAS: When the optional sump shown on drawing 790-582 is used these dimensions shall be: 165.9 –5; 175.0 –6; 176.4 –7; 181.2 –8; 182.6 -9

- Add a new Delta Note on NAC-UMS® drawing 790-583 to read as follows. Add the following new Delta Note to the drawing and to the drawing Bill of Material Items 2, 3, 4, 5 & 6: "When used with optional counterbore detail on Drawing 790-582, trial fit and adjust length if needed to ensure a .12 ± .1 clearance between end of tube and bottom of the .38 deep counterbore in the bottom plate."
- Revise BOM Item 7, Remove delta note 2, Name WAS: Metal Boss Seal IS: Seal, Material WAS: ST. STL. IS: See Note 2, Description WAS: Furon #10061-16-1-0 IS: See Note 2.
- Replace Delta Note 2 with the following "Item 7, seal material to be specified by user: elastomer seals: "Viton" Parker #3-916V0884-75 or "EPDM" Parker #916E0893-80 or metal seal: Furon #10061-16-1-0"

<u>Drawing 790-584, Revision 17 — Details, Canister, NAC-UMS®</u>

- Sheet 1, Zones F-6 and F-3, change 1.5 TYP to 1.5+1, -.1 TYP.
- Revise Sheet 3, Zone D-7, lid support ring diameter from hard dimension to reference dimension: IS: (↓65.8) and add Delta Note 10 callout; WAS: ↓65.8.
- Revise sheet 1, add Delta Note 10 to read...Item 6, lid support ring to be fit-up and welded to shell inside diameter in a manner to assure maintenance of the 1" nominal gap.
- Add Delta Note 11 as follows: Tool marks and other marks are acceptable on all unspecified machined surfaces as long as required thickness/diameter of items are met.
- Revise BOM, Item 7 Name to read: Spacer Ring.
- Sheet 3, Zone C4, Revise name of Item 7 to read Spacer Ring.
- Create independent drawing details for Assy-98.
- Change dimension callout Sht 1, Zone E-1: IS:....3.0; WAS: ....3.00.
- Update drawing graphics.
- Create alternate drawing detail for structural lid weld prep and update drawing graphics.
- Revise new detail H-H, added per DCR 790-584-12A to read...GTCC and TSC lids.
- Revise drawing details added per DCR 790-584-12A.
- Revise drawing details added per DCR 790-584-12B.
- Revise Note 2 to allow a circle in lieu of a triangle to be engraved to identify the key location. Note 2 shall read as follows: "Engrave delta .5" per side, or circle .5" diameter, x .03" deep, not to infringe on the weld bevel, and fill with weather resistant black paint."
- Revise Note 5 to allow engraving as well as steel stamping. The first sentence of Note 5 shall read: "Steel stamp/engrave ½" high the following sequence located approx. as shown."
- On Sheet 2, Zone D-1, revise the tolerance on the two weld bevel angles: IS: ±5°; WAS: ±1°
- Sheet 2, Zone C2, Remove the 64.0 dimension.
- Sheet 2, Zone D1, add the dimension .55 ± .10 for the depth of the space ring groove from the outer edge of the top lip.

- Add Delta Note to state "Item 2 (Nipple) can be substituted with Snap-Tite #SVHN16-16EMV with Viton seals."
- Add Delta to Part # 2 Sheet 1 of 3.
- Change the dimension leader in Section A-A, Sht 2 of 3, Zone B4: IS: SEE DETAIL J-J; WAS: SAE J514 BOSS FOR 1 TUBE.
- Add new drawing detail J-J.
- Add Delta Note 12 as follows: Item 3, alternate seal materials are: "Viton" Parker 3-916V0884-75 & "EPDM" Parker 3-916E0893-80.
- Add Delta Note 12 to Item 3 in BOM and in field of drawing.
- Revise Delta Note 1 to add: For alternate seal materials, EPDM and Viton, the fittings are to be tightened "snug plus one wrench flat".
- Revise Delta Note 1 to read: "...torque to 135 +/- 15 ft-lbs."
- Add a new Note as follows: "As an option, Item 2 may be rebuilt to install Viton or EPDM seals. Replacement seals are installed in accordance with manufacturer's instructions using Snap-Tite Kit numbers H-16-55-E and H-16-59-E for EPDM seals and H-16-55-V and H-16-59-V for Viton seals. Item 2 is re-assembled using a torque value of 100 +10/-0 foot-lbs.
- Revise Next Assembly: IS: 790-585; WAS: 790-085.
- Add note one callouts
- Revise BOM Item 3, Remove delta note 12, Name WAS: Metal Boss Seal IS: Seal, Material WAS: ST. STL. IS: See Note 12, Description WAS: Furon #10061-16-1-0 IS: See Note 12.
- Replace Delta Note 12 with the following "Item 3, seal material to be specified by user: elastomer seals: "Viton" Parker #3-916V0884-75 or "EPDM" Parker #916E0893-80 or metal seal: Furon #10061-16-1-0"
- Revise delta note 1, WAS: Lubricate with a spent fuel pool compatible lubricant such as Neolube and torque to 135 15 ft-lbs. For alternate seal materials EPDM and Viton, the fittings are to be tightened "snug plus on wrench flat". IS: Lubricate with a spent fuel compatible lubricant such as Neolube. Install fitting by hand until metal to metal is achieved then torque to (115 5 ft-lbs for elastomer seals) or (135 15 ft-lbs for metal seals).
- Add new note: "Small indentations and imperfections are allowed in the structural lid weld land area providing they do not adversely affect the welding procedures by requiring requalification and would be incorporated into the weld."
- Remove 1.5 dimension on detail J-J
- Change dimension leader callout Sht 2 of 3, Zone F7 IS: 455 X .48.12 WAS: 455 X .5
- Change dimension callout Sht 2 of 3, Zone E1 IS: 1.25.15 WAS: 1.3
- Change dimension callout Sht 2 of 3, Zone D1 IS: 1.25.15 WAS: 1.3
- Delete delta note 13 and all associated callouts.
- Delete Note 14.
- Change BOM Item 2 Description IS: Quick Disconnect Coupling WAS: Snap-Tite #SVHN16-16EM
- Change drawing note 12 to read, "Item 3, seal to be specified by user: elastomer seal (Viton or EPDM) or a metal seal."

- Change the general drawing note 12 to be delta note 12.
- When generating Revision 0 to the 407-284 drawing, the request was made by APS to replace the "H" series quick disconnect with the "E" series quick disconnect. However, this change was not picked up on this associated license drawing. As a result, AFR 04-001 was issued and NAC has initiated this DCR(L) to allow for the use of either quick disconnect.
- These changes were to make the seal type and the fitting to be more generic and less dependant on specific manufacturers part numbers.
- This change is to correct an inconsistency within the drawing. The list of notes shows that 12 is a general drawing note, however it is called out as a delta note in the field of the drawing.

Drawing 790-585, Revision 15 — Transportable Storage Canister (TSC), NAC-UMS®

- Revise Delta Note 6 to read: At the option of the user, stainless steel shims (ASME SA240/479, Type 304L) of appropriate thickness may be used in the welding of the structural lid (Item 19) to the shell weldment (Items 1 – 5). Also add Delta Note 6 callout at Zone F6, next to structural lid to shell weld callout.
- Revise Item 20 Name to: Spacer Ring.
- Revise Cover weld callout Zone E6 IS: (3/16) WAS: (1/4). Also revise bevel to show bevel flush.
- Remove backing ring symbol from structural lid/shell weld symbol in Zone F6.
- Zone E6, revise cover weld callout; WAS: (3/16) bevel flush IS: (3/16) bevel concave.
- Add text to Delta Note 3, "Length may be adjusted in the field by NAC, to allow for stack up conditions."
- Add Delta Note 10 to Item #19, "At the option of the user, spacer shims (drawing 790-587) may be used to adjust the stack height of the structural lid and ensure that the top of the lid is at either level with the top of the canister or extends past the top edge of the canister, so long as the min. effective weld throat is maintained for the closure welds."
- Change Delta Note 5: IS: PT Root and Final Surface. Should Root and Final Surface be one and the same (i.e., single pass weld) then only one PT examination is required; WAS: PT Root and Final Surface.
- Add Note: "Field installed Code nameplates shall be located on the Structural Lid as directed by the Client. Code nameplates to be welded to the Structural Lid with four-fillet tack welds ¼ inch long (minimum), one adjacent to each corner of the plate. Fillet weld size to be equal to the thickness of the nameplate."
- Add Note: "The Structural Lid to shell gap shall be ½ inch or less during fit-up prior to welding and the weld root gap will be controlled using shims as needed."
- Change Delta Note 8 to read: "Items 22, 23 and 24 may be field modified to fit flush to surface following the welding of their respective lids."

- Add new note: "Inspection of cold stack-up of the shield and structural lids must be performed prior to the commencement of field welding. The structural lid may range from up to .180" beyond the top edge of the canister shell or be located below the top edge of the canister shell up to 0.030". This inspection may either be performed at the fabricator's facility or in the field."
- Add new note: "The groove weld from the top of the structural lid root pass weld to the shortest distance of the finished weld profile shall be at least 0.72".
- Add new note: "The structural lid and installed spacer ring can be field dressed in localized areas to eliminate interference with the canister shell during installation of the lid."
- Add new note: "At the option of the user, stainless steel (ASTM/ASME A/SA240 type 304/304L) shims of appropriate size and thickness may be used in the spacer ring groove in the structural lid to ensure the ring fits tightly against the top of the groove at the bottom of the weld joint. The shim may be tack welded to the bottom of the spacer ring."
- Change dimension, Sheet 1, Zone D5: IS: 10.0; WAS: 9.96.
- Add new note: "At the intersection of the shell longitudinal seam and the top lip of the canister, the projection of the structural lid above the lip of the shell during cold stack up may exceed .18" up to .25" for a length of 6" in either direction from the centerline of the longitudinal seam."
- Add new note: "After shield lid welding, TSC shells may be re-rounded by mechanical methods or tooling. If re-rounding is performed, the examination of the shield lid final weld surface, pressure test and leak test shall be performed, after all re-rounding activities are completed."
- Revise weld callout for Item 18 (Cover) to Item 17 (Shield Lid Assy) Sheet 1, Zone E6 from a (3/16) to a (1/8) weld.
- Add Delta Note to read: "Weld not to exceed top surface of Item 17 (Shield Lid Assy)." Add Delta Note to weld callout Sheet 1, Zone E6.
- On Sheet 2, Zone D4-5, delete reference dimension, (2.00).
- On Sheet 2, Zone B4, revise the length of the Structural Lid Plug (Item 23): IS: 2.25 MIN; WAS: 2.5.
- Add text to Delta Note #8: "Item 24, dowel pin, may be ground to facilitate a press fit during installation."
- Add note: "The final weld profile of the Shield Lid weld will typically "wash" up onto the ID surface of the shell. To ensure that the reinforcement does not interfere with the structural lid, the weld reinforcement shall not exceed .110" and the wash up onto the shell ID shall not exceed .220". The weld profile acceptance will be verified with a Go/No Go Gage with dimensions equal to the worst-case dimensional configuration of the Structural Lid profile (tightest acceptable fit to the shell ID) noted in Detail C-C of drawing 790-584.
- Revise Delta Note 3 to add: For alternate seal materials, EPDM and Viton, the fittings are to be tightened "snug plus one wrench flat".
- Revise Delta Note 3 to read: …torque to 135 +/- 15 ft-lbs.

- Revise delta note 3, WAS: Lubricate with a spent fuel pool compatible lubricant such as Neolube and torque to 135 ± 15 ft-lbs. Length may be adjusted in the field by NAC, to allow for stack up conditions. For alternate seal materials EPDM and Viton, the fittings are to be tightened "snug plus on wrench flat". IS: Lubricate with a spent fuel compatible lubricant such as Neolube. Install fitting by hand until metal to metal contact is achieved then torque to (115 ± 5 ft-lbs for elastomer seals) or (135 ± 15 ft-lbs for metal seals). Length may be adjusted in the field by NAC, to allow for stack up conditions.
- Add note to Detail A-A and Detail A-A alternate configuration. "Optional engraved stripe shown"
- Change weld callout Sht 2 of 3, Zone E5 IS: (3/4) WAS: (7/8)
- Change weld callout Sht 2 of 3, Zone F5 IS: (3/8) WAS: (1/2)
- Change Delta Note 8 to read, "Items 22 and 24 shall be field modified if required to fit flush or below the top surface of the respective lid during installation. Item 24 may be ground to facilitate a press fit during installation. Item 23 is to be installed for the storage configuation (790-590) and is to be removed for the transport configuration (790-516)."
- Change dimension Sht 3 of 3, Zone B4 IS: 2.25/2.75; WAS: 2.25 MIN

<u>Drawing 790-587, Revision 1 — Spacer Shim, Canister, NAC-UMS®</u>

- Delete note 1: "space shim dimensions are approximate as all shims may be cut, machined and/or ground as needed for fit-up."
- Add new note: "alternate spacer shim dimensions of 48"± ¼ X 38"± ¼ may be used for all thickness listed on BOM."
- Add new note: "Edge's of sheet may be field dressed to eliminate curls, burrs, etc."

<u>Drawing 790-591, Revision 5 — Bottom Weldment, Fuel Basket, 24 Element PWR, NAC-UMS®</u>

- Add Delta Note 5 as follows: The 3XØ1.3 holes may be replaced with holes of Ø2.0. Also add Delta Note callout in Zone E7, to 3XØ1.3.
- Revise specification for Item 4, Pad, WAS "ASME SA479", IS "ASME SA240/479" and change description, WAS "3 ½ Dia Bar", IS "Plate / Bar".
- Change reference dimension in Zone D-7/8, "(Ø3.5)", to an actual dimension, "3.5".
- Add a Delta Note to the four corner locations (located outside of Items 5 & 6) as follows: "When a Maine Yankee Fuel Can (shown on NAC drawing 412-501) may be included as contents of the canister, these hole locations shall have openings of 8.70 x 8.70 with an inside corner radius of .13 maximum."
- Revise Drawing Title: IS: NAC-UMS®; WAS: NAC-UMS™.
- Revise Delta Note 3 to read: "Centered approx. on web."
- Add Delta 3 callout to Items 5 and 6 balloons.
- Revise the size of the two 1/8" fillet welds (Zones B-6 and E-6) to 1/16" minimum.

- Revise the size of the one ¼" fillet weld (Zone C-6) to 1/16" minimum.
- Add note to drawing as follows: "In any single quadrant of the bottom weldment, the orientation of Items 5 and 6 may be reversed."
- Add to BOM Item 7, Quantity: 20, Name: Support, Material: 304 St. Stl., Specification: ASME SA240/SA479, Description: 1 Plate/Bar.
- Add Delta Note to read: "Item 7 (Support) are to be cut to the length of 8.8±.1." Add Delta Note graphics to Item 7 (Support) balloon callout for Optional Configuration 99.
- Add Optional Configuration 99.
- Delete Item 7 (Support) from BOM.
- Delete Delta note 7 and remove any graphics relating to throughout drawing
- Revise Optional Configuration 99 per attached sketch
- Revise assy -99 (optional configuration) to add a dimension of 9.9 to Item 7 as shown on sketch
- Cancel DCR 790-591-5A

<u>Drawing 790-592, Revision 8 — Top Weldment, Fuel Basket, 24 Element PWR, NAC-UMS®</u>

- Add Note 5 as follows: "Tolerance for fuel tube openings, dimensions 5.39, 15.66, 16.16, and 25.81 is ±.04."
- Add Note 6 as follows: "Minimum thickness of Item 2 may be reduced to .355 for a length of up to 31 inches measured along the outer circumference."
- Revise the size of the five 1/8" fillet weld (Zones B5, B4, C4, C7 and E4) to a minimum of 1/16".
- Revise bevel size in Zone C-D/8: IS: REF .1 x 45° TYP; WAS: .1 x 45° TYP.
- In Zone E-8, in the weld symbol tail of the full penetration groove weld, add a note marker for Note 4.
- Add Note 4 to read, "As an alternative to the full-penetration, all-around groove weld, a 1/16" all-around groove weld on the outside of Item 2 and 1/16" all-around fillet weld on the inside of Item 2 may be used."
- Specify a full-penetration, double-V groove weld for the longitudinal weld of Item 2, and indicate that location is optional.
- Delete Item 5 from DCR 790-592-6A and replace with: "Specify a full penetration, double-V or single-V groove weld for the longitudinal weld of Item 2, and indicate that the location is optional."
- Zones B5 and D6: Revise 1/8 fillet welds to remove the all-around symbols.
- Correction to former DCR 6A, change #3 and change #4, reference to Note 4 should be Delta Note 7.
- Correction to former DCR 6C, to include the removal of the all-around weld symbol in Zone C4.

- Correction to former DCR 6C, Zones B4 and C4, revise fillet welds to add symbol for both sides.
- Modify weld symbol, Zone B4, to remove the 1/16" fillet weld, far side callout.

Drawing 790-593, Revision 7 – Support Disc and Misc. Basket Details, 24 Element PWR, NAC-UMS®

- Sheet 1, add Delta Note 3 to read...at fabricator option, chamfer on ID of split spacer up to .09" X .09" may be utilized.
- Add Delta Note 3 graphic at drawing Zone A-6.
- On Sheet 1, in Zone C/6-7, revise the size of the sawcut that is typical for 8 places: IS: .1; WAS: .06.
- Add note as follows: "One or more of Item 4 (top Nut) with damaged 1-8UNC-2B threads may be "used as is' as long as an approved alternate configuration for lifting the empty TSC using a minimum of four top nuts remains. Any Top Nut (Item 4) that has damage to the 1-UNC-2B threads cannot be utilized for lifting."
- Remove note 4

Drawing 790-595, Revision 9 — Fuel Basket Assembly, 24 Element PWR, NAC-UMS®

- Modify Delta Note 4 to read: Item 4 length to extend beyond Item 1 surface by .25+.02, -.25. Add Delta Note 4 in detail C-C, Sheet 2, Zone B5.
- Sheet 1, Zone C6, delete the fillet weld symbol.
- Sheet 2, Zone C4, delete TYP near .25 in detail C-C.
- Sheet 1, modify Delta Note 4 to read: Item 4 length to extend beyond Item 2, 17, or 18 surface by .25+.02, -.25.
- Sheet 2, Zone C4, and Sheet 1, Zone D1, delete Delta Note 4 callout.
- BOM, Item 4: IS 2 DIA TUBE WITH .035 OR .065 WALL, WAS: 2 DIA TUBE WITH .035 WALL.
- BOM, Item 4: Revise Spec: IS: COML; WAS: ASTM A249/A213.
- Add note as follows: One or more of Item 9 (Top Nut) with damaged 1-8UNC-2B threads may be "used as is" as long as an approved alternate configuration for lifting the empty TSC using a minimum of four top nuts remains. Any Top Nut (item 9) that has damage to the 1-8UNC-2B threads cannot be utilized for lifting.
- Replace note 6 of DCR(L) 790-595-8A with: "If after final assembly, the 1-8 UNC-2B threads of item 9 (top nut) are damaged, they will not require replacement if a minimum of 4 undamaged equally spaced top nuts remain."

Drawing 790-605, Revision 10 — BWR Fuel Tube, Over-Sized Fuel, NAC-UMS®

- Change dimension, Sheet 1 Zone D1: IS: 6.14; WAS: 6.11.
- Change dimension, Sheet 1, Zone B8: IS: 5.34; WAS: 5.31.

- Show original fabrication of Detail D-D.
- Update drawing border to current.
- Items 3 and 4: IS: "Neutron Absorber" and update Item/Assembly names and notes accordingly; WAS: Neutron Poison."
- Replace material in BOM: IS: Boral/Metamic; WAS: Boral.

Drawing 790-611, Revision 5 – GTCC Waste Basket, Maine Yankee, NAC-UMS®

- Sheet 1, Zone E3: IS: Ø48.3 + .20/-.35; WAS: Ø48.3.
- Sheet 1, add Delta Note 7 to read: "Thickness of localized areas of Item 3 may be reduced to 2.97 during fabrication."
- Sheet 2, Zone B5, add Delta Note 7 callout at Item 3 callout.

Drawing 790-612, Revision 8 – GTCC Canister, Maine Yankee, NAC-UMS®

- Add Delta Note 16 to read: "At the option of the user, stainless shims (ASME SA240/479, Type 304L) may be used in the welding of the structural lid (Item 11) to the shell (Item 3)." Also add Delta Note 16 callout at Zone E6, next to structural lid to shell weld callout.
- Revise Item 12 Name to: Spacer Ring.
- Remove backing ring symbol from structural lid/shell weld symbol in Zone F6.
- Revise cover weld callout Zone E6 IS: (3/16) WAS: (1/4).
- Remove backing ring symbol from structural lid/shell weld symbol in Zone F6.
- Revise cover weld callout Zone E6 IS: (3/16) WAS: (1/4).
- Add Delta Note 17 as follows: "Tolerances applied to localized areas of the shell diameter are -.24"/+.18". Localized areas being flatspots/bulges, etc. At no point shall there be any interference between the interfacing components and the shell."
- Zone E5, revise cover weld callout: WAS: (3/16) bevel flush IS: (3/16) bevel concave.
- Add text to Delta Note 3: "Length may be adjusted in the field by NAC Engineering, to allow for stack up conditions."
- Add Delta Note to Item #11: "At the option of the user, spacer shims (drawing 790-587, Items 1-3) may be used to adjust the stack height of the structural lid, to ensure that the top of the lid is at least level with the top of the canister. The structural lid may extend past the top edge of the canister, so long as the min. effective weld throat is maintained for the closure weld."
- Change Delta Note 18 to: "At the option of the user, spacer shims (drawing 790-587) may be used to adjust the stack height of the structural lid and ensure that the top of the lid is at either level with the top of the canister or extends past the top edge of the canister, so long as the min. effective weld throat is maintained for the closure weld."
- Change graphics Zone 5E (Port Cover Weld) Delta Note: IS: Delta Note 7; WAS: Delta Note 5.

- Add Item 17 to BOM: Dowel Pin, Qty. 2, Assy-99, Material, ST. STL, Spec. COML, Description 1" dia x 1" long.
- Add balloon callout for Item 17, next to balloon callouts for Items 9 and 11.
- Add Note: "Field installed code nameplates shall be located on the Structural Lid as directed by the Client. Code nameplates to be welded to the Structural Lid with four fillet tack welds ¼ inch long (minimum), one adjacent to each corner of the plate. Fillet weld size to be equal to the thickness of the nameplate."
- Add Note: "The Structural Lid to shell gap shall be ½ inch or less during fit-up prior to welding."
- Change Delta Note 8 to read: "Items 1, 14 and 17 may be field modified to fit flush to surface following the welding of their respective lids."
- Add new note: "The groove weld from the top of the structural lid root pass weld to the shortest distance of the finished weld profile shall be at least 0.72."
- Revise Delta Note 14 as follows: "....shell diameter are +.21/-.24. Localized...."
- Add new note: "The groove weld from the top of the structural lid root pass weld to the shortest distance of the finished weld profile shall be at least 0.72"."
- Add new note: "The structural lid and installed spacer ring can be field dressed in localized areas to a minimum diameter of 65.00" to facilitate lid installation."
- Revise new note of DCR 790-612-6B: IS: "The structural lid and installed spacer ring can be field dressed in localized areas to eliminate interference with the canister shell during installation of the lid."; WAS: "The structural lid and installed spacer ring can be field dressed in localized areas to a minimum diameter of 65.00" to facilitate lid installation."
- Revise Delta Note 14 as follows: ".....shell diameter are +.21/-.24. Localized....."
- Add new note: "At the option of the user, stainless steel (ASTM/ASME A/SA240 type 304/304L) shims of appropriate size and thickness may be used in the spacer ring groove in the structural lid to ensure the ring fits tightly against the top of the groove at the bottom of the weld joint. The shim may be tack welded to the bottom of the spacer ring."
- Add note: "Trim the spacer ring to appropriate length by aligning it with the ID of the canister shell, just below the lip bevel, at the minimum ID after shield lid weld. Let the spacer ring float to fill the root gap between the structural lid and the canister shell."
- Revise Note 18 to read: "At the option of the user, spacer shims (drawing 790-587) may be used to adjust the stack height of the structural lid and ensure that the top of the lid is at either level with the top of the canister or extends past the top edge of the canister or there will be a minimum area, at or above the top of the GTCC shell, at least equal to a 16 inch diameter circle centered on the structural lid, so long as the min. effective weld throat is maintained for the closure weld."
- Revise Note 18 change made by DCR 790-612-7A to read: "At the option of the user, spacer shims (drawing 790-587) may be used to adjust the stack height of the structural lid and ensure that the top of the lid is either level with or extends past the top edge of the canister. Alternately there shall be a minimum area, at or above the

top of the GTCC shell, at least equal to a 16 inch diameter circle approximately centered on the structural lid, so long as the min. effective weld throat is maintained for the closure weld."

Drawing 412-501, Revision 4 – Spent Fuel Can Assembly Maine Yankee (MY) NAC-UMS®

- Add an assembly –98 that uses the same top assembly (Item #2) as assembly –99 and a new SFC (Fuel Only) weldment 412-109-99.
- Change BOM (Item #3) SFC (Fuel Only) Weldment, Drawing No.: IS: 412-502-96; WAS: 412-109-99.
- Add Reference under Assembly 98, Sheet 2 to read: Alternate Configuration.

Drawing 412-502, Revision 4 – Fuel Can Details Maine Yankee (MY) NAC-UMS®

- Sheet 2 of 4, Zone C-4, change weld callout for Item 13 to Item 2 from full penetration groove weld all around to 1/16 partial penetration groove weld arrow side typical for 4 locations.
- Add Assembly 96, "SFC (Fuel Only) Weldment" Alternate Configuration, along with notes and BOM additions.
- Add Assembly 95, "Bottom Assembly" Alternate Configuration.
- Add note Sheet 1 Zone D7 to lid guide slot "Corners may be rounded provided the slot opening does not exceed 0.5"
- Update Dimension Sheet 4 Zone F3, E5 and B4 WAS: 8.4 IS: (8.4)
- Add note to Detail B-B for outside edge of wiper "Break sharp edges (.01 - .03) Typical 4 Sides"
- Add Detail L-L per attached sketch
- Update Item Assy 98 to reflect changes to Item 4.
- Sheet 2, Zone A6: Remove the .2 TYP Dimension.
- Remove weld symbol on sheet 2, zone C4. Replace with standard weld symbol with note "Seal Weld, Flush Outside, Geometry Optional, 1 side minimum".
- Sheet 2 Zone B6: Add alternate weld for Item 16 to Assy –98: Plug weld Both Ends, Typ.
- Add alternate st stl wiper per attached sketch
- Revise B.O.M, Item 4 to be **Material:** see note 5., **Spec:** see Note 5, **Description:** see note 5
- Add new note 5 " For Item 4 wiper material is 6061-T6 Aluminum ASTM B209, .032 sheet or Item 4 alternate wiper is st stl commercial, .005-.008 (.127-.203mm) Sheet/Strip, Material for st. stl wiper to have a minimum yield strength of 100ksi."
- Add delta note to slot openings shown on sheet 1, zone E7: "Break all interior edges of slot"
- Revise weld call for plug weld, sheet 2 Zone B6 (Item 3 from DCR 412-502-3B) to make this an optional weld and for the plug weld to be flush.
- Add note to Assy 98 Callout, "Shown with Aluminum Wiper, Item 4"
- Remove dimension, Sheet 4 Zone F1.

March 2004

Revision UMST-04A

NAC-UMS

Universal Multi-Purpose Cask System

SAFETY ANALYSIS REPORT

Volume 1 of 2

Docket No. 71-9270

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Chapter 1

Table 1-1 Terminology (continued)

Quick disconnect	The valved nipple used to operate the ports.
Lifting trunnions	Four high-strength stainless steel components located at the top forging that are used in pairs for lifting and handling the Universal Transport Cask. The two primary lifting trunnions are welded to the top forging and the two secondary lifting trunnions are bolted to the top forging.
Rotation pocket	Two stainless steel blocks, each provided with a deep machined groove to accept the rear cask support. These pockets are welded onto the outer shell near the bottom of the cask.
NS-4-FR	A solid, synthetic polymer; a borated hydrogenous material with neutron absorption capabilities similar to those of borated water. Developed by BISCO Products, Inc. and previously supplied by Genden Engineering Services & Construction Company, NS-4-FR is now supplied by the Japan Atomic Power Company and its product licensees. Genden Engineering Services & Construction Company is a former subsidiary of Japan Atomic Power.
Transport impact limiters (upper and lower)	Impact limiters designed for use during transport of the Universal Transport Cask. They protect the cask by limiting impact loads during the 1-ft free drop (normal conditions of transport) and the 30-ft free drop (hypothetical accident conditions).
Transportable Storage Canister	The stainless steel cylindrical shell, bottom end plate, shield lid, and structural lid that contains the fuel or GTCC waste basket structure and the contents.
Shield lid	A 7 in-thick stainless steel disk that is the inner component of a double-welded closure system for the Transportable Storage Canister. The shield lid provides a containment/confinement boundary (for storage only) and shielding for the contents.

Table 1-1 Terminology (continued)

Structural lid	A 3 in-thick stainless steel disk that is the outer component of a double-welded closure system for the Transportable Storage Canister. Positioned on top of the shield lid and welded to the canister, the structural lid provides a confinement boundary (for storage) shielding for the contents, and canister lifting/handling capability.
Basket	The structure located within the Transportable Storage Canister that provides structural support, criticality control, and primary heat transfer paths for the fuel assemblies or GTCC waste.
- support disk	A circular steel plate with 24 (PWR basket) or 56 (BWR basket) square holes machined in a symmetrical pattern. The support disk is the primary lateral load-bearing component of the basket. Each square hole in the support disk is a location for a fuel tube. For GTCC waste, the support disk design is modified to accommodate the GTCC basket configuration.
- heat transfer disk	A circular aluminum plate with 24 (PWR basket) or 56 (BWR basket) square holes machined in a symmetrical pattern. The heat transfer disks are the primary heat transfer component in the PWR and BWR fuel baskets.
- fuel tube	A stainless steel tube with a square cross-section that encases neutron absorber material on its exterior surfaces. One fuel tube is inserted through each square hole in the support disks and heat transfer disks of the PWR and BWR baskets. Fuel assemblies are loaded into the fuel tube.
- tie rod	Aligns, retains and supports the support disks and the heat transfer disks in the PWR and BWR fuel basket. The tie rods extend from the top weldment to the bottom weldment of the fuel basket.

Table 1-1 Terminology (continued)

-spacer	Installed on the tie rod between the support disks (BWR only) or between the support disks and upper and lower weldments (BWR and PWR) to properly position the disks and provide axial support for the support disks.
- split spacer	Installed on the tie rod between the support and heat transfer disks to properly position the disks and provide axial support for the support disks and heat transfer disks in the PWR and BWR baskets.
Canister spacer	Stainless steel or aluminum components that position the canister in the Universal Transport Cask cavity during transport. Spacers are used for canister Classes 1, 2, 4, or 5.
Transfer cask	A shielded lifting device used for handling of the Transportable Storage Canister during loading of spent fuel or GTCC waste, canister closure operations, and transfer of the canister into or out of the Universal Transport Cask, or into or out of the vertical concrete cask during storage operations. The Transfer Cask is described in the Safety Analysis Report for the onsite storage (10 CFR 72) components of the UMS®, Docket No. 72-1015.
Vertical concrete cask	The cask used to store the Transportable Storage Canister containing spent fuel or GTCC waste. The Vertical Concrete Cask is described in the Safety Analysis Report for the on-site storage (10 CFR 72) components of the UMS®, Docket No. 72-1015.

Table 1-1 Terminology (continued)

Maine Yankee Fuel Can	A specially designed stainless steel screened can sized to hold an intact fuel assembly, consolidated fuel or damaged fuel. The can screens permit draining and drying, while precluding the release of gross particulates into the canister cavity. The Maine Yankee Fuel Can may only be loaded into a Class 1 Canister.
High Burnup Fuel	A Maine Yankee fuel assembly having a burnup between 45,000 and 50,000 MWD/MTU, which must be preferentially loaded in periphery positions in the basket.

1.1 Introduction

The Universal Transport Cask is designed to safely transport a Transportable Storage Canister containing 24 intact PWR spent fuel assemblies, 56 intact BWR spent fuel assemblies or Greater Than Class C (GTCC) waste. Intact fuel assemblies are defined as those assemblies that are structurally intact and that do not have cladding defects greater than hairline cracks or pin holes. On the basis primarily of their lengths, three classes of PWR fuel assemblies and two classes of BWR fuel assemblies have been evaluated for transport. Three canister classes of different lengths transport the PWR fuel assemblies, and two canister classes of different lengths transport the BWR fuel assemblies.

Characteristics of PWR and BWR fuel assemblies are presented in Tables 1.2-4 and 1.2-5, respectively. Westinghouse and B&W core fuel assemblies may contain control component hardware (i.e., burnable poison rod assemblies and guide tube thimble plugs). These assemblies are typically loaded in canister class 1 and 2. The assembly weights listed in Tables 2.2-1 and Table 2.2-2 include the control component hardware weight.

The cask contents may also include site-specific fuel or GTCC waste, as defined in Table 1-1 and described in Section 1.3.1, provided that the contents characteristics are bounded by the analysis presented for the design basis fuel or the contents are separately evaluated and shown to be acceptable. The loading of site-specific fuels that include control component hardware may require the use of a longer Transportable Storage Canister than would be used if the hardware were excluded.

The Universal Transport Cask provides a radioactive material containment boundary to ensure maximum safety during the handling and transport operations required for shipment. The general configuration of the Universal Transport Cask and the major cask dimensions are shown in Figure 1.1-1. Figure 1.1-2 illustrates the transport configuration of the cask including the support and tiedown devices.

The transport cask with its impact limiters is securely attached to the bed of a railcar. To restrict unauthorized personnel from gaining access to the top, sides, and bottom of the transport cask, a personnel barrier is installed around the transport cask. The personnel barrier is securely attached to the bed of the railcar during normal transportation and it consists of a metal frame structure covered with expanded metal (i.e., a metal grating or screen). Thus the loaded cask, with the personnel barrier on the railcar ready for transport, meets the exclusive use definition of a closed conveyance.

The cask transport containment boundary is defined by the following components:

1. Inner shell.
2. Bottom forging.
3. Top forging.
4. Cask lid and lid inner O-ring.
5. Vent port coverplate and vent port coverplate inner O-ring.
6. Drain port coverplate and drain port coverplate inner O-ring.

The Universal Transport Cask is designed to meet 10 CFR 71 and IAEA Safety Series No. 6 licensing requirements for radioactive material transport packages. Other applicable codes and standards, as well as specific exceptions to those codes and standards, are discussed in Section 2.1.2.2. The transport licensing requirements include provision for safe containment during the handling and transport of the cask containing radioactive material. The value of the Transport Index for nuclear criticality control for the cask containing PWR or BWR spent fuel is determined to be zero (0) in accordance with 10 CFR 71.59. The Transport Index based on dose rate evaluations is eighteen (18) as determined in accordance with 10 CFR 71.4.

The design features of the transport cask include the lid, redundant seals at each containment boundary penetration, cavity penetrations located in the lid and bottom forging, and a puncture-resistant outer shell, rotation pockets, redundant lifting trunnions, impact limiters, and canister spacers.

The cask lid and its inner O-ring are part of the containment boundary. The O-ring provides the lid seal between the lid and top-forging seal surface. During transport, the port coverplate and the cask lid protect the vent port from external puncture events. A second O-ring of slightly larger diameter provides an interseal region that permits leak-testing of the inner O-ring. The O-rings provide long-term sealing capability in an elevated temperature and radiation environment.

The vent and drain port coverplates, which protect the vent and drain ports, are also part of the containment. Each coverplate is sealed by two O-rings. After initial installation, all of the primary containment seals are leak tested to verify proper containment sealing.

The body of the Universal Transport Cask is a smooth, right-circular cylinder of multiwall construction that consists of stainless steel inner and outer shells separated by lead gamma radiation shielding, which is poured in place. The inner and the outer shells are fabricated from Type 304 stainless steel and welded to the Type 304 stainless steel top forging, which mates with the cask lid. The inner shell is also welded to the Type 304 stainless steel bottom forging and the outer shell is welded to the bottom plate. The cask bottom consists of the bottom forging and a bottom plate with neutron shield material sandwiched between them. Layers of a 4.50 in-thick Type 304 stainless steel ring and two 0.75-in-thick Type 304 stainless steel disks are located at the bottom of the lead annulus between the bottom forging and the outer shell.

In addition to the cask bottom, neutron shield material is placed in an annulus that surrounds the cask outer shell along the length of the cask cavity. The neutron shielding material is a solid synthetic polymer (NS-4-FR), developed by BISCO Products, Inc., and now supplied by the Japan Atomic Power Company. The neutron shield annulus is enclosed by a Type 304 stainless steel shell and neutron shield top and bottom plates at the ends of the cask. Two relief valves in the bottom of the neutron shield annulus may aid recovery efforts associated with a severe thermal accident condition (fire) by precluding overpressurization of the stainless steel neutron shield shell.

Redundant lifting capability for the Universal Transport Cask is provided by four lifting trunnions located on the top forging at 90° intervals. The two primary lifting trunnions are welded to the top forging. The two secondary lifting trunnions are bolted to the top forging. Two rotation pockets are located on the outer shell near the bottom of the cask to permit the cask to be rotated to the horizontal position and to provide longitudinal tiedown restraint in the aft direction. A Type 304 stainless steel shear ring at the top end of the radial neutron shield provides forward longitudinal restraint when the cask is positioned horizontally for transport in the front support structure.

Spacer(s) are placed below each Class 1, 2, 4, or 5 canister to locate and support the canister in the cask cavity. The canister shell, bottom, and welded shield and structural lids are fabricated from stainless steel. The canister contains the basket and fuel assemblies or GTCC waste. The spent fuel basket design uses a series of high-strength stainless steel (PWR) or carbon steel (BWR) support disks to support the fuel assemblies in stainless steel tubes. The PWR fuel tubes contain neutron absorber neutron poison (0.025 g/cm^2 ^{10}B minimum areal density) on all four sides of the tubes. The BWR fuel tubes contain a neutron absorber with minimum areal density of 0.011 g/cm^2 ^{10}B. Three types of fuel tubes are designed to contain the BWR fuel: (1) tubes containing neutron absorber on two sides of the tubes; (2) tubes containing neutron absorber on one side; and (3) tubes containing no neutron absorber. Aluminum heat transfer disks are provided in both the PWR and the BWR fuel baskets to enhance thermal performance of the basket. The heat transfer disks are supported by stainless steel tie rods and split spacers that maintain the basket assembly configuration.

The GTCC waste basket design varies depending on the shape of the waste. Generally, the basket incorporates a thick wall to provide additional gamma radiation shielding, horizontal or vertical internal dividers for configuration control of the waste, and equally spaced support disks on the basket external wall.

Impact limiters consisting of a combination of redwood and balsa wood encased in Type 304 stainless steel limit the g-loads acting on the cask during a transport drop load condition. The g-loads acting on the cask are limited by the crush strength of the redwood and balsa wood contained in the impact limiters.

1.2 Package Description

This section presents a detailed description of the Universal Transport Cask and the contents that may be transported. An operational schematic of the cask is presented in Figure 1.2-1. Detailed License Drawings are provided in Section 1.3.4. The design characteristics of the cask and its components are summarized in Table 1.2-1.

1.2.1 Packaging

1.2.1.1 Gross Weight

The gross transport weight of the Universal Transport Cask varies depending upon its contents. The calculated cask component weights for each class of Transportable Storage Canister for PWR and BWR fuel are provided in Tables 2.2-1 and 2.2-2, respectively. The total weight (including the transport cask body, basket, impact limiters, fuel, canister with lids, cask lid, and spacers) for the cask is:

Canister Class	Total Cask Weight (lb)
Class 1 (PWR)	250,009
Class 2 (PWR)	251,492
Class 3 (PWR)	248,373
Class 4 (BWR)	255,022
Class 5 (BWR)	254,004

When the cask is loaded on its railcar, the gross weight of the railcar (including cask, impact limiters, supports, and personnel barrier) will meet the requirements of the railroad authority for free interchange.

The transport weight of the GTCC waste configuration is presented in Section 1.3.1.1.2.

1.2.1.2 Materials of Construction, Dimensions, and Fabrication

The Universal Transport Cask body is a cylindrical, multiwalled construction. The structural components of the cask body are constructed of Type 304 stainless steel. The primary structural components of the cask are the inner and outer shells. Poured in-place chemical-copper grade lead fills the annulus between the inner and outer shells and serves as the primary gamma radiation shield. The top forging, which is a ring that forms the upper end of the cask, is welded to the inner and outer shells. At the lower end of the cask, the inner shell is welded to the bottom forging and the outer shell is welded to the bottom plate. The SA-336 Type 304 stainless steel lid is recessed in and bolted to the top forging. The vent port is recessed into the lid and is protected by an SA-240, Type 304 stainless steel port coverplate.

Neutron radiation shielding is provided by NS-4-FR, a poured in-place solid synthetic neutron-absorbing polymer, which surrounds the outer shell along the cavity region and is enclosed by a shield shell and end plates that are welded to the outer shell. Twenty-four bonded copper and Type 304 stainless steel fins are located in the radial neutron shield to enhance the heat rejection capability of the cask and to support the neutron shield shell and end plates. A layer of NS-4-FR is also provided between the cask bottom forging and the bottom plate.

In the event of a drop during transport, where impact forces are applied to the Universal Transport Cask during deceleration, the cask is protected by two energy-absorbing impact limiters each consisting of redwood and balsa wood enclosed in a stainless steel shell. The impact limiters fit over each end of the cask and dissipate kinetic energy by crushing the wood, which has known crush strengths. The g-loads acting on the cask during an impact load condition are thus limited.

Four lifting trunnions on the outside of the top forging at 90° intervals, are fabricated from Type 17-4 PH stainless steel. Only the two diametrically opposite primary lifting trunnions are required to lift the cask. Two secondary lifting trunnions are also provided for those facilities that require redundant lifting. Two rotation pockets, fabricated from Type XM-19 stainless steel, are located on the outer shell near the bottom of the cask for use in rotating the cask between the vertical and horizontal positions.

The Transportable Storage Canister shell and bottom are constructed of Type 304L stainless steel. The canister is closed with a shield lid and a structural lid, both of which are welded in

1.2.1.2.7 PWR Fuel Basket

The PWR fuel basket is contained within the Transportable Storage Canister and is constructed of Type 304 stainless steel. The fuel basket design is a right-circular cylinder configuration with square fuel tubes laterally supported by a series of support disks. The basket design parameters for the transport of the three classes of PWR fuel are provided in Table 1.2-3. The Class 1, 2, or 3 fuel baskets incorporate 30, 32, or 34 support disks, respectively. The disks are retained by a top nut and supported by spacers on tie rods at eight locations. The top nut is torqued at installation to provide a solid load path in compression between the support disks. The 0.50 in.-thick, 65.50 in.-diam support disks are fabricated of SA 693, Type 630, 17-4PH stainless steel. The disks are spaced axially at 4.92 in. center-to-center and contain square holes for the fuel tubes.

The 1.25 in.-thick top and 1.0 in-thick bottom weldments are fabricated from Type 304 stainless steel and are geometrically similar to the support disks. The tie rods have a 2.5 in. length of 1 5/8 - 8 UN thread at the upper end and are fabricated from SA-479, Type 304 stainless steel. The top nut fabricated from a 3.5 in.-diam bar, and the spacers, fabricated from 2.5 in. pipe XXS, Type 304 stainless steel. The fuel tubes are fabricated from A-240, Type 304 stainless steel and support the encased BORAL sheet on each of the four sides. The BORAL provides criticality control in the basket. No structural credit is taken for the stainless steel tubes for structural strength of the basket.

Each PWR fuel basket can hold 24 PWR fuel assemblies in an aligned configuration in 8.80 in. ID square fuel tubes, which have 0.141 in. thick walls (including BORAL and cladding). The hole in the top weldment is 8.75 in. by 8.75 in. The hole in the bottom weldment is 8.65 in. by 8.65 in. The flange outer surface at the top of the fuel tube is to 9.65 in. by 9.65 in. The basket design traps the fuel tube between the top and bottom weldments, thereby preventing axial movement of the fuel tube. The fuel tubes are separated by webs in the support disks with widths of 0.9 in., 1.0 in., and 1.5 in., depending on location.

The PWR basket design incorporates Type 6061-T651 aluminum alloy heat transfer disks to enhance heat transfer in the basket. Thirty support disks are contained in the Class 1 fuel basket. Class 2 and 3 fuel baskets contain 32 and 34 disks, respectively. The heat transfer disks are spaced and supported by the tie rods and spacers, which also support and locate the support disks. The heat transfer disks, located at the center of the axial spacing between the support disks, are sized to eliminate contact with the cask inner shell and basket tie rods due to differential thermal expansion.

The Transportable Storage Canister is designed to facilitate filling with water and subsequent draining. Water fills and drains freely between the basket disks through three separate paths. One path is the gaps that exist between the disks and canister shell. The second path is through the gaps between the fuel tubes and disk that surrounds the fuel tubes. The third path is through three 1.3 inch-diameter holes in each of the disks that are intended to provide additional paths for water flow between disks. The basket bottom weldment supports the fuel tubes above the canister bottom plate. The fuel tubes are open at the top and bottom ends, allowing the free flow of water from the bottom of the fuel tube. The bottom weldment is positioned by supports 1.0 inch above the canister bottom to facilitate water flow to the drain line. These design features ensure that water flows freely in the basket so that the canister fills and drains freely.

1.2.1.2.8 BWR Fuel Basket

Like the PWR fuel basket, the BWR basket is contained within the stainless steel Transportable Storage Canister. The BWR fuel basket is also a right-circular cylinder configuration with square fuel tubes laterally supported by a series of support disks (40 disks for the Class 4 fuel basket and 41 disks for the Class 5 fuel basket). The basket design parameters for the transport of the two classes of BWR fuel are provided in Table 1.2-3. The support disks are retained by cylindrical spacers on tie rods at six locations. The top nut is torqued at installation to provide a solid load path in compression between the support disks. The 0.625 in-thick, 65.50 in-diam support disks are fabricated of SA 533, Type B, Class 2 carbon steel. The disks are spaced axially at 3.8 in center-to-center and contain square holes for the fuel tubes.

The 1.0 in-thick top and bottom weldments are fabricated from Type 304 stainless steel, and are geometrically similar to the support disks. The tie rods have a 2.5 in length of 1 5/8 - 8 UN thread at the upper end and are fabricated from Type 304 stainless steel. The top nut and spacers are fabricated from 3 in-diam bars of Type 304 stainless steel. The fuel tubes are also fabricated from Type 304 stainless steel and support the encased neutron absorber sheet. Three types of tubes are designed to contain BWR fuel: tubes with neutron absorber on two sides, tubes with neutron absorber one side, and tubes with no neutron absorber. No structural credit is taken for the stainless steel tubes for structural strength of the basket or support of the fuel assemblies.

Each BWR fuel basket can hold a total of 56 BWR fuel assemblies in an aligned configuration; 52 assemblies inside 5.90 in square fuel tubes, which have 0.201 in-thick walls (including neutron absorber and cladding) and 4 assemblies in oversized positions in the outer corners of the basket. The oversized positions provide additional space for BWR assemblies with channels that have been reused, since reused channels may have increased bowing or bulging. Standard BWR fuel assemblies may also be placed in these positions. The inside dimension of the four fuel tubes in the outside corners is 6.05 in square. The holes in the top weldment are 5.75 in by 5.75 in except for the four enlarged holes, which are 5.90 in^2. The holes in the bottom weldment are 5.63 in by 5.63 inch. The flange outer surface at the top of the fuel tube is 6.59 in by 6.59 in The basket design traps the fuel tube between the top and bottom weldments, thereby preventing axial movement of the fuel tube. The support disk webs between the fuel tubes are 0.65 in wide. The BWR fuel basket design also incorporates 17 Type 6061-T651 aluminum alloy heat transfer disks similar to the design and function of those in the PWR baskets.

The Transportable Storage Canister is designed to facilitate filling with water and subsequent draining. Water fills and drains freely between the basket disks through three separate paths. One path is the gaps that exist between the disks and canister shell. The second path is through the gaps between the fuel tubes and disk that surrounds the fuel tubes. The third path is through a 2.0 inch-diameter hole in each of the disks that is intended to provide an additional path for water flow between disks. The basket bottom weldment supports the fuel tubes above the canister bottom plate. The fuel tubes are open at the top and bottom ends, allowing the free flow of water from the bottom of the fuel tube. The bottom weldment is positioned by supports 4.0 inch above the canister bottom to facilitate water flow to the drain line. These design features ensure that water flows freely in the basket so that the canister fills and drains freely.

1.2.1.2.9 Transportable Storage Canister Cask Cavity Spacers

The Transportable Storage Canisters, except the PWR Class 3 canister, are positioned axially in the Universal Transport Cask cavity by cavity spacer(s). The spacers are free standing structures that are confined in place by the bottom of the canister and the cask bottom inner surface. The spacer(s) ensure that the canister lid is laterally supported by the cask top forging when the cask is horizontal and minimize axial movement of the canister. The spacers are shown in Drawing 790-520. Each Class 1 or Class 2 PWR canister is axially positioned by a stainless steel spacer that is 16.75 inches or 7.65 inches in length, respectively. The Class 5 BWR canister is located by one 1.5-inch aluminum spacer. Each Class 4 BWR canister is located by four 1.5-inch spacers. No spacers are used with the Class 3 PWR canister. Spacers are installed in the bottom of the cask cavity prior to loading the canister into the cask cavity. Spacers required for the transport of GTCC waste canisters are described in Section 1.3.1.

The PWR spacers consist of six 0.375 in-thick stainless steel rings welded, in concentric circles of various diameters, on to a 0.375 in-thick stainless steel plate. The length of the stainless steel rings varies according to the required length of the spacer to locate a Class 1 or Class 2 canister. The BWR spacer is a 1.5 in-thick aluminum circular plate. The plate has a beveled edge to aid in loading the spacer into the cask.

1.2.1.3 Heat Dissipation

The Universal Transport Cask Transportable Storage Canister and associated basket design basis decay heat dissipation capability is 20 kW for PWR fuel or 16 kW for BWR fuel. The cask is designed to accommodate 24 PWR fuel assemblies with a maximum decay heat load of 0.8 kW per assembly or 56 BWR fuel assemblies with a maximum decay heat load of 0.3 kW per assembly. Both the use of aluminum heat transfer disks and the use of bonded copper and stainless steel fins (extending through the NS-4-FR solid neutron shield) aid in the heat transfer capability of the cask. No significant heat is generated by GTCC waste. The heat dissipation features of the cask are entirely passive. No active or support cooling mechanisms are required during transport. A more detailed discussion of the thermal characteristics of the Universal Transport Cask is provided in Chapter 3.0.

1.2.1.4 Coolants

No coolants are used within the Universal Transport Cask. An inert helium gas atmosphere is used to backfill the cask cavity prior to transport.

1.2.1.5 Shielding

To attenuate gamma radiation, a 2.75-in thickness of chemical-copper grade lead and a 4.75-in total thickness of stainless steel are maintained between the cask contents and the exterior radial surface of the cask. To reduce the gamma radiation contribution above the radial neutron shield, a 0.4-in thick stainless steel ring is welded to the top weldment of the basket assembly. A thickness of 4.5 in of solid, borated neutron shielding material (NS-4-FR), which extends along the full length of the active fuel region, provides radial neutron shielding. The cask lid provides a thickness of 6.5 in of stainless steel on the top end of the cask to attenuate gamma radiation from the fuel and assembly hardware. The 7-in thick stainless steel shield lid and the 3-in thick stainless steel structural lid on the canister provide significant additional attenuation of gamma radiation at the top end of the cask. The bottom end of the cask provides 9.3 in of stainless steel gamma radiation shielding material and 1.0 in of solid, borated NS-4-FR neutron shielding material. A detailed description of the cask shielding design and the detailed shielding analysis are provided in Chapter 5.0.

1.2.1.6 Protrusions

No outer protrusions exist on the cask other than the four external lifting trunnions attached to the top forging near the upper end. The lifting trunnions are within the envelope protected by the impact limiters. All of the port covers are recessed into the cask body and none protrude above the cask surface. The cask lid surface is smooth unless the impact limiter positioner, which is covered by the impact limiter, is installed. The cask lid bolts are recessed in the cask lid and do not project above the lid surface. Refer to the License Drawings in Section 1.3.4 for more detail.

1.2.2 Operational Features

The Universal Transport Cask is designed to be easily loaded, unloaded, and handled at a nuclear facility. Canister loading and unloading operations are accomplished using a transfer cask. Detailed operating procedures are presented in Chapter 7.0 of this report.

The configuration and surface finish of the cask exterior surfaces are designed to facilitate and minimize cask decontamination. The cask lid and the port covers are all one-piece components designed to reduce handling times and to maintain personnel dose rates at levels that are as low as is reasonably achievable (ALARA). For improved handling operations, quick disconnect fittings are used in the vent, drain, and lid seal test ports. All operational features are shown on the License Drawings provided in Section 1.3.4. An operational schematic of the Universal Transport Cask is shown in Figure 1.2-1.

1.2.3 Contents of Packaging

The Universal Transport Cask is designed to safely transport up to 24 PWR spent fuel assemblies, or up to 56 BWR spent fuel assemblies, or Greater Than Class C (GTCC) waste contained within a Transportable Storage Canister. Fuel assemblies are grouped primarily on fuel assembly length and cross section. Fuel assemblies and their characteristics are shown in Tables 1.2-4 (PWR) and 1.2-5 (BWR).

The maximum decay heat load for all types of PWR fuel is 20 kW. The minimum cool time as a function of assembly class, minimum enrichment and maximum burnup for PWR fuel is shown in Table 1.2-6. Minimum cool time is based on the maximum decay heat load (20 kW) and radiation shielding dose rate limits set by the design basis 3-D shielding evaluation.

The maximum decay heat load for all types of BWR fuel is 16 kW. The minimum cool time as a function of assembly class, minimum enrichment and maximum burnup for BWR fuel is shown in Table 1.2-7. Minimum cool time is based on the maximum decay heat load (16 kW) and radiation shielding dose rate limits set by the design basis 3-D shielding evaluation.

For BWR fuel, the initial enrichment limit (the enrichment of the as-delivered fresh fuel assembly) represents the maximum peak planar-average enrichment allowed for loading into the canister. The peak planar-average enrichment is defined to be the maximum planar-average enrichment at any height along the axis of the fuel assembly.

Based on the minimum allowable cool times as a function of initial enrichment, as shown in Tables 1.2-6 and 1.2-7, the minimum allowable assembly average enrichment for loading is 1.9 wt % ^{235}U. Unenriched fuel assemblies are therefore excluded from loading into the transportable storage canister. BWR fuel assemblies with (unenriched) axial blankets also have an enriched central fuel region and are, therefore, acceptable for loading provided that the minimum enrichment of the central region is 1.9 wt % ^{235}U. Any empty fuel rod position must be filled with a solid filler rod fabricated from either Zircaloy or Type 304 stainless steel, unless the fuel assembly configuration is evaluated as a site specific fuel described in Section 1.3.1.

The stored fuel assemblies must be structurally intact, so that special handling or packaging of an assembly is not required. Individual assemblies may not have fuel rod cladding defects greater than pin holes and hairline cracks.

GTCC waste transport is separately evaluated as site specific contents. GTCC waste is transported in a Transportable Storage Canister, but the canister basket is designed to accommodate the shape of the GTCC waste. Site specific GTCC waste is described in Section 1.3.1.

Table 1.2-1 Design Characteristics of the Universal Transport Cask and Components (continued)

Design Characteristic	Value (in)	Material
Fuel basket		
• PWR Top Weldment	1.25	Type 304 Stainless Steel
• PWR Bottom Weldment	1.0	Type 304 Stainless Steel
• BWR Top and Bottom Weldment	1.0	Type 304 Stainless Steel
• Support disks thickness		
- PWR	0.5	Type 17-4 PH Stainless Steel
- BWR	0.625	SA-533,Type B Class 2 Carbon Steel
• Heat transfer disk thickness	0.5	Type 6061-T651 Aluminum Alloy
• Fuel tube dimensions		
- PWR (inside)	8.8 x 8.8	Type 304 Stainless Steel Encasing neutron absorber
- BWR Standard (inside)	5.9 x 5.9	Type 304 Stainless Steel Encasing neutron absorber
- BWR Enlarged (inside)	6.05 x 6.05	Type 304 Stainless Steel Encasing neutron absorber
• Spacers(s) diameter	2.875	Type 304 Stainless Steel
• Tie rod diameter		
PWR	1-5/8	Type 304 Stainless Steel
BWR	1-5/8	Type 304 Stainless Steel

Table 1.2-2 Transportable Storage Canister Design Parameters

Canister Parameter	Value
Internal fuel cavity length (in)	
Class 1 (PWR)	163.3
Class 2 (PWR)	172.4
Class 3 (PWR)	180.0
Class 4 (BWR)	173.8
Class 5 (BWR)	178.6
Overall length (in)	
Class 1 (PWR)	175.1
Class 2 (PWR)	184.2
Class 3 (PWR)	191.8
Class 4 (BWR)	185.6
Class 5 (BWR)	190.4
Internal cavity diameter (in)	65.8
Fuel cell opening (in-square) top weldment	
Classes – 1 - 3	8.75
Classes – 4 - 5 (Standard)	5.75
Classes – 4 - 5 (Oversized — 4 places)	5.90
Shell (in)	
Outer Diameter	67.06
Thickness	0.625
Structural lid thickness (in)	3
Shield lid thickness (in)	7
Neutron absorber	BORAL, METAMIC

Table 1.2-3 Basket Assembly Design Parameters

Basket Parameter	Value
Basket Assembly Length (in)	
Class 1 (PWR)	162.8
Class 2 (PWR)	171.9
Class 3 (PWR)	179.5
Class 4 (BWR)	173.3
Class 5 (BWR)	178.1
Basket Assembly Diameter (in)	65.5
No. of support disks	
Class 1 (PWR)	30
Class 2 (PWR)	32
Class 3 (PWR)	34
Class 4 (BWR)	40
Class 5 (BWR)	41
No. of heat transfer disks	
Class 1 (PWR)	29
Class 2 (PWR)	31
Class 3 (PWR)	33
Class 4 (BWR)	17
Class 5 (BWR)	17
No. of fuel tubes	
Classes 1 - 3 (PWR)	24 (neutron absorber on all four sides)
Classes 4 - 5 (BWR)	56 (42 with neutron absorber on two sides; 11 with neutron absorber on one side; and 3 with no neutron absorber)
No. of tie rods	
Classes 1 - 3 (PWR)	8
Classes 4 - 5 (BWR)	6

Table 1.2-4 PWR Fuel Assembly Characteristics

Canister Class[1]	Vendor[2]	Array	Max. Length (in)	Max. Width (in)	Max. Assembly Weight (lb)	Max. MTU	No of Fuel Rods	Max. Pitch (in)	Min. Rod Dia. (in)	Min. Clad Thick (in)	Max. Pellet Dia.(in)	Max. Active Length (in)	Min. Guide Tube Thick (in)
1	CE	14x14	157.3	8.11	1292	0.404	176	0.590	0.438	0.024	0.380	137.0	0.040
1	Ex/ANF	14x14	160.2	7.76	1271	0.369	179	0.556	0.424	0.030	0.351	142.0	0.034
1	WE	14x14	159.8	7.76	1177	0.362	179	0.556	0.400	0.024	0.345	144.0	0.034
1	WE	14x14	159.8	7.76	1302	0.415	179	0.556	0.422	0.022	0.368	145.2	0.034
1	WE, Ex/ANF	15x15	159.8	8.43	1472	0.465	204	0.563	0.422	0.024	0.366	144.0	0.015
1	Ex/ANF	17x17	159.8	8.43	1348	0.413	264	0.496	0.360	0.025	0.303	144.0	0.016
1	WE	17x17	159.8	8.43	1482	0.468	264	0.496	0.374	0.022	0.323	144.0	0.016
1	WE	17x17	160.1	8.43	1373	0.429	264	0.496	0.360	0.022	0.309	144.0	0.016
2	B&W	15x15	165.7	8.54	1515	0.481	208	0.568	0.430	0.026	0.369	144.0	0.016
2	B&W	17x17	165.8	8.54	1505	0.466	264	0.502	0.379	0.024	0.324	143.0	0.017
3	CE	16x16	178.3	8.10	1430	0.442	236	0.506	0.382	0.023	0.3255	150.0	0.035
1	Ex/ANF[3]	14x14	160.2	7.76	1215	0.375	179	0.556	0.417	0.030	0.351	144.0	0.036
1	CE[3]	15x15	147.5	8.20	1360	0.432	216	0.550	0.418	0.026	0.358	132.0	----
1	Ex/ANF[3]	15x15	148.9	8.25	1339	0.431	216	0.550	0.417	0.030	0.358	131.8	----
1	CE[3]	16x16	158.2	8.10	1300	0.403	236	0.506	0.382	0.023	0.3255	136.7	0.035

1. Minimum and maximum initial enrichments are 1.9 wt % ^{235}U and 4.2 wt % ^{235}U, respectively. All fuel rods are Zircaloy clad.
2. Vendor ID indicates the source of assembly base parameters. Loading of assemblies meeting dimensional limits is not restricted to the vendor(s) listed.
3. 14x14, 15x15 and 16x16 fuel manufactured for Prairie Island, Palisades and St. Lucie 2 cores, respectively. These are not generic fuel assemblies provided to multiple reactors.

1.3.1 Site Specific Contents

This section describes fuel assembly characteristics and configurations, or waste configurations, which are unique to specific reactor sites. These site specific content configurations result from conditions that occurred during reactor operations, participation in research and development programs, testing programs intended to improve reactor operations, from decommissioning activities, and from the placement of control components or other items within the fuel assembly.

Site specific fuel assembly configurations are either shown to be bounded by the analysis of the standard design basis fuel assembly configuration of the same type (PWR or BWR), or are shown to be acceptable contents by specific evaluation of the configuration.

Site specific Greater Than Class C (GTCC) waste configurations are shown to be acceptable by specific evaluation.

In general, the evaluations of site specific contents are presented in the Appendix section of the appropriate SAR Chapter. This enables the site specific fuel assembly configuration evaluations, which encompasses a wide range of configurations, to be separated from the evaluations performed for the standard fuel assembly configurations.

1.3.1.1 Maine Yankee Site Specific Contents

This section describes Transportable Storage Canister spent fuel contents which differ from the standard design basis 14x14 fuel assembly by virtue of reconfiguration of individual fuel assemblies during the course of reactor operations. It also describes the GTCC waste placed in the GTCC waste canister and basket, Drawings 790-612 and 790-611, respectively. The design basis fuel assembly (Westinghouse 17x17 as described in Section 1.2.3 and Table 1.2-4) bounds most of the Maine Yankee site specific fuel configurations. However, as appropriate to the configuration, additional analysis is provided in the Appendix to the appropriate Chapter.

1.3.1.1.1 Maine Yankee Site Specific Spent Fuel Configurations

The standard Maine Yankee reactor fuel assembly is the Combustion Engineering (CE) 14x14. The principal characteristics of this fuel are shown in Table 1.2-4. Fuel of the same design has also been supplied by Westinghouse and by Exxon. The evaluation of this standard fuel is bounded by the evaluation of the Westinghouse 17x17 spent fuel assembly, which is the design basis PWR fuel assembly for the NAC-UMS® Universal Transport Cask.

In the course of reactor operations, certain of the 14x14 fuel assemblies were modified to change the standard configuration. The principal modifications are of three general types:

- The removal of fuel rods without replacement;
- The replacement of removed fuel rods or burnable poison rods with rods of another material, such as stainless steel, or with fuel rods of a different enrichment; and,
- The insertion of control elements, or instrument or plug thimbles, in guide tube positions.

In addition to the modified fuel assemblies, there are fuel assemblies that were designed with variable enrichment and axial blankets. These fuel assemblies are not modified, but differ from the cask design basis fuel assemblies.

As part of a research and development program, Maine Yankee removed the fuel rods from several fuel assemblies and installed those fuel rods in two lattice structures that are similar to a 17x17 fuel assembly. This fuel is referred to as consolidated fuel. The lattice structures are constructed of stainless steel 17x17 grids that are equally spaced on 4 stainless steel support rods. Stainless steel end plates are attached to the ends of the support rods to hold the spent fuel rods within the grids. The upper end plate conforms to the fuel assembly upper end fitting design so that the consolidated fuel rod holder can be lifted with the fuel assembly grapple. One consolidated fuel lattice has 283 fuel rods with 2 empty fuel rod positions. The second lattice has 172 fuel rods with the remaining fuel rod positions either unused or holding stainless steel dummy rods.

A fuel assembly with removed fuel rods, poison rods or a consolidated fuel lattice shall be loaded in one of the four corner positions of the PWR fuel basket. Additionally, only one consolidated fuel lattice may be loaded in any single basket. These corner positions, designated "P/C" in the following figure, are separated from the other fuel positions by slightly larger flux traps, which results in these positions having less reactive interaction with the remaining fuel positions. The corner positions are also peripheral positions designated by the letter "P."

Preferential loading is also used for spent fuel having a burnup between 45,000 and 50,000 MWD/MTU. This fuel is assigned to peripheral basket locations. Locating the high burnup fuel in the peripheral basket locations reduces the maximum temperatures of these assemblies.

1.3.4 License Drawings

This section contains the License Drawings pertinent to the Universal Transport Cask. The dimensions indicated on the drawings are generally limited to one significant digit past the decimal point. Note that analysis of systems or components may present dimensions with additional significant digits based on more detailed engineering drawings.

Drawing No.	Rev. No.	Title
790-209	1	Impact Limiter Assembly-Upper, Cask, NAC-UMS®
790-210	1	Impact Limiter Assembly-Lower, Cask, NAC-UMS®
790-500	4	Assembly, Universal Transport Cask, Overpack, NAC-UMS®
790-501	3	Canister/Basket Assembly Table, NAC-UMS®
790-502	6	Cask Body, Transport Cask, NAC-UMS®
790-503	2	Lid Assembly, NAC-UMS® Cask
790-504	2	Port Coverplate Assembly, NAC-UMS®
790-505	2	Lifting Trunnion, NAC-UMS®
790-508	2	Misc. Details, Transport Cask, NAC-UMS®
790-509	2	Nameplates - NAC-UMS®
790-516	2	Package Assembly, Universal Transport Cask (UTC), NAC-UMS®
790-519	1	Package Assembly, Transport, Universal Transport Cask (UTC), NAC-UMS®
790-520	2	Spacers, Universal Transport Cask (UTC), NAC-UMS®
790-570	4	Fuel Basket Assembly, 56 Element BWR, NAC-UMS®
790-571	3	Bottom Weldment, Fuel Basket, 56 Element BWR, NAC-UMS®

Licensed Drawings (Continued)

Drawing No.	Rev. No.	Title
790-572	4	Top Weldment, Fuel Basket, 56 Element BWR, NAC-UMS®
790-573	7	Support Disk and Misc. Basket Details, 56 Element BWR, NAC-UMS®
790-574	3	Heat Transfer Disk Fuel Basket, 56 Element BWR, NAC-UMS®
790-575	9	BWR Fuel Tube, NAC-UMS®
790-581	8	PWR Fuel Tube, NAC-UMS®
790-582	11	Shell Weldment, Canister, NAC-UMS®
790-583	7	Assembly, Drain Tube, Canister, NAC-UMS®
790-584	17	Details, Canister, NAC-UMS®
790-585	16	Transportable Storage Canister (TSC), NAC-UMS®
790-587	1	Spacer Shim, Canister, NAC-UMS®
790-591	6	Bottom Weldment, Fuel Basket, 24 Element PWR, NAC-UMS®
790-592	8	Top Weldment, Fuel Basket, 24 Element PWR, NAC-UMS®
790-593	7	Support Disk and Misc. Basket Details, 24 Element PWR, NAC-UMS®
790-594	2	Heat Transfer Disk, Fuel Basket, 24 Element PWR, NAC-UMS®
790-595	9	Fuel Basket Assembly, 24 Element PWR, NAC-UMS®
790-605	10	BWR Fuel Tube, Over-Sized Fuel, NAC-UMS®
790-611	5	GTCC Waste Basket, Maine Yankee, NAC-UMS®
790-612	8	GTCC Waste Canister, Maine Yankee, NAC-UMS®
412-501	4	Spent Fuel Can Assembly, Maine Yankee (MY), NAC-UMS®
412-502	4	Fuel Can Details, Maine Yankee (MY), NAC-UMS®

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW.
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
		UNDER 3	±.003	UNDER 6	±.02
	FLATNESS	3-12	±.005	6-18	±.03
	STRAIGHTNESS	OVER 12	±.010	OVER 18	±.06
		.X	±.1	ANGLES ±0.5°	
	ANGULARITY	ALL UNSPECIFIED TOOL RADII: .015 - .030			
	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 - .030			
	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
	CONCENTRICITY	NEXT ASSEMBLY: 790-516			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER		7/19/02
CHECKER		7-19-02
PROJECT MANAGER		7/23/02
DIRECTOR DESIGN AND ANALYSIS		7-23-02
DIRECTOR LICENSING		7/23/02
VICE PRESIDENT QUALITY		7/30/02

ASSEMBLY,
UNIVERSAL TRANSPORT CASK,
OVERPACK
NAC-UMS®

PROJECT 790		DRAWING 500	REV 4
SCALE 1/6	EST WT. NOTED	SH 1 OF 2	9-19-2002

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL			
ASSEMBLY, UNIVERSAL TRANSPORT CASK OVERPACK NAC-UMS®			
PROJECT 790		DRAWING 500	REV 4
SCALE 1/8	EST WT. NOTED	SH 2 OF 2	

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ANSI Y14.5-82
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW.
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
	FLATNESS	UNDER 3		UNDER 6	±.04
		3-12		6-18	±.06
	STRAIGHTNESS	OVER 12		OVER 18	±.09
	ANGULARITY	.X	±.1	ANGLES ±.5°	
		ALL UNSPECIFIED TOOL RADII .01 - .03			
	PERPENDICULARITY	BREAK ALL SHARP CORNERS .01 - .03			
	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
	CONCENTRICITY	NEXT ASSEMBLY: 790-500			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	1/8/02
CHECKER	R Walker	1-8-02
PROJECT MANAGER	[illegible]	2/5/02
DIRECTOR DESIGN AND ANALYSIS	[illegible]	2-6-02
DIRECTOR LICENSING	[illegible]	2/6/02
VICE PRESIDENT QUALITY	[illegible]	2/11/02

LIFTING TRUNNION,
NAC-UMS®

PROJECT 790		DRAWING 505	REV 2
SCALE 1/2	EST.WT. NOTED	SH 1 OF 2	1-8-2002

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

ASSEMBLY,
UNIVERSAL TRANSPORT CASK
OVERPACK
NAC-UMS®

PROJECT 790		DRAWING 500	REV 4
SCALE 1/8	EST WT. NOTED	SH 2 OF 2	

FIGURE WITHHELD UNDER 10 CFR 2.390

QUANTITY

DIMENSIONING AND TOLERANCING SHALL BE PER ANSI Y14.5-82
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW.
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL	.XX	TOL
	FLATNESS	UNDER 3		UNDER 6	±.04
	STRAIGHTNESS	3-12		6-18	±.06
	ANGULARITY	OVER 12		OVER 18	±.09
	PERPENDICULARITY	.X	±.1	ANGLES ± 5°	
	PARALLELISM	ALL UNSPECIFIED TOOL RADII: .01 - .03			
	CONCENTRICITY	BREAK ALL SHARP CORNERS .01 - .03			
	TRUE POSITION	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			

NEXT ASSEMBLY: 790-570

DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARED	S. Graham	4/5/02
CHECKED	[illegible]	4-11-02
PROJECT MANAGER	[illegible]	4/17/02
DIRECTOR DESIGN AND ANALYSIS	[illegible]	4.23.02
DIRECTOR, LICENSING	[illegible]	4/23/02
VICE PRESIDENT QUALITY	[illegible]	4/25/02

INTERNATIONAL

BOTTOM WELDMENT,
FUEL BASKET,
56 ELEMENT BWR
NAC-UMS®

PROJECT 790

DRAWING 571

REV 3

SCALE 1/5

EST WT.

SH 1 OF 1

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
		UNDER 3	±.003	UNDER 6	±.02
	FLATNESS	3-12	±.005	6-18	±.03
	STRAIGHTNESS	OVER 12	±.010	OVER 18	±.06
		.X	±.1	ANGLES ±0.5°	
	ANGULARITY	ALL UNSPECIFIED TOOL RADII: .015 - .030			
	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 - .030			
//	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ∀ OR BETTER			
	CONCENTRICITY	NEXT ASSEMBLY: 790-570			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	S. Graham	12-5-02
CHECKER	[illegible]	12/9/02
PROJECT MANAGER	[illegible]	12/10/02
DIRECTOR DESIGN AND ANALYSIS	[illegible]	12-13-02
DIRECTOR, LICENSING	TC Thompson	12/17/02
VICE PRESIDENT QUALITY	[illegible]	12/24/02

BWR FUEL TUBE,
NAC-UMS®

PROJECT 790		DRAWING 575	REV 9
SCALE 1/1	EST WT	SH 1 OF 2	3:32PM 12-5-2002

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

BWR FUEL TUBE,
NAC-UMS®.

PROJECT 790		DRAWING 575	REV 9
SCALE 1/1	EST WT.	SH 2 OF 2	12-5-2007

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94 UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW. DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
⏥	FLATNESS	UNDER 3	±.003	UNDER 6	±.02
—	STRAIGHTNESS	3-12	±.006	6-18	±.03
∠	ANGULARITY	OVER 12	±.010	OVER 18	±.06
⊥	PERPENDICULARITY	.X	±.1	ANGLES ±0.5°	
//	PARALLELISM	ALL UNSPECIFIED TOOL RADII: .015 - .030			
◎	CONCENTRICITY	BREAK ALL SHARP CORNERS .015 - .030			
⊕	TRUE POSITION	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			

NEXT ASSEMBLY: 790-595

DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARER		1-17-03
CHECKER	R. Wallen	1-18-03
PROJECT MANAGER		1/24/03
DIRECTOR DESIGN AND ANALYSIS		1-24-03
DIRECTOR LICENSING	for TCT	1-27-03
VICE PRESIDENT, QUALITY	M Miller for	1/29/03

PWR FUEL TUBE, NAC-UMS®.

PROJECT 790 | DRAWING 581 | REV 8

SCALE FULL | EST.WT. | SH 1 OF 2 | 2:24PM 1-17-2003

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

PWR FUEL TUBE,
NAC-UMS®

PROJECT 790		DRAWING 581	REV 8
SCALE FULL	EST WT.	SH 2 OF 2	1-17-2003

A

FIGURE WITHHELD UNDER 10 CFR 2.390

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5M-94, UNSPECIFIED DIMENSIONAL TOLERANCES ARE SHOWN BELOW			
ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN. DEPTH OF PERFECT THREADS. THE ACTUAL DEPTH OF THE THREADS IS NOT SUBJECT TO TOLERANCE CONTROLS.			12-8-03
WEIGHTS ARE APPROXIMATE AND ARE TO BE USED FOR HANDLING PURPOSES ONLY		R. [illegible]	12-15-03
ALL DIMENSIONS ARE IN INCHES	PROJECT MANAGER		1/6/04
BORDER SIZE: F (40 X 28)			
ALL UNSPECIFIED TOOL RADII .015 – .030			1/24/04
BREAK ALL SHARP CORNERS .015 – .030			
MACHINED SURFACES TO BE [illegible] OR BETTER			12/16/03
NEXT ASSEMBLY: 790-585			
DRAWING TYPE: LICENSE	QUALITY		2/2/04

SHELL WELDMENT
CANISTER
NAC-UMS®

PROJECT 790	DRAWING 582	REV 11
SCALE 1/8	WEIGHT	SH 1 OF 2

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

SHELL WELDMENT
CANISTER
NAC-UMS®

PROJECT 790		DRAWING 582	REV 11
SCALE 1/8	CST.WT.	SH 2 OF 2	

FIGURE WITHHELD UNDER 10 CFR 2.390

UNLESS OTHERWISE STATED

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5M-94, UNSPECIFIED DIMENSIONAL TOLERANCES ARE SHOWN BELOW.

ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN. DEPTH OF PERFECT THREADS. THE ACTUAL DEPTH OF THE THREADS IS NOT SUBJECT TO TOLERANCE CONTROLS.

.XXX	UNDER 3	±.003
	3-12	±.005
	OVER 12	±.010
.XX	UNDER 6	±.02
	6-18	±.03
	OVER 18	±.06
.X	ALL	±.1
FRACTIONAL ±1/8		
ANGLES ±0.5°		

WEIGHTS ARE APPROXIMATE AND ARE TO BE USED FOR HANDLING PURPOSES ONLY

ALL DIMENSIONS ARE IN INCHES

BORDER SIZE: F (40 X 28)

ALL UNSPECIFIED TOOL RADII .015 – .030

BREAK ALL SHARP CORNERS .015 – .030

MACHINED SURFACES TO BE 250 OR BETTER

NEXT ASSEMBLY: 790-585

DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARER		1-15-04
CHECKER		1-15-04
PROJECT MANAGER		1/15/04
ENGINEERING		1/15/04
LICENSING		1/16/04
QUALITY		1/16/04

ASSEMBLY, DRAIN TUBE, CANISTER NAC-UMS®

PROJECT 790

DRAWING 583

REV 7

SCALE 1/1

WEIGHT

SH 1 OF 1

FIGURE WITHHELD UNDER 10 CFR 2.390

QUANTITY

UNLESS OTHERWISE STATED

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5M-94. UNSPECIFIED DIMENSIONAL TOLERANCES ARE SHOWN BELOW

ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN. DEPTH OF PERFECT THREADS. THE ACTUAL DEPTH OF THE THREADS IS NOT SUBJECT TO TOLERANCE CONTROLS.

.XXX	UNDER 3	± .003
	3–12	± .005
	OVER 12	± .010
.XX	UNDER 6	± .02
	6–18	± .03
	OVER 18	± .06
.X	ALL	± .1
FRACTIONAL ±1/8		
ANGLES ±0.5°		

WEIGHTS ARE APPROXIMATE AND ARE TO BE USED FOR HANDLING PURPOSES ONLY

ALL DIMENSIONS ARE IN INCHES

BORDER SIZE: F (40 X 28)

ALL UNSPECIFIED TOOL RADII: .015 – .030

BREAK ALL SHARP CORNERS .015 – .030

MACHINED SURFACES TO BE ▽ OR BETTER

NEXT ASSEMBLY: 790-585

DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARER		1-15-04
CHECKER		1-15-04
PROJECT MANAGER		1/15/04
ENGINEERING		1/15/04
LICENSING		1/16/04
QUALITY		1/16/04

DETAILS,
CANISTER
NAC-UMS®

PROJECT 790

DRAWING 584

REV 17

SCALE 1/8

WEIGHT

SH 1 OF 3

1-15-2004

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

DETAILS,
CANISTER
NAC-UMS®

PROJECT 790		DRAWING 584		REV 17
SCALE 1/8	EST WT	SH 2 OF 3		

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

DETAILS,
CANISTER
NAC-UMS®

PROJECT 790		DRAWING 584	REV 17
SCALE 1/8	EST WT.	SH 3 OF 3	10 JAN 1-15-2004

A

FIGURE WITHHELD UNDER 10 CFR 2.390

QUANTITY

UNLESS OTHERWISE STATED

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5M-94. UNSPECIFIED DIMENSIONAL TOLERANCES ARE SHOWN BELOW

ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN. DEPTH OF PERFECT THREADS. THE ACTUAL DEPTH OF THE THREADS IS NOT SUBJECT TO TOLERANCE CONTROLS.

.XXX	UNDER 3	±.003	WEIGHTS ARE APPROXIMATE AND ARE TO BE USED FOR HANDLING PURPOSES ONLY
	3-12	±.005	ALL DIMENSIONS ARE IN INCHES
	OVER 12	±.010	BORDER SIZE. F (40 X 28)
.XX	UNDER 6	±.02	ALL UNSPECIFIED TOOL RADII .015 - .030
	6-18	±.03	BREAK ALL SHARP CORNERS .015 - .030
	OVER 18	±.06	MACHINED SURFACES TO BE ∜ OR BETTER
.X	ALL	±.1	NEXT ASSEMBLY: 790-590/516
FRACTIONAL ±1/8			
ANGLES ±0.5°			DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARER		3-3-04
CHECKER	R. Welton	3-3-04
PROJECT MANAGER		3/4/04
ENGINEERING		3/4/04
LICENSING		3/10/04
QUALITY		3/10/04

INTERNATIONAL

TRANSPORTABLE STORAGE CANISTER, (TSC) NAC-UMS®

PROJECT 790		DRAWING 585	REV 16
SCALE 1/8	WEIGHT	SH 1 OF 3	

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

TRANSPORTABLE STORAGE CANISTER, (TSC) NAC-UMS®

PROJECT 790		DRAWING 585	REV 16
SCALE 1/8	EST WT.	SH 2 OF 3	

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

TRANSPORTABLE STORAGE CANISTER, (TSC) NAC-UMS®

PROJECT 790		DRAWING 585	REV 16
SCALE 1/8	EST WT.	SH 3 OF 3	3-3-2004

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW.
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
		UNDER 3	±.003	UNDER 6	±.02
▱	FLATNESS	3–12	±.005	6–18	±.03
—	STRAIGHTNESS	OVER 12	±.010	OVER 18	±.06
		.X	±.1	ANGLES ±0.5°	
∠	ANGULARITY	ALL UNSPECIFIED TOOL RADII .015 – .030			
⊥	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 – .030			
//	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
○	CONCENTRICITY	NEXT ASSEMBLY 790-585/-612			
⊕	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	3/13/02
CHECKER	[illegible]	3-14-02
PROJECT MANAGER	[illegible]	3/15/02
DIRECTOR DESIGN AND ANALYSIS	[illegible]	3-22-02
DIRECTOR LICENSING	[illegible]	3/25/02
VICE PRESIDENT QUALITY	[illegible]	3/27/02

SPACER SHIM,
CANISTER
NAC-UMS®

PROJECT 790 | DRAWING 587 | REV 1

SCALE 1/3 | EST.WT. NOTED | SH 1 OF 1 | 3-13-2002

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL	.XX	TOL
		UNDER 3	±.003	UNDER 6	±.02
⏥	FLATNESS	3-12	±.005	6-18	±.03
—	STRAIGHTNESS	OVER 12	±.010	OVER 18	±.06
		X	±.1	ANGLES ±0.5°	
∠	ANGULARITY	ALL UNSPECIFIED TOOL RADII: .015 – .030			
⊥	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 – .030			
//	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
○	CONCENTRICITY	NEXT ASSEMBLY: 790-595			
⊕	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
		4/8/03
	S. Graham	4.8.03
		4/10/03
		5-7-03
		5/7/03
		5/7/03

BOTTOM WELDMENT,
FUEL BASKET,
24 ELEMENT PWR
NAC-UMS®

PROJECT 790 | DRAWING 591 | REV 6
SCALE 1/5 | EST WT 513# | SH 1 OF 2

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

BOTTOM WELDMENT,
FUEL BASKET,
24 ELEMENT PWR
NAC–UMS®

PROJECT 790		DRAWING 591	REV 6
SCALE 1/5	EST WT. 513#	SH 2 OF 2	

FIGURE WITHHELD UNDER 10 CFR 2.390

UNLESS OTHERWISE STATED

ALL DIMENSIONS ARE IN INCHES

GROUP	NAME	DATE
PREPARED	[illegible]	12-9-03
CHECKED	R. Walker	12-15-03
PROJECT MANAGER	[illegible]	1/6/04
ENGINEERING	M Yatsko	1/26/04
LICENSING	Anthony L. Patko	12/16/03
QUALITY	[illegible]	2/2/04

NEXT ASSEMBLY: 790-595

DRAWING TYPE: LICENSE

TOP WELDMENT,
FUEL BASKET,
24 ELEMENT PWR
NAC-UMS®

PROJECT 790 | DRAWING 592 | REV 8

SCALE 1/5 | WEIGHT 725# | SH 1 OF 1

FIGURE WITHHELD UNDER 10 CFR 2.390

GROUP	NAME	DATE
		1-26-04
	R. Walker	1-27-04
		1/27/04
		1/29/04
		2/3/04
		2/3/04

INTERNATIONAL

SUPPORT DISK AND
MISC. BASKET DETAILS,
24 ELEMENT PWR
NAC-UMS®

NEXT ASSEMBLY: 790-595

DRAWING TYPE: LICENSE

PROJECT 790

DRAWING 593

REV 7

SCALE 1/5

SH 1 OF 2

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

SUPPORT DISK AND
MISC. BASKET DETAILS,
24 ELEMENT PWR
NAC-UMS®

PROJECT 790		DRAWING 593	REV 7
SCALE 1/5	EST.WT.	SH 2 OF 2	

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW.
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
		UNDER 3	±.003	UNDER 6	±.02
⏥	FLATNESS	3-12	±.005	6-18	±.03
—	STRAIGHTNESS	OVER 12	±.010	OVER 18	±.06
		X	±.1	ANGLES ±0.5°	
∠	ANGULARITY	ALL UNSPECIFIED TOOL RADII: .015 - .030			
⊥	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 - .030			
//	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
◎	CONCENTRICITY	NEXT ASSEMBLY: 790-585			
⊕	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	8-22-03
CHECKER	[illegible]	8-25-03
PROJECT MANAGER	[illegible]	8/25/03
DIRECTOR DESIGN AND ANALYSIS	[illegible]	8/26/03
DIRECTOR LICENSING	[illegible] for TCT	8/25/03
VICE PRESIDENT QUALITY	[illegible]	9/5/03

FUEL BASKET ASSEMBLY,
24 ELEMENT PWR
NAC-UMS®

PROJECT 790 | DRAWING 595 | REV 9

SCALE 1/6 | EST WT. | SH 1 OF 2 | A 42PM 8-22-2003

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL			
FUEL BASKET ASSEMBLY, 24 ELEMENT PWR NAC-UMS®			
PROJECT 790		DRAWING 595	REV 9
SCALE 1/6	EST WT.	SH 2 OF 2	[illegible]

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW.
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
		UNDER 3	±.003	UNDER 6	±.02
	FLATNESS	3-12	±.005	6-18	±.03
	STRAIGHTNESS	OVER 12	±.010	OVER 18	±.06
		X	±.1	ANGLES ±0.5°	
∠	ANGULARITY	ALL UNSPECIFIED TOOL RADII: .015 - .030			
⊥	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 - .030			
//	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
◎	CONCENTRICITY	NEXT ASSEMBLY: 790-570			
⊕	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	S. Graham	12-5-02
CHECKER	[illegible]	12/9/02
PROJECT MANAGER	[illegible]	12/16/02
DIRECTOR DESIGN AND ANALYSIS	[illegible]	12-18-02
DIRECTOR LICENSING	[illegible]	12/17/02
VICE PRESIDENT, QUALITY	[illegible]	12/20/[illegible]

BWR FUEL TUBE,
OVER-SIZED FUEL,
NAC-UMS®

PROJECT 790 | DRAWING 605 | REV 10

SCALE 1/1 | EST.WT. | SH 1 OF 2

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL			
GTCC WASTE BASKET, MAINE YANKEE, NAC-UMS®			
PROJECT 790		DRAWING 611	REV 5
SCALE 1/10	EST WT.	SH 2 OF 2	

FIGURE WITHHELD UNDER 10 CFR 2.390

QUANTITY	

DIMENSIONING AND TOLERANCING SHALL BE PER ANSI Y14.5-82 UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW. DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
	FLATNESS	UNDER 3		UNDER 6	±.04
		3-12		6-18	±.06
	STRAIGHTNESS	OVER 12		OVER 18	±.09
		.X	±.1	ANGLES ± 5°	
	ANGULARITY	ALL UNSPECIFIED TOOL RADII: .01 - .03			
	PERPENDICULARITY	BREAK ALL SHARP CORNERS .01 - .03			
	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
	CONCENTRICITY	NEXT ASSEMBLY: 790-612			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	[illegible]	11-30-01
CHECKER	[illegible]	11/30/01
PROJECT MANAGER	[illegible]	11/30/01
DIRECTOR DESIGN AND ANALYSIS	[illegible]	12-5-01
DIRECTOR, LICENSING	[illegible]	12/6/01
VICE PRESIDENT QUALITY	[illegible]	12/11/01

INTERNATIONAL

GTCC WASTE BASKET,
MAINE YANKEE,
NAC-UMS®

PROJECT 790		DRAWING 611	REV 5
SCALE 1/10	EST WT.	SH 1 OF 2	10:22 AM 11-30-2001

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

GTCC WASTE BASKET,
MAINE YANKEE,
NAC-UMS®

PROJECT 790		DRAWING 611	REV 5
SCALE 1/10	EST WT.	SH 2 OF 2	11-30-2001

FIGURE WITHHELD UNDER 10 CFR 2.390

QUANTITY					
DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94 UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW. DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8					
SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
		UNDER 3	±.003	UNDER 6	±.02
	FLATNESS	3–12	±.005	6–18	±.03
	STRAIGHTNESS	OVER 12	±.010	OVER 18	±.06
		.X	±.1	ANGLES ±0.5°	
	ANGULARITY	ALL UNSPECIFIED TOOL RADII .015 – .030			
	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 – .030			
	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
	CONCENTRICITY	NEXT ASSEMBLY 790-590/516			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARED	[illegible]	10/28/02
CHECKED	R McCullum	10-28-02
PROJECT MANAGER	[illegible]	10/29/02
DIRECTOR DESIGN AND ANALYSIS	[illegible]	10/25/02
DIRECTOR LICENSING	[illegible]	10/29/02
VICE PRESIDENT QUALITY	[illegible]	11/7/02

INTERNATIONAL

GTCC WASTE CANISTER,
MAINE YANKEE,
NAC–UMS®

PROJECT 790		DRAWING 612		REV 8
SCALE 1/10	EST WT	SH 1 OF 2		10-29-2002

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

SPENT FUEL CAN ASSEMBLY
MAINE YANKEE (MY)
NAC–UMS®

PROJECT 412		DRAWING 501	REV 4
SCALE FULL	EST.WT. 133#	SH 2 OF 2	

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5-94 UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW. DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
		UNDER 3	±.003	UNDER 6	±.02
	FLATNESS	3-12	±.006	6-18	±.03
	STRAIGHTNESS	OVER 12	±.010	OVER 18	±.06
		.X	±.1	ANGLES ±0.5°	
	ANGULARITY	ALL UNSPECIFIED TOOL RADII: .015 - .030			
	PERPENDICULARITY	BREAK ALL SHARP CORNERS .015 - .030			
	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
	CONCENTRICITY	NEXT ASSEMBLY: N/A			
	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARER	S. Graham	11-15-02
CHECKER	[illegible]	11-15-02
PROJECT MANAGER	Norman Eng	11-19-02
DIRECTOR DESIGN AND ANALYSIS	[illegible]	11-26-02
DIRECTOR, LICENSING	[illegible] for TC	11/2?/02
VICE PRESIDENT QUALITY	[illegible]	11/26/02

NAC INTERNATIONAL

SPENT FUEL CAN ASSEMBLY
MAINE YANKEE (MY)
NAC-UMS®

PROJECT	412	DRAWING	501	REV 4
SCALE FULL	EST.WT. 133#	SH 1 OF 2		11-19-2002

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

SPENT FUEL CAN ASSEMBLY
MAINE YANKEE (MY)
NAC-UMS®

PROJECT 412		DRAWING 501	REV 4
SCALE FULL	EST.WT. 133#	SH 2 OF 2	

FIGURE WITHHELD UNDER 10 CFR 2.390

GROUP	NAME	DATE
		12-10-03
		12-15-03
		1/6/04
		1/21/04
		12/16/03
		2/2/04

NEXT ASSEMBLY: 412-501
DRAWING TYPE: LICENSE

FUEL CAN DETAILS
MAINE YANKEE (MY)
NAC-UMS®

PROJECT 412
DRAWING 502
REV 4
SCALE FULL
WT NOTED
SH 1 OF 6

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

FUEL CAN DETAILS
MAINE YANKEE (MY)
NAC-UMS®

PROJECT 412		DRAWING 502	REV 4
SCALE FULL	WEIGHT NOTED	SH 5 OF 6	

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

FUEL CAN DETAILS
MAINE YANKEE (MY)
NAC-UMS®

PROJECT 412		DRAWING 502	REV 4
SCALE FULL	DETAIL NOTED	SH 5 OF 6	

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

FUEL CAN DETAILS
MAINE YANKEE (MY)
NAC-UMS®

PROJECT 412		DRAWING 502	REV 4
SCALE FULL	NOTED	SH 5 OF 6	

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

FUEL CAN DETAILS
MAINE YANKEE (MY)
NAC-UMS®

PROJECT 412		DRAWING 502	REV 4
SCALE FULL	MATERIAL NOTED	SH 5 OF 6	

FIGURE WITHHELD UNDER 10 CFR 2.390

NAC INTERNATIONAL

FUEL CAN DETAILS
MAINE YANKEE (MY)
NAC-UMS®

PROJECT 412		DRAWING 502	REV 4
SCALE FULL	EST.WT. NOTED	SH 5 OF 6	

Chapter 2

List of Tables (Continued)

List of Tables (Continued)

transportation normal conditions of transport and hypothetical accident conditions. The basket can be loaded with up to 24 intact PWR fuel assemblies or up to 56 intact BWR fuel assemblies. Some design features are common to both the PWR and BWR fuel baskets and some features are unique to each basket, as described in the following paragraphs.

The common design features between the PWR and BWR basket structure designs are the top and bottom weldments, support disks, heat transfer disks, fuel tubes, tie rods and nuts, and split spacers. When complete, the basket structure is a rigid cylindrical structure. The base of the structure is the stainless steel bottom weldment.

Either 8 (PWR) or 6 (BWR) stainless steel tie rods are welded to the bottom weldment. The tie rods are used to mechanically join the bottom weldment with the top weldment and hold in place all layers of the support disks and heat transfer disks. Each weldment is designed to support the entire basket structure for all loads. The axial loads are bounded by hypothetical accident condition top/bottom-end drop loads. The fuel assemblies are self-supporting in the axial direction.

The basket structure is assembled by stacking the support disks and the heat transfer disks over the tie rods, each separated by either a spacer or split spacer and washer. The system of multiple support disks is designed to support the fuel assemblies and fuel tubes for all lateral loads. The lateral loads are bounded by hypothetical accident condition side-drop loads. The heat transfer disks do not transmit structural loads (other than self-weight) for any load condition.

The support disks satisfy structural design criteria requirements at temperatures that result from either the normal conditions of transport or hypothetical accident. The aluminum heat transfer disks enhance thermal performance of the basket structure by augmenting its overall heat the conduction properties.

The support disks in the PWR basket are separated and supported at 4.92-in center-to-center intervals by tie rods and spacer nuts at eight locations. The heat transfer disks are located in the central region of the basket and supported by the eight tie rods and spacer nuts. The number of support disks and heat transfer disks in the PWR basket varies depending upon the class of fuel basket (Class 1, 2, or 3). The PWR fuel tubes are encased by neutron absorber plates on each of the four sides.

The support disks in the BWR basket are separated and supported at 3.83-in center-to-center intervals by tie rods and spacer nuts at six locations. The heat transfer disks are located in the central region of the basket and supported by the six tie rods and spacer nuts. As is the case for the PWR basket, the number of support disks and heat transfer disks in the BWR basket varies depending upon the class of fuel basket (Class 4 or Class 5). Three types of tubes are designed to contain BWR fuel: tubes with neutron absorber on two sides, tubes with neutron absorber one side, and tubes with no neutron absorber.

2.1.1.4 Impact Limiters

The Universal Transport Cask packaging includes two removable, cup-shaped impact limiters, which absorb the energy of a cask drop impact through the crushing of redwood and balsa wood.

Prior to shipment, the upper impact limiter is bolted to the top forging with 16 retaining rods, washers, and nuts. Likewise, the lower impact limiter is bolted to the bottom plate with 16 retaining rods, washers, and nuts. Both impact limiters are designed to limit impact loads on the cask and its contents resulting from either the normal conditions of transport or hypothetical accident drop scenarios. The impact limiters are fabricated from redwood and balsa wood wedge-shaped sections glued together to form a cylindrical shape. The wood impact-absorbing medium is completely enclosed in a stainless steel shell that is fabricated from 0.25-in thick stainless steel plate.

The maximum normal condition of transport (1-ft free drop) impact load is calculated to be 17.1g in the bottom end drop orientation. The design load used in all normal conditions of transport impact calculations is 20g. The maximum hypothetical accident condition (30-ft free drop) impact load is calculated to be 57.8g in the top end drop orientation. A design load of 60g is used in all hypothetical accident condition impact calculations.

2.1.1.5 GTCC Waste Canister and Basket

The GTCC waste canister is identical in design to the spent fuel transportable storage canister described in Section 2.1.1.2. The GTCC waste basket is designed to ASME Code, Section III, Subsection NF and conforms to the applicable load combinations and buckling criteria of Regulatory Guide 7.8, and NUREG/CR-6322, respectively. Exceptions to applicable code requirements for these components are shown in Table 2.1.2-1.

primary containment boundary components, but exclude the lifting trunnions, rotation pockets, and impact limiters. Allowable stresses for the noncontainment structures and noncontainment bolting materials are presented in Table 2.1.2-4.

The allowable stresses for the lifting and handling components of the Universal Transport Cask are based on the requirements of 10 CFR 71.45(a) [1] which requires use of material yield strength with a load factor of 3.0. The lifting and handling components of the cask also satisfy the structural requirements of NUREG-0612 [3] and ANSI N14.6 [4]: the maximum allowable stress is the material yield strength with a load factor of 6.0 or the material ultimate strength with a load factor of 10.0, whichever is less.

The lead (gamma-shielding material) is enclosed between the inner and outer cask shells and the top forging and bottom plate. The lead does not perform a structural function. However, the weight and low yield strength of the lead is considered, where appropriate, in the analyses of cask shell components.

The impact limiters are not stress-limited. While performing their intended function during a free-drop impact, the impact limiters crush and thereby absorb the energy of the impact. The crushing of the redwood and balsa wood contained in the limiter dissipates the kinetic energy of the cask while limiting the deceleration forces applied to the cask.

The Transportable Storage Canister is analyzed as a containment structure. The canister is structurally sound, criticality safe and contains a thermally efficient basket. The canister, which has a double welded closure, serves as a second enclosure of the spent fuel with the fuel cladding being the first enclosure. The basket provides the lateral structural support for the fuel assemblies and maintains the subcritical configuration during all normal conditions of transport and hypothetical accident conditions.

Table 2.1.2-1 Exceptions to Codes and Standards

Code Section	**ASME SECTION III, SUBSECTION NB CODE EXCEPTIONS**
	Transport Cask
Article NB-8000: Nameplates, Stamping, and Reports	The Code requirements for this article are not met for the Transport Cask as it is not N-stamped and code data reports are not required. However, the Cask is marked as required by 10 CFR 71.
	Transportable Storage Canister
NB-1100 Code Stamping of Components	The canister is designed and fabricated in accordance with Subsection NB of the Code to the maximum practical extent. However, code stamping of canister components is not required and canister components are not code stamped and there is no involvement of an Authorized Inspection Agency.
NB-2000 ASME Approved Material Supplier	Materials will be supplied by NAC-approved suppliers with Certified Material Test Reports in accordance with NB-2000 requirements.
Subparagraph NB-3352.3 Joints of Category C	The structural lid-to-shell weld joint does not comply with the allowable joint configurations (NB4243 - full penetration joint). The weld joint design ensures protection of the lid in side impacts.
NB-4243 Full Penetration Welds Required for Category C Joints	The shield lid and structural lid welds are not full penetration welds. These welds are field installed after the canister is loaded with spent fuel and access to the inside of the canister to complete a full penetration weld with a weld build-up is not possible (i.e., t_c=0"). However, the thickness of the groove weld is 0.88 inch, which is greater than the required thickness of 0.3125 inch.
Paragraph NB-4421 Removal of Backing Rings	In accordance with NB-4243 (Category C) corner joints welded from one side with the backing ring removed are acceptable. The UMS® structural lid to shell weld design uses a spacer ring for the joint that is not removed. The spacer ring permits completion of the partial depth groove weld. It is not considered in any analyses and has no detrimental effect on canister function.

2.3 Mechanical Properties of Materials

The material mechanical properties corresponding to the calculated material temperatures of the Universal Transport Cask are used in the structural analyses for the normal conditions of transport and the hypothetical accident load conditions. The mechanical properties at the applicable temperature are also used in calculating the allowable stresses in each component analysis. The cask materials and their mechanical properties are described in the following sections.

2.3.1 Summary of Materials

A summary list of the materials from which the Universal Transport Cask and other major components are fabricated is presented here. The mechanical properties of these materials are presented in tables in Sections 2.3.2 through 2.3.8. The effects of temperature on the mechanical properties are shown. The coefficients of thermal expansion presented in this section represent the mean value for the temperature range from 70°F to the indicated temperature.

Cask Component	Material
Cask inner shell	ASME SA-240, Type 304 stainless steel
Cask outer shell	ASTM A-240, Type 304 stainless steel
Cask bottom plate	ASTM A-240, Type 304 stainless steel
Bottom forging	ASME SA-336, Type 304 stainless steel
Top forging	ASME SA-336, Type 304 stainless steel
Neutron shield shell	ASTM A-240 Type 304 stainless steel
Neutron shield	NS-4-FR
Neutron shield heat transfer fins	Explosively bonded ASTM B-152 copper/ASTM A-240 Type 304 stainless steel
Gamma shield	ASTM B-29, chemical copper grade lead
Cask lid	ASME SA-336, Type 304 stainless steel
Lid bolts	ASME SB-637, Grade N07718, nickel alloy
Port coverplates	ASME SA-240/SA-479 Type 304 stainless steel
Port coverplate bolts	ASME SA-193, Grade B6 (Type 410) stainless steel
Lifting trunnions	ASME SA-564, TYPE 630, 17-4PH stainless steel
Rotation pockets	ASTM A-182, XM-19 stainless steel
Canister spacers - PWR cask	ASTM A240 Type 304 stainless steel
- BWR Cask	ASTM SB-209, Type 6061-T6 aluminum alloy
Canister shell	ASME SA-240, Type 304L stainless steel
Canister bottom plate	ASME SA-240, Type 304L stainless steel
Canister shield lid	ASTM A-240, Type 304 stainless steel
Canister structural lid	ASME SA-240, Type 304L stainless steel
Support disks-PWR basket	ASME SA-693, Type 630, 17-4 PH stainless steel
Support disks-BWR basket	ASME SA-533, Type B class 2 carbon steel
Heat transfer disks	ASME SB-209, Type 6061-T651 aluminum alloy
Spacers	ASME SA-312, Type 304 stainless steel
Tie rods	ASME SA-479, Type 304 stainless steel
Basket end weldments	ASME SA-240, Type 304 stainless steel
Fuel tubes	ASTM A-240 Type 304 stainless steel
Impact limiters	Redwood/balsa wood encased in ASTM A-240, Type 304 stainless steel
Retaining Rod	ASME SA-193, Grade B8S, austenitic stainless steel

a = moment arm for the equivalent ring = 45.63 - 40.905 = 4.725 in

On the basis of a total weight of 260,000 lb, q is calculated as:

$$q\,(\pi)(40.905)(2) = 260{,}000 \;\Rightarrow\; q = 1{,}011.6 \text{ lb/in}$$

The moment and torque on the equivalent ring are given by:

$$M = \frac{T_o \sin\theta}{2} - qr^2\left(1 - \frac{\pi}{2}\sin\theta\right)$$

$$T = \frac{T_o \cos\theta}{2} - qr^2\left(\theta + \frac{\pi}{2}\cos\theta - \frac{\pi}{2}\right)$$

where theta, θ, is measured from the trunnion ($\theta = 0$) in plane perpendicular to the centerline of the cask ($0 \leq \theta \leq 180$).

$$T_o = (F)(a) = (130{,}000)(4.725) = 611{,}997 \text{ in-lb.}$$

Substituting for T_o, q, and r,

$$M = 3.06 \times 10^5 \sin\theta - 1.693 \times 10^6\left(1 - \frac{\pi}{2}\sin\theta\right)$$

$$T = 3.06 \times 10^5 \cos\theta + 1.693 \times 10^6\left(\theta + \frac{\pi}{2}\cos\theta - \frac{\pi}{2}\right).$$

The normal stress is treated as bending resulting from the moment acting over a cross-section.

$$\sigma = \frac{M(h/2)}{I} = 0.00511M$$

where $h = 18.44$ in

$$I = \frac{Wh^3}{12} = \frac{3.45 \times 18.44^3}{12} 14 = 1802.7 \text{ in}^4$$

The shear stress is (Roark's, 6th Edition, Table 20, Case 4)

$$\tau = \frac{3T}{8ab^2}\left[1 + 0.6095\frac{b}{a} + 0.8865\left(\frac{b}{a}\right)^2 - 1.8023\left(\frac{b}{a}\right)^3 + 0.9100\left(\frac{b}{a}\right)^4\right] = 0.0176T$$

where $a = \dfrac{h}{2} = \dfrac{18.44}{2} = 9.22$ in, length of longer side, (8.22 is conservatively used in the calculation for τ)

$b = \dfrac{w}{2} = \dfrac{3.45}{2} = 1.725$ in, length of shorter side.

The maximum stress intensity, where the moment and torque are functions of θ, is calculated as:

$$SI = 2\sqrt{\frac{\sigma^2}{4} + \tau^2} = 2\sqrt{(6.528 \times 10^{-6})M^2 + (3.10 \times 10^{-4})T^2}.$$

Resultant values of the stress intensity are evaluated in Table 2.6.7.8-1. The minimum margin of safety is:

$$MS = \frac{30{,}000}{28{,}309} - 1 = +0.06$$

where: $S_m = 20{,}000$ psi

$S_{allow} = 1.5\ S_m = 30{,}000$ psi.

2.6.12 PWR Transportable Storage Canister Analysis - Normal Conditions of Transport

In this section, the Transportable Storage Canister assembly containing PWR fuel is evaluated for the normal conditions of transport. The principal components of the canister assembly are the canister, the fuel basket assembly, the shield lid, and the structural lid. The canister and the canister shell, bottom plate, and lids are shown in Figures 2.6.12-1 and 2.6.12-2.

Spacers are used to properly locate the canisters of different classes in the cask cavity. The analysis of the spacers is presented in Section 2.6.16. The geometries and materials of construction of the canister, baskets, and spacers are described in Section 1.2.1.2.

2.6.12.1 Analysis Description

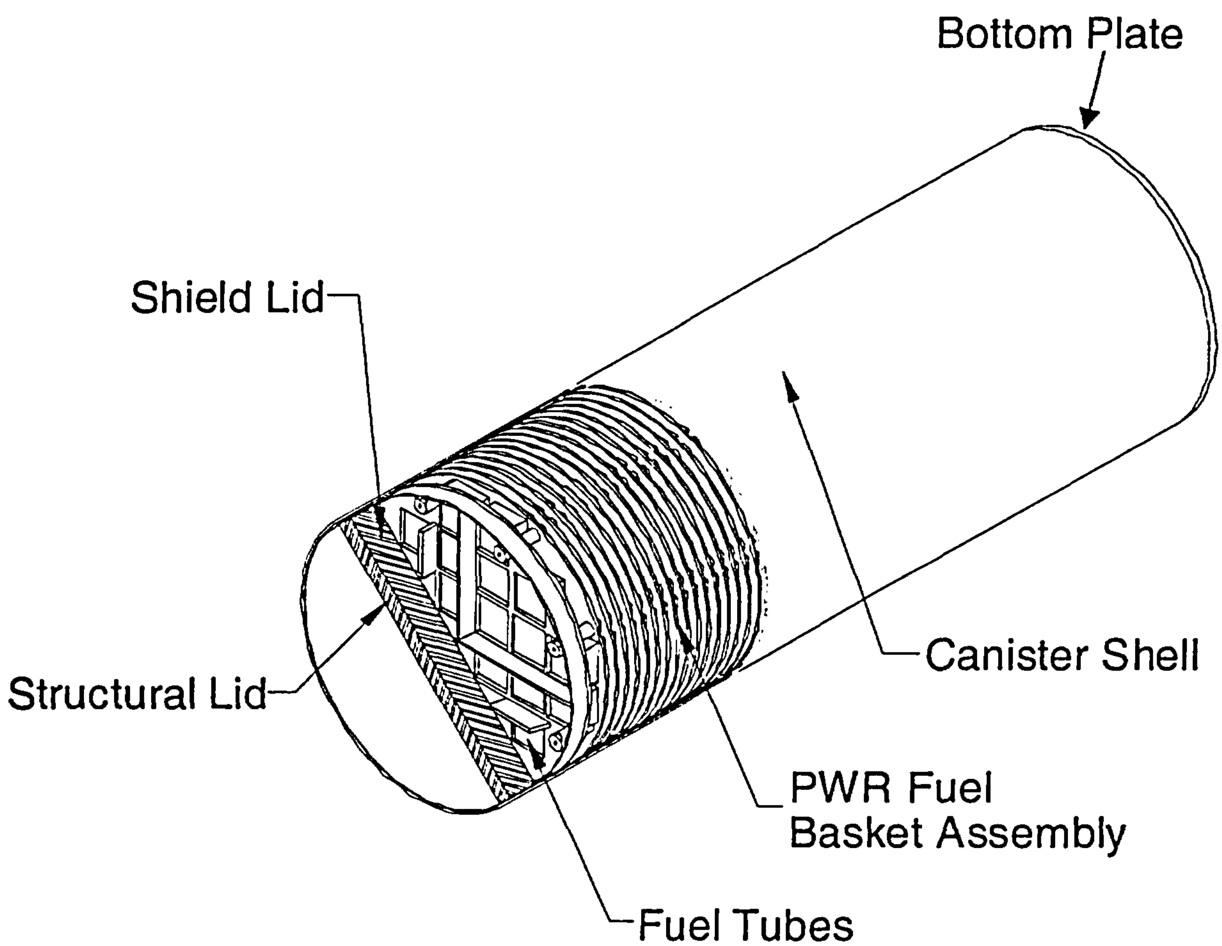
The Transportable Storage Canister contains and confines the spent fuel in the fuel basket. The canister is the defined confinement boundary for its contents during transport and storage operations, but the canister is not considered to provide containment during transport operation; the Universal Transport Cask provides the containment boundary for transport. The canister in the transfer cask serves as the handling component for its basket and contents during loading, closure, and transfer from the pool to storage or to the transport vehicle.

Three canister classes of varying lengths accommodate the PWR fuel. The design parameters of the canisters are provided in Table 1.2-2. For this analysis, the canister is modeled with the heaviest fuel (Class 2).

The structural design criteria for the canister is from the ASME Code Section III, Subsection NB. Consistent with this criterion, the structural components of the canister are shown to satisfy the allowable stress limits presented in Tables 2.1.2-3 and 2.1.2-4 as applicable. The allowable stresses used in this analysis are based on a temperature of 380°F for all locations in the canister, unless otherwise indicated. These allowables are conservative for all sections in the canister with the exception of Sections 5 and 6 (see Figure 2.6.12.3-1 for section locations).

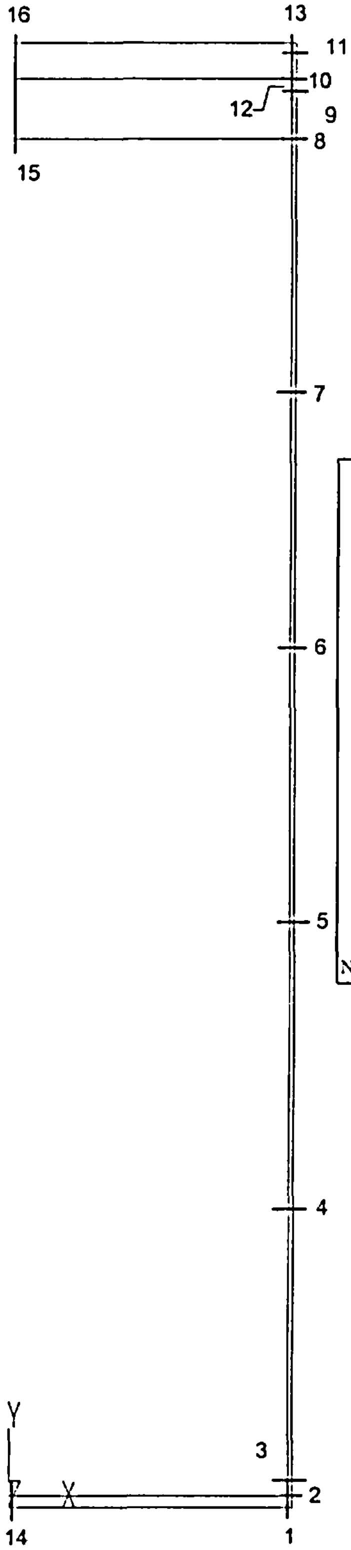
For the canister structural lid weld (Section 13, Figure 2.6.12.3-1), base metal properties are used to define the allowable stress limits since the weld filler rod tensile properties are greater than the base metal. Also, the allowable stress is multiplied by a stress reduction factor of 0.8 per ISG-4 [49].

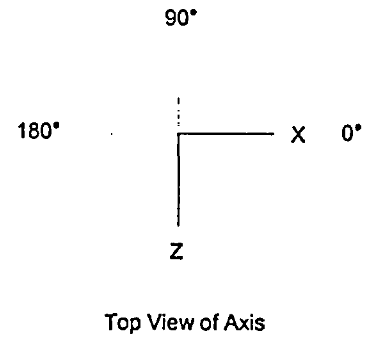
Figure 2.6.12-1 PWR Transportable Storage Canister



The cask cavity length increases to 192.5 + 0.13 = 192.63 in. The resulting axial gap is 192.63 - 192.53 = 0.1 inch. Therefore, the canister and cask will expand axially and not bind during normal transport conditions.

Figure 2.6.12.3-1 Identification of Sections for Evaluating Linearized Stresses in Canister





Section Coordinates at Z = 0

Axial Section	Node 1 x	Node 1 y	Node 2 x	Node 2 y
1	32.905	0.0	32.905	1.75
2	32.905	1.75	33.53	1.75
3	32.905	2.25	33.53	2.25
4	32.905	34.15	33.53	34.15
5	32.905	66.55	33.53	66.55
6	32.905	98.95	33.53	98.95
7	32.905	131.35	33.53	131.35
8	32.905	163.75	33.53	163.75
9	32.905	170.38	33.53	170.38
10	32.905	170.75	33.53	170.75
11	32.905	173.00	33.53	173.00
12	32.905	170.38	32.905	170.75
13	32.905	173.00	32.905	173.75
14	0.1	0.0	0.1	1.75
15	0.1	163.75	0.1	170.73
16	0.1	170.75	0.1	173.75

Note: Dimensions in inches.

Table 2.6.12.3-1 PWR Canister Linearized Q Stresses - Thermal Only (Hot 1)

Section Location	Angle of Peak Stress Location	Q Stresses (ksi)						SI (ksi)
		Sx	Sy	Sz	Sxy	Syz	Sxz	
1	180	0.2	0.1	2.1	-0.1	0	-0.1	2.2
2	9	-0.3	-1.2	0.7	-0.1	0	0.2	1.9
3	9	-0.1	-1.1	0.9	-0.1	0	0.2	1.9
4	0	0	-0.2	0.1	0	0	0	0.3
5	0	0	-0.8	0.7	0	-0.2	0	1.5
6	0	0	-0.6	0.3	0	0.1	0	0.9
7	0	0	-0.6	0.1	0	0	0	0.6
8	90	1	1.6	0	0	0	0	1.6
9	162	0.2	1.3	0.1	0	-0.1	0	1.3
10	90	0.3	1.6	-0.1	0	0	0	1.7
11	81	-0.4	-1	0.2	0.1	-0.1	-0.1	1.2
12	162	-0.2	0.6	-0.1	-0.1	0.1	-0.2	0.9
13	81	-0.4	0	-0.6	0	-0.1	0.1	0.6
14	0	-8.1	-1.4	-7.9	0.8	0.8	0.5	7.3
15	180	0.4	0	-0.1	-0.8	0	1.7	3.8
16	180	-0.2	0	0.1	-0.7	0	-1.2	2.7

Table 2.6.12.3-2 Linearized Stresses - Thermal Only (Cold 2)

Section Location	Angle of peak stress location	Q Stresses (ksi)						SI (ksi)
		Sx	Sy	Sz	Sxy	Syz	Sxz	
1	180	0.2	0.1	2.4	-0.1	0	-0.2	2.4
2	9	-0.3	-1.2	0.9	-0.1	0	0.2	2.1
3	9	-0.1	-1.1	1	-0.1	0	0.2	2.1
4	0	0	-0.3	0.1	0	0	0	0.4
5	0	0	-0.9	0.8	0	-0.2	0	1.7
6	0	0	-0.7	0.4	0	0.1	0	1.1
7	0	0	-0.7	0.1	0	0	0	0.8
8	90	1.1	1.8	0	0	0	0	1.8
9	90	0.3	1.5	0.1	-0.1	-0.1	0	1.4
10	90	0.3	1.8	-0.1	-0.1	0	0	1.9
11	81	-0.5	-1.2	0.2	0.1	-0.1	-0.1	1.4
12	162	-0.2	0.6	-0.1	-0.1	0.1	-0.2	1.0
13	36	-0.1	0.3	0.5	0.1	0.1	-0.1	0.6
14	0	-9.1	-1.7	-8.8	0.7	0.9	0.5	8.0
15	180	0.4	0	-0.1	-0.7	0	1.5	3.4
16	180	-0.2	0	0.1	-0.6	0	-1.0	2.4

Table 2.6.12.4-2 PWR Canister P_m Stresses - Internal Pressure

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	0.2	2.4	1	-0.3	0	0.1	2.4	16	5.75
2	0	1.6	-1.6	-2	-0.3	0	-0.2	3.7	16	3.32
3	0	0.3	0	-2.7	0.3	0	-0.2	3.3	16	3.83
4	0	0	0.6	1.3	0	0	0.1	1.3	16	10.98
5	0	0	0.6	1.3	0	0	0.1	1.3	16	11.02
6	0	0	0.6	1.3	0	0	0.1	1.3	16	11.02
7	0	0	0.6	1.3	0	0	0.1	1.3	16	11.02
8	0	0	0.6	0.7	0	0	0.1	0.7	16	22.64
9	180	0	0.5	0.3	-0.1	0	0	0.5	16	33.00
10	180	-0.2	0.3	0.2	0.1	0	0	0.6	16	27.04
11	0	0.3	-0.1	0.2	0	0	0	0.4	16	39.97
12	0	-0.1	-0.4	0	-0.1	0	0	0.5	16	31.61
13	9	0	0.3	0.2	0	0	0	0.3	12.8*	40.29
14	90	0.2	-0.2	0.2	-0.1	0.2	0	0.6	16	23.81
15	90	0	0	0	0	0	0	0	16	1025.99
16	0	0	0	0	0	0	0	0	16	365.18

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.4-3 PWR Canister $P_m + P_b$ Stresses - Internal Pressure

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	1.9	5.9	0.2	0	0	-0.1	5.7	24	3.24
2	0	0.8	-11.2	-5.1	-0.8	0	-0.4	12.2	24	0.97
3	0	0.7	-13.3	-6.5	0.1	0	-0.5	14	24	0.71
4	0	0	0.6	1.3	0	0	0.1	1.4	24	16.74
5	0	0	0.7	1.3	0	0	0.1	1.4	24	16.73
6	0	0	0.7	1.3	0	0	0.1	1.4	24	16.73
7	0	0	0.6	1.3	0	0	0.1	1.4	24	16.73
8	180	0	0.7	0.7	0	0	-0.1	0.7	24	31.59
9	135	0.3	0.9	0.3	-0.1	-0.1	-0.2	0.9	24	25.05
10	180	-0.1	1.4	0.6	0	0	-0.1	1.5	24	14.67
11	0	0.2	-0.9	-0.1	0	0	0	1.1	24	21.83
12	0	-0.3	-0.8	-0.1	-0.2	0	0	0.7	24	31.84
13	180	-0.4	-0.1	0	0	0	0	0.4	19.2*	48.23
14	90	7.6	-0.2	7.6	-0.1	0.2	0	7.8	24	2.06
15	90	-0.6	0	-0.6	0	0	0	0.6	24	40.86
16	81	0.3	0	0.3	0	0	0	0.3	24	74.05

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.4-4 PWR Canister P_m Stresses - 1-Foot Top End Drop

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-0.1	-2	-0.7	0.3	0	0	1.9	16	7.31
2	0	-1.3	1.2	1.8	0.3	0	0.2	3.2	16	4.04
3	0	-0.3	0	2.5	-0.2	0	0.2	3	16	4.38
4	144	0	-0.7	0	0	0	0	0.7	16	20.58
5	153	0	-0.9	0	0	0	0	0.9	16	16.18
6	162	0	-1.1	0	0	0	0	1.1	16	13.28
7	180	0	-1.3	0	0	0	0	1.3	16	11.21
8	180	0	-1.2	0	0	0	0	1.3	16	11.57
9	180	0	-0.9	-0.1	0	0	0	0.9	16	16.76
10	153	-0.1	-0.9	-0.1	0	0	0.1	0.9	16	17.80
11	27	0	-0.9	-0.1	0	0	-0.1	0.9	16	17.58
12	27	0	-0.7	-0.1	0	0	0	0.7	16	21.51
13	0	0	-0.7	-0.1	0	0	0	0.7	12.8*	17.03
14	90	-0.2	0	-0.2	0.1	-0.1	0	0.4	16	44.06
15	144	0	-0.3	0	0	0	0	0.4	16	44.54
16	0	0	-0.4	0	0	0	0	0.4	16	40.07

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.4-5 PWR Canister $P_m + P_b$ Stresses - 1-Foot Top End Drop

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-1.4	-4.7	0.1	0	0	0.1	4.8	24	3.99
2	0	-0.6	9	4.3	0.7	0	0.4	9.8	24	1.45
3	0	-0.5	10.8	5.6	0	0	0.5	11.4	24	1.1
4	162	0	-0.8	0	0	0	0	0.8	24	30.8
5	162	0	-0.9	0	0	0	0	0.9	24	24.77
6	144	0	-1.1	0	0	0	0	1.1	24	20.42
7	171	0	-1.3	0	0	0	0	1.3	24	17.3
8	180	0.1	-1.2	0	-0.1	0	0	1.3	24	17.37
9	153	-0.1	-1.0	-0.1	0	0	0.1	1	24	23.21
10	0	0	-1.0	-0.2	0	0	0	1	24	23.46
11	36	-0.1	-1.0	-0.1	0	0	-0.1	1	24	23.21
12	0	0.1	-0.7	-0.1	0.1	0	0	0.7	24	31.39
13	0	0	-0.8	-0.1	0	0	0	0.7	19.2*	25.67
14	90	-6.8	-0.1	-6.8	0.1	-0.1	0	6.7	24	2.57
15	81	0.1	-0.3	0.1	0	0	0	0.4	24	55.49
16	0	0	-0.4	0	0	0	0	0.4	24	59.08

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.4-6 PWR Canister P_m Stresses - 1-Foot Bottom End Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	180	0	-0.6	0	0.1	0	0	0.6	16	24.4
2	180	0.3	-1.9	-0.3	0.1	0	0	2.2	16	6.24
3	180	0.1	-1.9	-0.3	-0.1	0	0	2	16	7.08
4	180	0	-1.7	1.3	0	0	-0.1	3	16	4.33
5	180	0	-1.5	1.3	0	0	-0.1	2.8	16	4.69
6	180	0	-1.3	1.3	0	0	-0.1	2.6	16	5.11
7	180	0	-1.1	1.3	0	0	-0.1	2.4	16	5.58
8	180	0	-0.7	0.7	0	0	-0.1	1.4	16	10.31
9	180	-0.1	-0.5	-0.4	0.1	0	0	0.4	16	36.16
10	180	0.3	-0.3	-0.3	-0.1	0	0	0.7	16	23.21
11	0	-0.4	0.1	-0.2	0	0	0	0.5	16	29.73
12	0	0.1	0.5	-0.1	0.1	0	0	0.6	16	26.08
13	180	0	-0.4	-0.2	0	0	0	0.4	12.8*	28.77
14	0	0.1	-0.4	0.1	0	0	0	0.4	16	34.57
15	108	0	0	0	0	0	0	0.1	16	302.05
16	0	0	0	0	0	0	0	0.1	16	286.36

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.4-7 PWR Canister $P_m + P_b$ Stresses - 1 Foot Bottom End Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	180	0.2	-0.4	0.1	0.1	0	0	0.7	24	34.19
2	180	0.2	-3.4	-0.7	0.1	0	0.1	3.6	24	5.71
3	180	0.1	-3.3	-0.6	-0.1	0	0	3.3	24	6.16
4	0	0	-1.7	1.3	0	0	0.1	3	24	6.95
5	0	0	-1.5	1.3	0	0	0.1	2.8	24	7.5
6	0	0	-1.3	1.3	0	0	0.1	2.6	24	8.11
7	0	0	-1.1	1.3	0	0	0.1	2.4	24	8.82
8	27	0.2	-0.9	0.5	0	0	0.2	1.5	24	14.94
9	108	-0.6	-1.2	-0.1	0	0.1	0.2	1.1	24	20.59
10	72	-0.6	-1.5	0.1	0	0.1	-0.2	1.7	24	13.18
11	0	-0.2	1.1	0.2	-0.1	0	0	1.4	24	16.62
12	180	0.5	0.8	0.1	-0.2	0	0	0.8	24	28.59
13	180	0.6	0.1	0.1	0.1	0	0	0.5	19.2*	35.23
14	0	0.1	-0.4	0.1	0	0	0	0.5	24	49.26
15	90	0.8	0	0.8	0	0	0	0.8	24	28.07
16	0	-0.4	0	-0.4	0	0	0	0.4	24	56.39

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.5-2 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Top End Drop, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	90	1.3	-5.8	-1.8	0	0	0	7.2	47.9	5.67
2	45	3.4	10.6	3.4	0.4	-0.6	3.5	10.8	47.9	3.46
3	9	-0.1	-10.9	0.8	-0.6	0	0.2	11.8	47.9	3.08
4	0	0	-1.2	0	0	0	0	1.2	47.9	37.94
5	0	0	-2.1	0.6	0	-0.2	0	2.8	47.9	16.12
6	0	0	-2.3	0.2	0	0	0	2.5	47.9	18.39
7	0	0	-2.6	0	0	0	0	2.6	47.9	17.46
8	9	-0.2	-3.4	-0.3	0	0.1	0	3.3	47.9	13.67
9	153	0	-0.9	-0.1	0	0	0.1	0.9	47.9	52.27
10	180	0	-0.9	-0.2	0	0	0	0.9	47.9	50.00
11	36	-0.1	-1	-0.1	0	0	-0.1	1	47.9	48.42
12	0	0.1	-0.7	-0.1	0.1	0	0	0.8	47.9	62.92
13	180	0	-0.8	-0.1	0	0	0	0.7	38.3*	51.49
14	0	-15.7	-1.8	-15.4	0.1	-1	0.1	14	47.9	2.44
15	81	0.1	-0.3	0.1	0	0	0	0.4	47.9	116.3
16	0	0.1	-0.5	0.1	0	0	0	0.6	47.9	85.61

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.5-3 PWR Canister $P_m + P_b + Q$ Stresses-1-Foot Top End Drop, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	90	1.2	-5.9	-1.8	0	0	0	7.1	47.9	5.77
2	45	3.3	10.5	3.3	0.4	-0.6	3.5	10.8	47.9	3.44
3	9	-0.1	-11	0.7	-0.6	0.1	0.1	11.8	47.9	3.08
4	0	0	-1.1	0	0	0	0	1.2	47.9	40.01
5	0	0	-2	0.5	0	-0.2	0	2.5	47.9	17.84
6	0	0	-2.1	0.2	0	0	0	2.3	47.9	20.04
7	0	0	-2.4	0	0	0	0	2.4	47.9	19.03
8	9	-0.2	-3.2	-0.3	0	0.1	0	3	47.9	14.85
9	27	0	-0.9	-0.1	0	0	-0.1	0.9	47.9	52.27
10	0	0	-0.9	-0.2	0	0	0	0.9	47.9	50.00
11	36	-0.1	-1	-0.1	0	0	-0.1	1	47.9	48.94
12	180	0	-0.7	-0.1	-0.1	0	0	0.7	47.9	63.78
13	0	0	-0.8	-0.1	0	0	0	0.7	38.3*	51.49
14	0	-14.8	-1.6	-14.6	0.1	-0.9	0	13.3	47.9	2.6
15	81	0.1	-0.3	0.1	0	0	0	0.4	47.9	116.41
16	0	0.1	-0.5	0.1	0	0	0	0.5	47.9	87.74

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.5-4 PWR Canister $P_m + P_b + Q$ Stresses -1-Foot Bottom End Drop, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	9	0.1	-2.1	1.2	-0.3	0.1	0.2	3.4	47.9	13.23
2	9	-0.3	-4.5	0.3	-0.1	0.1	0.1	4.8	47.9	9.04
3	9	-0.1	-4	0.6	0	0.1	0.1	4.6	47.9	9.38
4	0	0	-3.2	0	0	0	0	3.2	47.9	14.02
5	0	0	-3.5	0.6	0	-0.2	0	4.1	47.9	10.6
6	0	0	-3	0.2	0	0.1	0	3.2	47.9	13.91
7	0	0	-2.6	0	0	0	0	2.7	47.9	17.02
8	9	-0.2	-2.7	-0.2	0	0.2	0	2.6	47.9	17.55
9	162	-0.1	-1.2	-0.6	0.1	0	0.2	1.1	47.9	42.98
10	108	-0.6	-1.6	0.1	0	0	0.3	1.8	47.9	25.93
11	0	-0.2	1.2	0.2	-0.1	0	0	1.5	47.9	31.84
12	0	0.5	0.9	0.2	0.3	0	0	0.8	47.9	56.07
13	180	0.6	0	0	0.1	0	0	0.6	38.3*	65.07
14	0	-11.2	-5.5	-10.9	0	0.1	0.1	5.7	47.9	7.47
15	81	1.7	0	1.4	0	0	0	1.7	47.9	27.66
16	72	-0.7	0	-0.6	0	0	0	0.7	47.9	68.32

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.5-5 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Bottom End Drop, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	9	0.1	-1.9	1.1	-0.3	0.1	0.2	3.1	47.9	14.36
2	9	-0.3	-4.5	0.1	-0.1	0.1	0.1	4.6	47.9	9.45
3	9	-0.1	-4	0.4	0	0.1	0.1	4.4	47.9	9.79
4	0	0	-3.1	0	0	0	0	3.1	47.9	14.64
5	0	0	-3.3	0.6	0	-0.2	0	3.9	47.9	11.41
6	0	0	-2.8	0.2	0	0.1	0	3	47.9	14.76
7	0	0	-2.5	0	0	0	0	2.5	47.9	17.96
8	9	-0.2	-2.6	-0.2	0	0.2	0	2.4	47.9	18.74
9	135	-0.4	-1.2	-0.4	0.1	0.1	0.3	1.1	47.9	42.98
10	108	-0.6	-1.6	0.1	0	0	0.3	1.8	47.9	25.93
11	0	-0.2	1.2	0.2	-0.1	0	0	1.5	47.9	31.84
12	0	0.5	0.9	0.2	0.3	0	0	0.8	47.9	56.07
13	180	0.6	0	0	0.1	0	0	0.6	38.3*	65.07
14	0	-10	-4.9	-9.7	0	0.1	0	5.1	47.9	8.44
15	72	1.7	0	1.4	0	0	0	1.6	47.9	28.14
16	72	-0.7	-0.1	-0.6	0	0	0	0.7	47.9	68.12

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

2.6.12.6 Stress Evaluation of PWR Canister for 1-Foot Side Drop Load Condition

The stresses in the PWR canister that result from a 1-ft side-drop are determined by using ANSYS. In the local regions of the lids and bottom plate, the loads are transmitted through the canister shell into the cask body inner shell. Outside of the lid and bottom plate regions, stress develops in the canister shell as a result of the basket loading the canister wall. The difference in the radii of the basket, canister, and cask body implies that the contact angle between the components is dependent on the loading. For this reason, the finite element model described in Section 2.6.12.2 contains a half model of the basket. Gap elements between the basket and the canister allow the interface to be dependent on the loading. The interface between the canister and the cask body inner shell is also represented by gap elements.

The load resulting from the contents is applied to the basket by means of pressure acting in the plane of the disks. The weight is assumed to act over the effective width of 9.272 in., in which the disk is 0.5 in. thick. This weight is distributed over the 32 support disks plus two end weldments. A deceleration factor of 20 *g* applied to the weights provides the loading for the basket assembly. In addition to the contents load, a 25-psig pressure is applied to the inner surface of the canister.

Analyses of the canister are performed for basket orientations of 0° and 45°. The angles describe the orientation of the basket elements with respect to the symmetry plane of the model. A value of 0° orients the ligaments in the basket elements parallel and perpendicular to the symmetry plane, a value of 45°orients the basket ligaments at +/- 45° from the symmetry plane. To assess the impact of the basket orientation on the canister response during impact, both basket orientations are run for the side-impact loading.

The methodology used to evaluate the stresses for the side-drop are similar to that used for the end-drop (Section 2.6.12.4) with following exceptions. Sections 9, 10, and 11 at the 0° circumferential position (see Figure 2.6.12.3-1) are not included in the evaluation. These regions are characterized as a bearing stress since they result from the canister shell bearing against the cask inner shell. Section 2.6.12.11 provides an assessment of the canister shell bearing stresses. Sections 9, 10, and 11 at all other angular locations are included in the evaluation. Also, Sections 12 and 13 at 0° are treated as local membrane stresses. According to the ASME Code Section III, Paragraph NB-3213.10, a stressed region may be considered local if the distance over which the membrane stress intensity exceeds 1.1 S_m does not extend more than 1.0 times the square root of RT in the meridional direction, where R is the minimum midsurface radius of curvature and T is the minimum thickness in the region considered. For Section 13, the minimum thickness is that of the canister shell (0.625 in.) and the midsurface radius of the shell is 33.2175 in. The resulting distance is 4.56 in. A section located 4.56 in. from Section 13 in the meridional direction results in a membrane stress intensity of 6.7 ksi, which is below S_m. This section conservatively encompasses Section 12 since it is located 1.56 in. from this section. The stresses at adjacent circumferential sections (i.e., at 9°) for Sections 12 and 13 are also included in the tables for comparison. The critical section stresses are reported in Table 2.6.12.6-1 for the P_m and $P_m + P_b$ stresses.

Results are calculated for 1-ft side-drop with internal pressure both the 0° and 45° basket orientations. Tables 2.6.12.6-2 and 2.6.12.6-3 present the worst-case margins for the side-drop which occurs with the conditions noted. The minimum margin occurs for membrane without pressure and with pressure for membrane plus bending. The minimum margin of safety for the PWR canister in the side-drop is +0.04, which occurs at Section 9 in Table 2.6.12.6-1. The margins of safety are calculated as:

$$MS = (\text{allowable stress/SI}) - 1.$$

Table 2.6.12.6-1 PWR Canister Critical Sections for the 1-Foot Side Drop Load Condition

Condition	Stress	Critical Section	Table	Minimum Factor of Safety
Side Drop	Pm	9	2.6.12.6-2	+0.04
Side Drop + Pressure	$P_m + P_b$	1	2.6.12.6-3	+0.07

Table 2.6.12.6-2 PWR Canister: P_m Stresses - 1 Foot Side Drop

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-14.7	-0.2	-5.2	-0.4	-0.1	-2	14.9	16	0.07
2	0	-13	-0.8	-6.4	-0.8	-0.4	-1.2	12.5	16	0.28
3	0	-3.8	-0.6	-3.3	-0.3	-0.6	-1.3	4.5	16	2.55
4	81	0	-0.2	0	0.8	0.1	0	1.5	16	9.39
5	9	-0.7	0.9	0.2	0	0	0.2	1.6	16	9.23
6	9	-0.7	1	0.2	0	0	0.2	1.7	16	8.19
7	9	-0.8	1.1	0.3	0	-0.1	0.2	2	16	7.18
8	0	-0.7	2.5	-1.1	-0.1	0.5	-0.1	3.7	16	3.34
9	0 – 15**	-10.9	3.8	-4.5	-1.6	1.6	-0.3	15.4	16	0.04
10	0 – 14.8**	-7.6	1.5	-4.4	-2.3	1.1	-0.1	10.4	16	0.53
11	0 – 9**	-17.1	0.4	-6.7	-0.3	1.7	-0.8	18	24***	0.33
12	0 – 15.4**	-10.4	-2.5	-5.8	-2.6	0.7	-1.2	9.8	16	0.63
13	0 – 8.4**	-12.5	-3.2	-4.8	-0.5	1	-2.1	10.5	12.8*	0.22
14	0	-0.9	-0.1	0.3	0	0	0	1.2	16	11.92
15	0	-0.3	0	0.1	0	0	0	0.4	16	35.79
16	0	-0.5	0.1	0.2	0	0	0	0.7	16	22.61

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

** Stress averaged over weld compression region.

*** Stresses treated as a local membrane stress. Allowable for normal conditions is $1.5S_m = 24$ ksi.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.6-3 PWR Canister $P_m + P_b$ Stresses - 1-Foot Side Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-23	-0.9	-7.6	0.6	0	-2	22.5	24	0.07
2	18	0.5	-12.7	-3.1	-0.2	0.2	-1.5	13.7	24	0.74
3	27	-0.6	-12.5	-4.6	0.1	-0.6	-2.3	13	24	0.85
4	9	-0.8	1.9	3.9	0	0.1	0.7	4.8	24	3.95
5	9	-0.6	2.3	3.7	0	0	0.7	4.5	24	4.3
6	9	-0.6	2.4	3.7	0	-0.1	0.7	4.5	24	4.33
7	9	-0.7	2.4	3.7	0	-0.1	0.7	4.7	24	4.12
8	0	-0.4	2.7	-2.4	-0.2	0.4	-0.2	5.1	24	3.66
9	0 – 14.5**	-10.3	8.2	-3.8	-1.1	2	0.4	19	24	0.26
10	0 – 14.6**	-7.4	3.6	-4.4	-0.8	1.4	0.4	11.3	24	1.11
11	0 – 9.3**	-15.4	3.2	-6.3	0.3	1.7	-0.9	19	24	0.26
12	0 – 17**	-11.7	-2.6	-6	-2	0.8	-1.2	10.4	24	1.3
13	0 – 8**	-17.6	-6.3	-7.3	-1.4	0.8	-1.8	12.6	20*	0.59
14	90	-0.8	0	0.4	0	0	0	1.2	24	18.27
15	90	-0.6	0	-0.2	0	0	0	0.6	24	39.77
16	0	-0.4	0	0.3	0	0	0	0.7	24	33.98

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

** Stress averaged over weld compression region

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

2.6.12.7 Stress Evaluation of PWR Canister for Combined Thermal and 1-Foot Side Drop Load Condition

The thermal stress loads described in Section 2.6.12.3 are applied in conjunction with the primary loads in Section 2.6.12.6 to produce a combined thermal stress plus 1-ft side-drop loading. The stress evaluation is performed according to the ASME Code, Section III, Subsection NB. The most critical sections are listed in Table 2.6.12.7-1. Results from the side-drop plus thermal load cases for the configurations that result in the minimum margins are presented in Tables 2.6.12.7-2 and 2.6.12.7-3. The stresses reported in this table correspond to the nodal stress at the surface. The minimum margin is +0.16 at Section 9 (see Table 2.6.12.7-1) when 3 S_m is used as the stress criteria. The margins of safety are calculated as:

MS = (allowable stress/SI) -1.

Table 2.6.12.7-1 PWR Canister Critical Sections for Combined 1-Foot Side Drop and Thermal Load Condition

Condition	Stress	Critical Section	Table	Minimum Margin of Safety
Side Drop + Thermal (cold)	$P_m + P_b + Q$	9	2.6.12.7-2	+ 0.16
Side Drop + Thermal (hot)	$P_m + P_b + Q$	9	2.6.12.7-3	+ 0.18

Table 2.6.12.7-2 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Side Drop, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-15.3	-0.4	-4	-0.1	0.1	-1.7	15.1	47.9	2.17
2	0	-11.7	-0.2	-2.2	-1.2	-0.4	-1.7	12.1	47.9	2.97
3	27	0.7	5.2	1.3	1.2	1.6	1.2	6.4	47.9	6.46
4	0	-0.4	1.1	2.9	0	-0.1	0.6	3.5	47.9	12.73
5	45	-1.2	1.5	-1.2	-0.4	-0.4	-1.3	4.2	47.9	10.41
6	45	-1	1.2	-1.1	0.3	0.3	-1.2	3.5	47.9	12.51
7	0	-0.4	1.1	2.6	0	0	0.5	3.1	47.9	14.33
8	0	0	2.7	-1.5	-0.1	0.6	-0.1	4.3	47.9	10.04
9	0	-30.6	10.1	-10.8	-3.3	1.8	0.6	41.3	47.9	0.16
10	0	-24	3.4	-10.4	-1.1	1.7	0.3	27.7	47.9	0.73
11	0	-30.3	4.4	-10.3	-0.5	1.8	0.1	35	47.9	0.37
12	0	-29.8	-5.5	-10.5	-5.6	1.5	-0.7	27.1	47.9	0.77
13	0	-37.5	-11.2	-13	-3	1.9	-1.3	28.3	38.3*	0.35
14	180	-9.3	-2.5	-7.6	0.1	1.2	-0.1	7	47.9	5.8
15	0	-0.7	0	-0.1	0	0	0	0.7	47.9	69.76
16	0	-0.6	0.1	0.1	0	0	0	0.7	47.9	63.87

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.7-3 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Side Drop, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-13.4	-0.3	-3.8	-0.1	0.1	-1.4	13.2	47.9	2.62
2	0	-9.8	0	-2	-1	-0.3	-1.4	10.2	47.9	3.7
3	27	0.6	4.6	1.1	1	1.3	1	5.5	47.9	7.65
4	0	-0.4	0.8	2.4	0	-0.1	0.5	3	47.9	15.13
5	45	-1	1.2	-1.1	-0.4	-0.4	-1.2	3.6	47.9	12.17
6	45	-0.9	1.1	-0.9	0.3	0.3	-1	3.1	47.9	14.39
7	0	-0.4	1	2.1	0	0	0.4	2.7	47.9	16.98
8	0	0	2.6	-1.2	-0.1	0.5	-0.1	4	47.9	11.05
9	0	-30.1	9.9	-10.7	-3.2	1.8	0.6	40.7	47.9	0.18
10	0	-23.6	3.4	-10.3	-1.1	1.7	0.3	27.3	47.9	0.76
11	0	-29.8	4.3	-10.1	-0.5	1.8	0.2	34.4	47.9	0.39
12	0	-29.3	-5.4	-10.4	-5.5	1.5	-0.6	26.7	47.9	0.79
13	0	-36.8	-10.9	-12.8	-2.9	1.9	-1.3	27.8	38.3*	0.38
14	180	-8.8	-1.6	-7.1	0.1	0.8	-0.1	7.4	47.9	5.51
15	0	-0.6	0	0.1	0	0	0	0.7	47.9	69.62
16	0	-0.7	0	-0.1	0	0	0	0.8	47.9	61.85

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

2.6.12.8 Stress Evaluation of PWR Canister for 1-Foot Corner Drop Load Condition

A structural analysis performed by using ANSYS to evaluate the effect of a 1-ft end-drop impact for both the top-and bottom-corner orientations of the PWR canister. The ASME Code, Section III, Subsection NB, requires that stresses arising from operational loads be assessed on the basis of the primary loads. The primary loads for the 1-ft corner-drop result from the deceleration of the canister and its contents and the 25-psig pressure load internal to the canister. The applied deceleration is 20 *g* for both orientations (Note—the actual deceleration is 5.6 *g*; therefore, the results presented in this section are conservative). The inertial load of the canister is addressed by the deceleration factor applied to the canister density. The contents weight is represented by a pressure load on the inner end surface of the canister and a pressure applied to the basket by means of pressure acting in the plane of the disks. Displacement constraints are applied to the plane of symmetry and the gap elements attached at the canister end to represent the top or bottom of the transport cask.

The locations of the linearized stresses are shown in Figure 2.6.12.3-1. The maximum stresses for P_m and $P_m + P_b$ are tabulated in Tables 2.6.12.8-2 through 2.6.12.8-5 for the conditions that result in the worst-case stresses. The critical sections for the pressure and the pressure plus the deceleration load, with reference to the section and the appropriate tables, are shown in Table 2.6.12.8-1. The margins of safety in these tables are calculated as:

MS = (allowable stress/SI)-1.

Table 2.6.12.8-1 PWR Canister Critical Sections for the 1-Foot Corner Drop Load Condition

Condition	Stress	Critical Section	Table	Margin of Safety*
Top Corner Drop + Pressure	P_m	9	2.6.12.8-2	+ 0.02
Top Corner Drop Inertia	$P_m + P_b$	2	2.6.12.8-3	+ 0.02
Bottom Corner Drop + Pressure	P_m	13	2.6.12.8-4	+ 0.14
Bottom Corner Drop + Inertia	$P_m + P_b$	9	2.6.12.8-5	+0.21

* These margins of safety are based on stresses calculated for corner drops with a 20 g deceleration load. The actual deceleration load is 5.6 g; therefore, these margins of safety are conservative.

Table 2.6.12.8-2 PWR Canister P_m Stresses 1-Foot Top Corner Drop, Internal Pressure

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-5.9	0.3	-1.7	0.2	-0.1	-0.8	6.4	16	1.5
2	0	-1.6	0.3	-1.5	-0.1	-0.3	-0.4	2.4	16	5.75
3	0	-0.5	0.5	-0.9	0.2	-0.3	-0.3	1.7	16	8.18
4	0	-1.2	-0.1	1.5	0	0	0	2.7	16	4.89
5	0	-1.2	-0.2	1.4	0	0	0	2.6	16	5.14
6	0	-1.2	-0.4	1.4	0	0	0	2.6	16	5.12
7	0	-1.2	-0.8	1.5	0	-0.1	0	2.7	16	4.91
8	45	0.4	-0.8	0.3	-0.4	-0.4	0.4	1.9	16	7.39
9	0	-17.0	-1.9	-4.7	-2.0	0.4	-0.5	15.7	16	0.02
10	0	-13.8	-4.4	-3.8	-2.5	0.1	-0.7	10.9	16	0.47
11	0	-17.2	-7.0	-6.0	-1	0.4	-0.4	11.5	16	0.40
12	0	-15.3	-6.7	-3.6	-3.8	0.1	-1	13.3	16.	0.20
13	0	-15.3	-8.6	-4.2	-1.2	0.3	-1	11.6	12.8*	0.11
14	0	-0.2	0	0.2	0	0	0	0.4	16	37.89
15	171	-0.1	-0.3	0	0	0	0	0.4	16	40.38
16	0	-0.2	-0.4	0.1	0	0	0	0.5	16	34.04

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.8-3 PWR Canister $P_m + P_b$ Stresses - 1-Foot Top Corner Drop

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-15.3	-6.5	-4.5	-3.9	-0.2	-1	12.4	24	0.93
2	0	-19.4	3.9	-4.4	-0.7	1.2	-0.1	23.5	24	0.02
3	180	-0.5	9.9	5.3	0	0	-0.4	10.4	24	1.3
4	0	-1.4	0	2.5	0	0	0.1	4	24	5.04
5	0	-1.4	-0.1	2.4	0	0	0.1	3.8	24	5.37
6	0	-1.4	-0.4	2.4	0	0	0.1	3.8	24	5.35
7	0	-1.4	-0.7	2.5	0	-0.1	0.1	3.9	24	5.09
8	36	0.1	-1.4	0.1	-0.4	-0.7	0.1	2.2	24	9.92
9	0	-17.9	0.9	-5.2	-1.6	0.5	-0.1	19.1	24	0.81
10	0	-13.8	-6.2	-3.0	-4.8	-0.2	-0.9	13.3	24	0.80
11	0	-19.0	-9.2	-6.2	-1.8	0.5	-0.8	13.4	24	0.80
12	0	-15.0	-7.4	-3.2	-4.8	-0.2	-1	14.3	24	0.68
13	0	-17.3	-10.3	-5.2	-2.3	0.4	-0.8	13.0	19.2*	0.48
14	90	-6.4	-0.1	-5.9	0.1	-0.1	0	6.3	24	2.78
15	81	0	-0.3	0.1	0	0	0	0.4	24	54.38
16	0	-0.2	-0.3	0.1	0	0	0	0.4	24	53.04

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.8-4 PWR Canister P_m Stresses - 1-Foot Bottom Corner Drop

Section Location	Angle of Peak Stress Location	P_m Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-7	-1.9	-2.4	-0.3	0	-1	6	16	1.67
2	18	0.6	-3.3	-0.6	0.1	-0.1	-0.5	4	16	2.95
3	18	0	-3.1	-0.9	0.1	-0.2	-0.4	3.3	16	3.84
4	0	-1.2	-2.3	0.2	0	0	-0.1	2.8	16	4.75
5	180	0	-2.2	-0.1	0	0	0	2.3	16	6.07
6	180	0	-2.2	-0.1	0	0	0	2.2	16	6.36
7	180	0	-1.9	-0.1	0	0	0	1.9	16	7.27
8	45	0.1	-1.1	0	-0.3	-0.3	0	1.5	16	10.29
9	0 – 7.7**	-7.6	0.9	-2.7	-0.8	0.7	-0.6	8.8	16	0.81
10	0	-10.5	-0.4	-2.8	-1.9	0.7	-0.5	11.1	16	0.44
11	0 – 7.6**	-8.9	0	-3.1	-0.1	0.9	-0.6	9.2	16	0.73
12	0	-12.8	-2.8	-2.8	-2.9	0.5	-0.8	12.1	16	0.32
13	0	-13.0	-2.8	-2.7	-0.4	0.7	-1.2	11.3	12.8*	0.14
14	0	-0.4	-0.3	0.2	0	0	0	0.5	16	28.96
15	0	-0.1	0	0.1	0	0	0	0.2	16	104.27
16	0	-0.3	0	0	0	0	0	0.3	16	50.45

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

** Stress averaged over weld compression region.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.8-5 PWR Canister $P_m + P_b$ Stresses - 1-Foot Bottom Corner Drop

Section Location	Angle of Peak Stress Location	$P_m + P_b$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-7.5	-0.8	-2.5	0.3	0.1	-1	7	24	2.44
2	18	-0.2	-6.9	-1.4	-0.1	0	-0.5	6.9	24	2.46
3	18	-0.3	-6.1	-1.3	0.2	0	-0.5	6	24	3.02
4	0	-1.4	-1.9	2.5	0	0	0.1	4.4	24	4.39
5	0	-1.3	-1.4	2.4	0	0	0.1	3.9	24	5.21
6	0	-1.3	-1.1	2.4	0	0	0.1	3.7	24	5.4
7	0	-1.4	-0.8	2.4	0	0	0.1	3.8	24	5.27
8	18	0.3	-1.1	-0.9	0.3	0.4	-0.4	2	24	11.1
9	0	-15.9	3.5	-4.7	-1.4	0.9	-0.1	19.7	24	0.21
10	0	-10.8	0.8	-3.9	-0.2	1	-0.4	11.7	24	1.04
11	0	-16.2	2.8	-4.5	0.1	1.1	0	19.1	24	0.25
12	0	-14.2	-3.1	-3.7	-2.3	0.7	-0.9	12.7	24	0.89
13	0	-18.3	-6.1	-5.1	-1	0.9	-0.7	13.9	19.2*	0.38
14	0	-0.4	-0.3	0.2	0	0	0	0.5	24	43.89
15	72	1.3	0	1.4	0	0	0	1.4	24	15.9
16	18	-0.9	0	-0.6	0	0	0	0.9	24	25.01

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

2.6.12.9 Stress Evaluation of PWR Canister for Combined Thermal and 1-Foot Corner Drop Load Conditions

The thermal stress loads described in Section 2.6.12.3 are applied in conjunction with the primary loads in Section 2.6.12.8 to produce a combined thermal stress plus corner impact loading. The stress evaluation is performed according to the ASME Code, Section III, Subsection NB. On the basis of the results in Section 2.6.12.8, the most critical sections are identified in Table 2.6.12.9-1. The stresses reported in this table correspond to the nodal stress at the surface. The minimum margin of safety is +1.14 when 3 S_m is used as the stress criterion. Tables 2.6.12.9-2 through 2.6.12.9-5 tabulate the results for top and bottom corner-drop with thermal results for the conditions that result in the minimum margins of safety. The stress intensity criterion of 3.0 S_m is satisfied. The margins of safety are calculated as:

MS = (allowable stress/SI)-1.

Table 2.6.12.9-1 PWR Canister Critical Sections for the Combined 1-Foot Corner Drop and Thermal Load Condition

Condition	Stress	Critical Section	Table	Minimum Margin of Safety
Top Corner Drop + Thermal (cold)	$P_m + P_b + Q$	2	2.6.12.9-2	+ 1.14
Top Corner Drop + Thermal (hot)	$P_m + P_b + Q$	2	2.6.12.9-3	+ 1.24
Bottom Corner Drop + Pressure + Thermal (cold)	$P_m + P_b + Q$	13	2.6.12.9-4	+1.58
Bottom Corner Drop + Pressure + Thermal (hot)	$P_m + P_b + Q$	13	2.6.12.9-5	+1.59

Table 2.6.12.9-2 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Top Corner Drop, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-19.5	-7.1	-4.4	-3.7	-0.2	-1	16.3	47.9	1.95
2	0	-19.9	2.3	-3.3	-0.6	1.2	-0.3	22.4	47.9	1.14
3	126	0.4	-10.3	0.3	0.7	0.1	-0.5	11.2	47.9	3.3
4	0	-1.4	-0.6	2.4	0	-0.1	0	3.7	47.9	11.79
5	0	-0.8	-2.9	1.7	0	-0.4	-0.2	4.8	47.9	9.08
6	0	-1.1	-1.9	2.1	0	0.2	-0.2	4.1	47.9	10.72
7	0	-1.3	-0.7	2.3	0	0	0	3.5	47.9	12.54
8	171	-0.2	-3.6	-0.4	0	0.2	0	3.5	47.9	12.78
9	0	-16.9	0	-5.3	-1.9	0.5	-0.3	17.4	47.9	1.76
10	0	-14.6	-7.2	-3.4	-4.7	-0.2	-1	13.6	47.9	2.53
11	0	-18.8	-10.2	-6.5	-2.2	0.4	-0.9	13	47.9	2.69
12	0	-14.6	-7.2	-3.4	-4.7	-0.2	-1	13.6	47.9	2.53
13	0	-18.8	-10.2	-6.5	-2.2	0.4	-0.9	13	38.3*	1.95
14	0	-15.3	-1.8	-14.4	0	-1	0	13.6	47.9	2.52
15	81	-0.1	-0.3	0.1	0	0	0	0.4	47.9	116.04
16	0	-0.1	-0.4	0.1	0	0	0	0.6	47.9	82.56

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.9-3 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Top Corner Drop, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-18.3	-6.7	-4.4	-3.4	-0.2	-0.9	14.9	47.9	2.22
2	0	-18.7	2.5	-3.1	-0.7	1	-0.3	21.4	47.9	1.24
3	126	0.4	-10.2	0.2	0.7	0.1	-0.4	11	47.9	3.35
4	0	-1.1	-0.5	2	0	-0.1	0.1	3.1	47.9	14.7
5	0	-0.5	-2.4	1.7	0	-0.3	0.1	4.2	47.9	10.38
6	0	-0.6	-1.5	2.1	0	0.2	0.3	3.7	47.9	12.08
7	180	0	-2.9	0	0	0	0	2.9	47.9	15.69
8	171	-0.1	-3.6	-0.4	0	0.2	0	3.5	47.9	12.78
9	0	-16.9	-0.1	-5.3	-1.9	0.5	-0.3	17.3	47.9	1.77
10	0	-14.5	-7.1	-3.4	-4.7	-0.2	-1	13.5	47.9	2.54
11	0	-18.7	-10.2	-6.5	-2.2	0.4	-0.9	13	47.9	2.70
12	0	-14.5	-7.1	-3.4	-4.7	-0.2	-1	13.5	47.9	2.54
13	0	-18.7	-10.2	-6.5	-2.2	0.4	-0.9	13	38.3*	1.96
14	0	-14.5	-1.6	-13.6	0.1	-0.9	0	13	47.9	2.69
15	90	-0.1	-0.3	0.1	0	0	0	0.4	47.9	116.24
16	0	-0.1	-0.4	0.1	0	0	0	0.6	47.9	84.45

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.9-4 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Bottom Corner Drop, Internal Pressure, Thermal Cold

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-6.3	-0.9	-1.9	0.1	0	-0.8	5.6	47.9	7.53
2	27	-0.2	-5	-1.4	-0.2	-0.1	-0.8	5.2	47.9	8.15
3	27	-0.2	-5.1	-1.3	0	-0.3	-0.6	5.2	47.9	8.20
4	0	-1	-1.5	2.8	0	0	-0.2	4.3	47.9	10.03
5	0	-1	-1.1	2.8	0	0	0.2	3.9	47.9	11.33
6	0	-0.9	-0.8	2.8	0	0	0.2	3.8	47.9	11.75
7	0	-0.9	-0.6	2.8	-0.2	0	0.2	3.7	47.9	11.81
8	0	-0.6	0.2	1.2	-1.1	0.4	0.1	2	47.9	22.65
9	0	-15.1	2.8	-4.7	-1.7	0.9	-0.2	18.3	47.9	1.62
10	0	-11.4	0.1	-4.1	0	0.9	-0.4	11.7	47.9	3.10
11	0	-15.9	1.7	-4.9	-0.3	1	-0.1	17.8	47.9	1.69
12	0	-13.7	-2.9	-3.8	-2.3	0.7	-0.8	12.2	47.9	2.95
13	0	-19.4	-5.9	-6.1	-1.4	1.1	-0.9	14.8	38.3*	1.58
14	0	-0.3	-0.4	0.2	0	0	0	0.6	47.9	85.16
15	81	0.7	0	0.9	0	0	0	0.9	47.9	51.95
16	45	-0.6	-0.1	-0.4	0	0	0	0.6	47.9	82.75

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.6.12.9-5 PWR Canister $P_m + P_b + Q$ Stresses - 1-Foot Bottom Corner Drop, Internal Pressure, Thermal Heat

Section Location	Angle of Peak Stress Location	$P_m + P_b + Q$ Stresses (ksi)						SI (ksi)	Allowable Stress (ksi)	Margin of Safety
		Sx	Sy	Sz	Sxy	Syz	Sxz			
1	0	-2.1	0	1.3	0	0.1	-0.1	3.5	47.9	12.79
2	162	0.1	-5.1	0.3	0.1	0	-0.1	5.4	47.9	7.87
3	162	0.1	-4.9	0.4	0	-0.1	-0.1	5.3	47.9	8.12
4	180	0	-3.7	1.2	0	0	-0.1	4.9	47.9	8.76
5	180	0	-3.8	1.5	0	-0.2	0	5.3	47.9	8.06
6	0	-0.5	-1.6	3.5	0	0.1	0.2	5.1	47.9	8.34
7	0	-0.9	-0.6	3.2	0	-0.1	0.3	4.1	47.9	10.82
8	0	-0.6	0.8	2	-0.1	0.6	0.3	2.9	47.9	15.7
9	0	-15.1	2.8	-4.7	-1.6	0.9	-0.2	18.3	47.9	1.62
10	0	-11.3	0.1	-4.1	0	0.9	-0.4	11.7	47.9	3.12
11	0	-15.9	1.7	-4.9	-0.3	1	-0.1	17.8	47.9	1.7
12	0	-13.7	-2.9	-3.8	-2.2	0.7	-0.8	12.1	47.9	2.95
13	0	-19.4	-5.9	-6.1	-1.4	1.1	-0.9	14.8	38.3*	1.59
14	0	-10	-4.9	-9.7	0	0.1	0	5.1	47.9	8.33
15	90	0.8	0	1	0	0	0	1	47.9	47.69
16	27	-0.6	-0.1	-0.3	0	0	0	0.6	47.9	79.93

* Allowable stress includes a stress reduction factor for weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

2.6.12.10 Shear Stresses for 1-Foot Drops

The primary mechanism for shear loading in the canister drop analyses occurs for the bottom end-drop in the canister structural and shield lid welds. The maximum stress intensity for Section 12 during the bottom end-drop is 0.8 ksi for the bottom end-drop with thermal heat (Table 2.6.12.5-5). The maximum shear is 0.8/2 = 0.4 ksi. The allowable shear is 0.6 S_m per the ASME Code, Section III, Subsection NB-3227.2 for pure shear loading. The maximum canister shell temperature is 399°F and the margin of safety for pure shear is

$$MS = (0.6 \times 15.8 / 0.4) - 1 = +22.7$$

2.6.12.11 Canister Bearing Stresses for 1-Foot Side Drop

The average bearing stress on the canister wall is computed for the side-drop using the smallest length of canister and the maximum mass for either the PWR or BWR canisters. This results in a conservatively bounding value of the average bearing stress. The maximum canister plus contents mass is for the BWR Class 5 with a weight of 75,896 lb. For contact of the canister wall with the inner shell over an 18° arc (conservative), the projected bearing width is 10.54 inch. The length of the shortest canister is 175.25 in (PWR Class 1). The average bearing stress is

$$\text{Bearing Stress} = 75{,}896 \text{ lb} \times 20g / (175.25 \text{ in} \times 10.54 \text{ in}) = 822 \text{ psi}$$

Based on a yield strength of 17.5 ksi at 400°F, the margin of safety is

$$MS = (17.5 / 0.822) - 1 = + \text{Large}$$

The bearing stress evaluation is presented for the regions under the shield lid and structural lid welds (see Sections 9, 10, and 11 in Figure 2.6.12.3-1) for the governing normal condition (one-foot side drop). The averaged stress components, Sx, in Sections 9, 10, and 11 of Table 2.6.12.6-2, are considered the bearing stresses at the weld region. The maximum bearing stress of 17.1 ksi occurs at Section 11.

The margin of safety is

$$MS = \frac{S_y}{\sigma_{bearing}} - 1 = +0.16$$

where:

S_y = 19.95 ksi, the yield stress of 304L at the peak temperature of 266°F in the lid region of the canister shell.

2.6.12.12 Canister Buckling Evaluation for 1-Foot End Drop

Code Case N-284-1 [12] of the ASME Boiler and Pressure Vessel Code is used to analyze the PWR canister for the normal condition 1-foot end drop (both top and bottom end drops). The evaluation requirements of Regulatory Guide 7.6, Paragraph C.5, are shown to be satisfied by the results of the buckling interaction equation calculations of Code Case N-284-1. The canister buckling design criteria are described in Section 2.1.2.5.3.

The data considered for the buckling evaluation includes shell geometry parameters, shell fabrication tolerances, shell material properties, theoretical elastic buckling stress values for the shell, and membrane stress components in the shell. The internal stress field that controls the buckling of a cylindrical shell consists of the longitudinal (axial) membrane, circumferential (hoop) membrane, and in-plane shear stresses. These stresses may exist singly or in combination, depending on the applied loading. Only these three stress components are considered in the buckling analysis.

A 20 g deceleration load was used for all the 1-ft drop canister analyses that are presented in Sections 2.6.12.4 through 2.6.12.9. The 20 g-load bounds all 1-ft deceleration loads for all other drop angles. The top- and bottom-end drops result in the largest potential for canister shell buckling and, therefore, are the two load cases presented here. The side drop load case is not considered a credible buckling mode of the canister shell and is, therefore, not presented here.

The stress results from the canister analysis are screened for the maximum values of the longitudinal compression, circumferential compression, or in-plane shear stresses for the 1-ft drop cases (top- and bottom-end drops) with and without pressure. For each loading case, the largest of each of the three stress components anywhere regardless of location within the PWR canister shell are combined. To these maximum stress components are added the maximum stresses from the hot and cold thermal cases (Tables 2.6.12.3-1 and 2.6.12.3-2). Combining the

Table 2.6.12.12-2 Buckling Evaluation Results for the PWR Canister for 1-Foot End Drop

Load Condition	Longitudinal (Axial) Stress* S_ϕ (psi)	Circumferential (Hoop) Stress* S_θ (psi)	In-plane Shear Stress $S_{\phi\theta}$ (psi)	Elastic Buckling Interaction Equations				Plastic Buckling Interaction Equations			
				Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1-Ft Top End Drop	2400	300	400	.009	.077	.066	.009	.077	.065	.077	.066
1-Ft Bottom End Drop	3600	600	300	.063	.115	.131	.064	.115	.131	.115	.131

Component stresses include thermal stresses.

* Compressive stresses

2.6.13 PWR Basket Analysis - Normal Conditions of Transport

The Universal Transport Cask PWR basket is a right-cylinder structure fabricated with 24 square fuel tubes, a number of circular support disks, a number of heat transfer disks, eight tie rods with spacers, and two end weldment plates. The number of support disks and heat transfer disks varies depending upon the class of PWR fuel basket. The basket components and their geometry are illustrated in Figure 2.6.13-1 and Figure 2.6.13-2. Figure 2.6.13-3 shows the details of the fuel tube with the encasing neutron absorber. The fuel tubes are open at each end; therefore, longitudinal fuel assembly loads are imparted to the canister shield lid or the bottom plate, and not the fuel basket structure. The fuel basket contains the fuel and is laterally supported by the canister shell.

The fuel assemblies together with the tubes are laterally supported in the holes in the stainless steel support disks. The aluminum heat transfer disks are located throughout the cavity to fully optimize the passive heat rejection from the package. They serve no structural function other than supporting their own weight. The dimensional differences between the heat transfer disk and the support disk accommodate the different rate of thermal growth between aluminum and stainless steel, thereby preventing interference between the tube, support disk, and heat transfer disks.

The primary function of the spacers and the threaded top nut is to locate and structurally assemble the support disks, heat transfer disks, and top and bottom weldment plates into an integral assembly. The spacers carry the inertial weight of the support disks, heat transfer disks, one end plate, and their own inertial weight for a normal transport condition 1-ft end-drop. The end-drop loading of the split spacers and tie rods represents a classical, closed-form structural analysis. The support disk requires a detailed finite element analysis for side-drop, end-drop, and oblique drops. The stainless steel fuel tubes are not considered to be a structural component with respect to the disks other than consideration of their mass contribution to loading.

The PWR fuel basket is evaluated for the normal transport loads in this section. End-drop, side-drop, oblique drop orientations are evaluated. The basket is evaluated for the hypothetical accident condition in Section 2.7.8.

Table 2.6.13.6-1 [Deleted]

Table 2.6.13.6-2 P_m Stresses for Support Disk—1-Foot Side-Drop, 0° Orientation, Thermal Case A

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
25	11.0	-9.2	0.0	20.2	43.9	1.17
107	-10.6	-13.2	8.1	20.1	44.5	1.21
123	-10.6	-13.2	-8.1	20.1	44.5	1.21
20	8.7	-7.3	0.0	16.0	43.0	1.70
29	0.0	-13.7	0.0	13.7	44.2	2.22
28	4.8	-6.9	3.2	13.4	43.9	2.28
26	4.8	-6.9	-3.2	13.4	43.9	2.28
27	-4.4	-12.5	0.0	12.5	43.9	2.51
2	6.1	-5.2	0.0	11.4	42.0	2.70
24	0.0	-11.4	0.0	11.4	43.5	2.81
22	-4.9	-10.4	0.0	10.4	43.1	3.16
21	2.8	-5.9	-2.6	10.1	43.0	3.25
23	2.8	-5.9	2.6	10.1	43.0	3.25
114	4.8	-5.3	-0.5	10.2	44.3	3.34
98	4.8	-5.3	0.5	10.2	44.3	3.34
30	-4.7	-9.6	0.0	9.6	44.5	3.63
19	0.0	-9.1	0.0	9.1	42.4	3.67
8	5.5	-3.1	0.0	8.6	43.1	3.99
4	-6.4	-7.9	0.0	7.9	42.0	4.30
31	-6.7	-6.2	1.7	8.2	44.5	4.45
32	-6.7	-6.2	-1.7	8.2	44.5	4.45
115	2.7	-5.2	-0.5	7.9	44.3	4.60
99	2.7	-5.2	0.5	7.9	44.3	4.60
112	2.7	-4.4	0.0	7.1	43.7	5.13
96	2.7	-4.4	0.0	7.1	43.7	5.13
95	2.5	-4.4	-0.2	6.9	43.7	5.32
111	2.5	-4.4	0.2	6.9	43.7	5.32
11	-6.9	-4.0	0.0	6.9	43.9	5.32
13	5.3	-1.3	0.0	6.6	43.9	5.64
6	-6.4	-5.9	0.0	6.4	43.0	5.74
5	0.0	-6.3	0.0	6.3	42.4	5.77
1	0.3	-4.5	-1.9	6.1	42.0	5.89
3	0.3	-4.5	1.9	6.1	42.0	5.89
110	6.2	-0.1	0.1	6.3	44.1	5.96
94	6.2	-0.1	-0.1	6.3	44.1	5.96
116	0.0	-6.1	0.0	6.1	43.4	6.16
100	0.0	-6.1	0.0	6.1	43.4	6.16
121	0.0	-5.9	-0.1	5.9	44.0	6.47
105	0.0	-5.9	0.1	5.9	44.0	6.47
7	-0.6	-3.2	-2.3	5.3	43.0	7.09

2.6.14 BWR Transportable Storage Canister Analysis - Normal Conditions of Transport

In this section, the Transportable Storage Canister Assembly containing BWR fuel is evaluated for the normal conditions of transport. The principal components of the canister assembly are the canister, fuel basket assembly, shield lid, and structural lid. The canister and the canister shell, bottom plate, and lids are shown in Figures 2.6.14-1 and 2.6.14-2.

Spacers are used to properly locate the canisters of different classes in the cask cavity. The analysis of the spacers is presented in Section 2.6.16. The geometries and materials of construction of the canister, baskets, and spacers are described in Section 1.2.1.2.

Figure 2.6.14-1 BWR Transportable Storage Canister

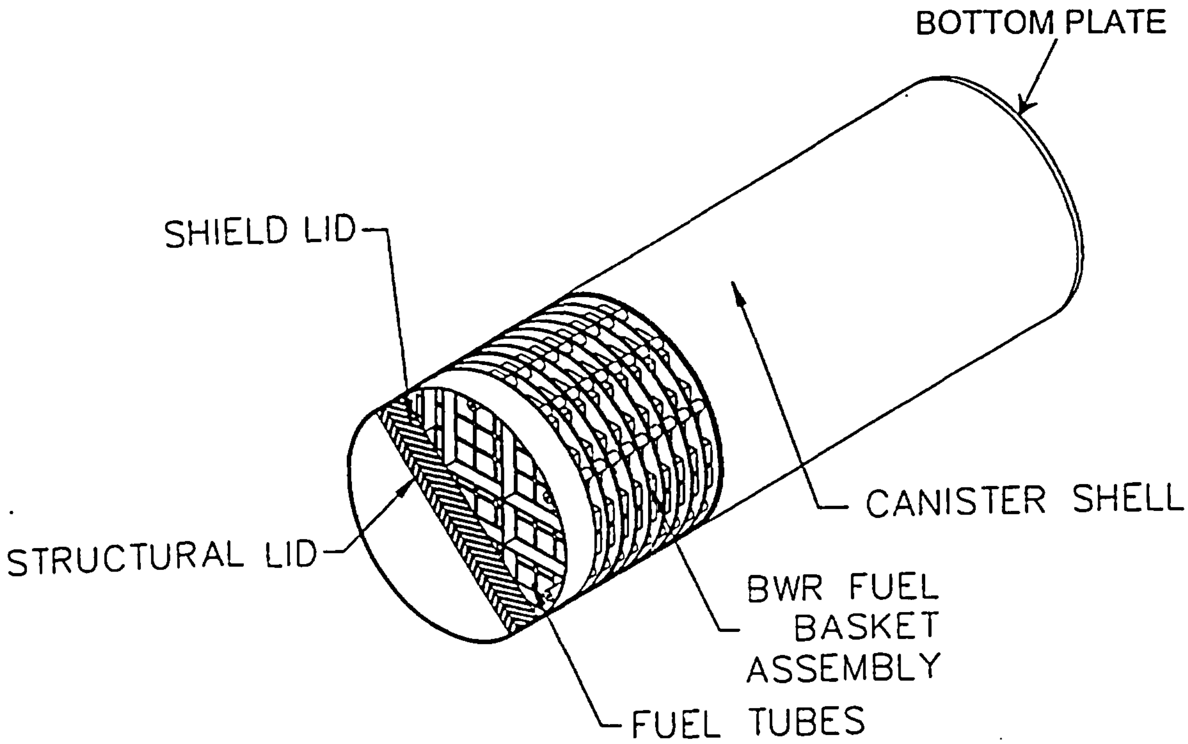
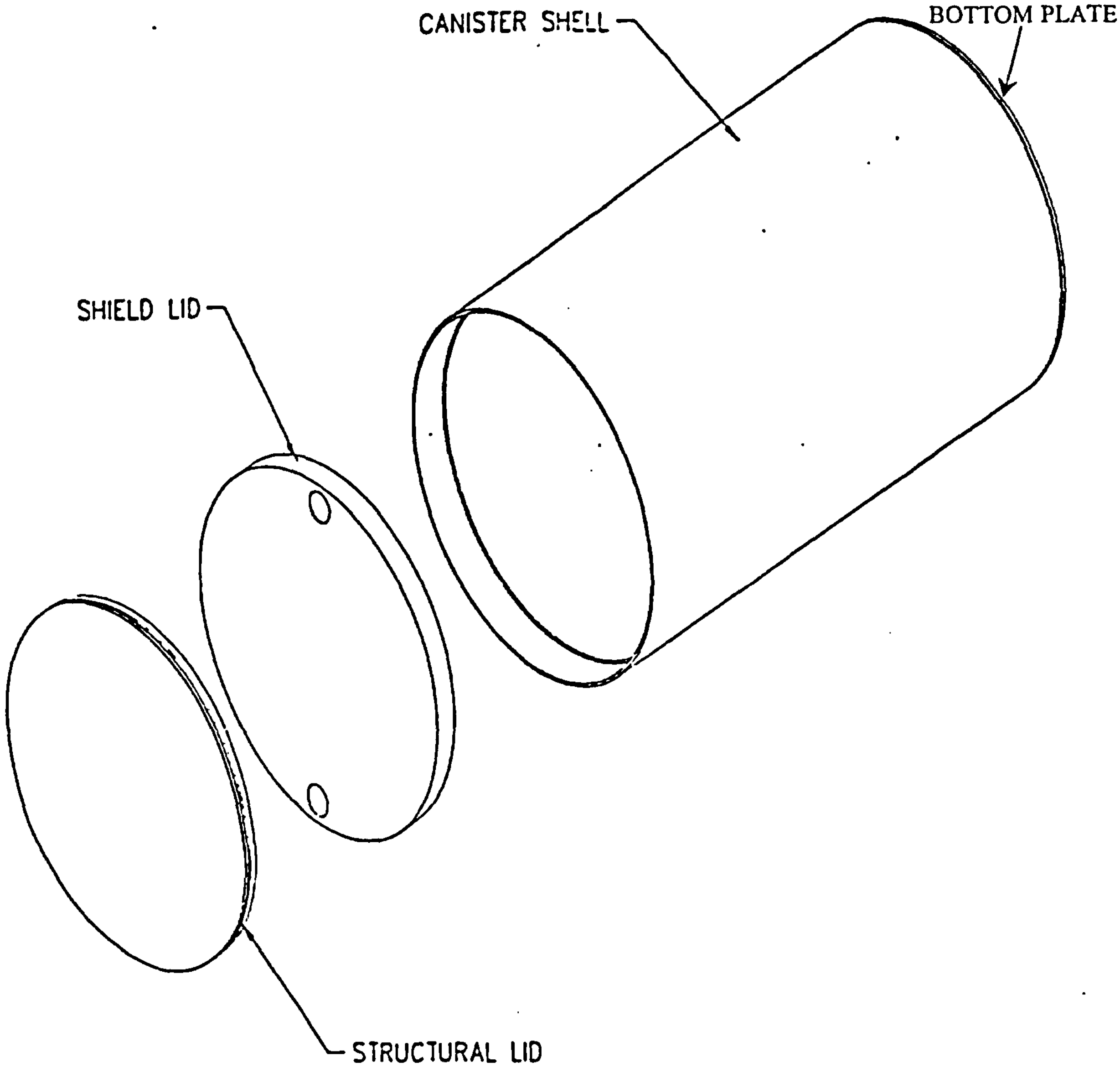


Figure 2.6.14-2 BWR Transportable Storage Canister Shell and Lids



2.6.14.1 Analysis Description

Two canister classes of different lengths accommodate the BWR fuel. The overall lengths of the two BWR canisters are 185.6 in and 190.4 inch. Other design parameters of the canisters are provided in Table 1.2-2. For this analysis, the largest load per disk configuration (BWR Class 4) is modeled with the longest canister of 191.80 inches.

As is the case for the PWR canister, the structural design criteria for the BWR canister is the ASME Code, Section III, Subsection NB. Consistent with this criterion, the structural components of the canister are shown to satisfy the allowable stress limits presented in Tables 2.1.2-3 and 2.1.2-4 as applicable. The allowable stresses used in this analysis are based on a maximum material temperature of 380°F for all locations in the canister, unless otherwise indicated. These allowables are conservative for all sections because the maximum temperature in the canister shell central region is determined to be 363°F in the thermal analysis presented in Section 3.4.2. For the canister structural lid weld (Section 13, Figure 2.6.12.3-1), base metal properties are used to define the allowable stress limits since the weld filler rod tensile properties are greater than the base metal. Also, the allowable stress is multiplied by a stress reduction factor of 0.8 per ISG-15 [49].

The ANSYS finite element computer program is used to analyze the canister for the 1-ft free-drop condition in the top and bottom end, side, and top and bottom corner-impact orientations. In addition, the effects of normal operating internal pressure and thermal stresses resulting from exposure of the cask to the hot (100°F ambient and solar insolance) and cold (-40°F ambient) normal conditions are evaluated. The worst-case stresses from these analyses are presented in Section 2.6.14.4.

2.6.14.2 Finite Element Model Description - BWR Canister

To evaluate the BWR Transportable Storage Canister for normal conditions of transport, ANSYS is used to construct and analyze a finite element model of the canister and its contents. The contents modeled consist of the fuel basket support disks and weldments. The fuel assemblies, fuel tubes, tie-rods, and related hardware are not explicitly modeled but are accounted for by applying pressure loads to the support disk slots as appropriate.

2.6.15 BWR Basket Analysis—Normal Conditions of Transport

The Universal Transport Cask BWR basket is similar in design to the PWR basket. It is a right-cylinder structure fabricated with 56 square fuel tubes, a number of circular support disks, a number of heat transfer disks, six tie rods with split spacers, and two end weldment plates. The number of support disks and heat transfer disks varies depending upon the class of BWR fuel basket. The basket components and their geometry are illustrated in Figure 2.6.15-1 and Figure 2.6.15-2. Figure 2.6.15-3 shows the details of the fuel tube with the encasing neutron absorber on two sides. The fuel tubes are open at each end; therefore, longitudinal fuel assembly loads are imparted to the canister shield lid or bottom plate, and not the fuel basket structure. The fuel basket contains the fuel and is laterally supported by the canister shell.

In the BWR basket, the fuel assemblies, together with the tubes, are laterally supported in the holes in the carbon steel support disks. The aluminum heat transfer disks located at the mid section of the cavity are used to fully optimize the passive heat rejection from the package and are self-supporting. The dimensional differences between the heat transfer disk and the support disk accommodate the different rate of thermal growth between aluminum and stainless steel, thereby preventing interference between the tube, support disk, and heat transfer disks.

The primary function of the spacers and the threaded top nut is the same as those in the PWR basket described in Section 2.6.13. As described in that section, the only component that requires a detailed finite element analysis is the support disk. The stainless steel fuel tubes are not considered to be structural components with respect to the disks other than consideration of their mass contribution to loading.

The basket support disk is designed to restrain 56 fuel assemblies, which would nominally fit into a 6.278 inch square slot. Since a populace of BWR fuel assemblies are not expected to fit into the 6.278 inch square, four oversized fuel assemblies slots are specified as 6.478 inch squares. This will reduce the thickness of the ligament at the outer most corner. However, the size of the web (.65 inch) is not changed. Therefore, the oversized slots will not affect the buckling calculations, since they pertain to the in-plane and out of plane buckling of the webs. In an inspection of the maximum stresses of the BWR basket, the ligament that contains the reduction due to the oversized slots, does not appear in the maximum stress summaries. The smallest ligament at the corner is still significantly controlled by the .8 inch ligament. Therefore, the use of oversized holes is not considered to alter the model of the BWR basket, which employs a slot size of 6.278 inches.

In this section, the BWR fuel basket is evaluated for the normal transport loads. As discussed in Section 2.6.13, the g-loads produced by the corner-drops are bounded by the g-loads produced by the end and side-drops. Therefore, only the end-drop and side-drop orientations are evaluated. The basket is evaluated for the hypothetical accident condition in Section 2.7.10.

Table 2.6.15.14-2 Minimum Margins of Safety from Buckling Evaluation of BWR Support Disk (Strong Axis)

Section No.	G-Load	Disk Drop Orientation	Heat Case	MS1	MS2
298	20	0	1	+2.95	+3.303
298	20	0	2	+3.0	+3.36
298	20	0	2 + thermal load	+1.97	+2.25
295	20	31.82	1	+1.82	+1.99
295	20	31.82	2	+1.96	+2.14
295	20	31.82	2 + thermal load	+1.52	+1.69
243	20	49.46	1	+1.98	+2.13
243	20	49.46	2	+2.00	+2.16
246	20	49.46	2 + thermal load	+1.44	+1.60
244	20	77.92	1	+2.56	+2.85
244	20	77.92	2	+2.64	+2.93
244	20	77.92	2 + thermal load	+1.79	+2.03
53	20	90	1	+5.56	+6.15
53	20	90	2	+5.49	+6.08
53	20	90	2 + thermal load	+3.42	+3.82

2.6.16 Universal Transport Cask Cavity Spacers

This section documents the design analysis of the spacers used to position the Transportable Storage Canisters containing PWR or BWR fuel in the Universal Transport Cask cavity during transport of fuel. The spacers are freestanding components that are placed at the bottom of the cask cavity below the canister bottom, and are confined by the end of the canister and the bottom inner surface of the Universal Transport Cask. The spacers are designed to maintain the centers of gravity of the canisters at the required distance from the bottom inner surface of the cask.

The following requirements bound the spacer design:

1. The spacers must meet the normal conditions of transport requirements detailed in 10 CFR 71.43(f) when subjected to the free drop (10 CFR 71.71).

2. The spacers must provide spacing of the canister so that the center of gravity of the cask and contents is maintained.

For impact loading conditions, the spacer is designed to meet the requirements of 10 CFR 71.43(f) for the 1-ft drop condition (10 CFR 71.71). 10 CFR 71.43(f) requires that no substantial reduction in the effectiveness of the package be experienced in normal conditions of transport. Classical analysis is used to demonstrate compliance with these requirements.

2.6.16.1 PWR Cask Cavity Spacers

The Class 1 and Class 2 Transportable Storage Canisters are located by one spacer. The Class 3 canisters have no spacers. The PWR spacer is a weldment made of Type 304 stainless steel, ASTM A 240, 3/8-in plate. The weldment consists of a base that is 67 in in diameter with 6 raised cylinders of different diameters welded to it. The six different diameters are: 12, 24, 32, 50, 56, and 65 inch. The lengths of the spacers used to locate the Class 1 and Class 2 canisters vary. The Class 1 spacer is 18.25 in long and the Class 2 spacer is 11.25 in long. A sketch of the PWR spacer is provided below.

$$MS = (46{,}200 \text{ psi}/25{,}993 \text{ psi}) - 1 = +0.78$$

To evaluate buckling the critical stress was determined and compared to the actual:

$$\sigma_{critical} = E((0.605 - 10^{-7}m^2)/(m(1 + 0.004\phi))$$

where:

E = modulus of elasticity for 304 SS @ 300°F---27 10^6 psi
$m = R/T$ = radius/thickness
$\phi = E/S_y$ for 304 SS = 27E6/20,000psi = 1,350 psi

$\sigma_{critical-1}$ = critical stress for each individual cylinder
$\sigma_{critical-1} = 27E6((0.605 - 10^{-7}(5.8125/0.375)^2)/((5.8125/0.375)(1 + 0.004(1350)) = 164{,}602$ psi
$\sigma_{critical-2} = 27E6((0.605 - 10^{-7}(11.8125/0.375)^2)/((11.8125/0.375)(1 + 0.004(1350)) = 80{,}894$ psi
$\sigma_{critical-3} = 27E6((0.605 - 10^{-7}(15.8125/0.375)^2)/((15.8125/0.375)(1 + 0.004(1350)) = 60{,}352$ psi
$\sigma_{critical-4} = 27E6((0.605 - 10^{-7}(24.8125/0.375)^2)/((24.8125/0.375)(1 + 0.004(1350)) = 38{,}295$ psi
$\sigma_{critical-5} = 27E6((0.605 - 10^{-7}(27.8125/0.375)^2)/((27.8125/0.375)(1 + 0.004(1350)) = 34{,}100$ psi
$\sigma_{critical-6} = 27E6((0.605 - 10^{-7}(32.3125/0.375)^2)/((32.8125/0.375)(1 + 0.004(1350)) = 29{,}257$ psi

The buckling evaluation produces a minimum margin of safety as follows:

$$MS = (38{,}295/17{,}516) - 1 = +1.19$$

The base disk of the canister spacer is evaluated to determine its ability to carry the loading of the canister. ANSYS Version 5.2 is used to construct a finite element model of the canister spacer. Plane 42 elements are used to represent the spacer. The model includes the bottom of the canister to minimize the bending experienced by the base disk. Link 1 elements are used to transmit the load from the canister bottom to the base disk.

A maximum stress intensity of 11,103 psi is calculated by ANSYS. Based on the maximum stress intensity a margin of safety is calculated as follows:

Allowable stress at 300°F = $0.7S_u$= 46,200 psi.

$$MS = (46,200/11,103) - 1 = +3.2$$

PWR Cask Cavity Spacers Normal Condition

The normal condition cask cavity spacer evaluation was performed by ratioing stresses based on the linear accident condition analysis results.

The compressive buckling load is calculated as

$$S_{1\text{-ft}} = (S_{30\text{-ft}})(20\text{ g}/60\text{ g}) = (17,106)(20\text{ g}/60\text{ g}) = 5,702\text{ psi}$$

The critical buckling allowable stress calculated earlier is 38,295 psi.

The minimum margin of safety for critical buckling is:

$$MS = \left(\frac{38.29516}{5.70216}\right) - 1 = +5.71$$

The maximum stress intensity in the canister spacer was calculated to be:

$$(SI)_{1\text{-ft}} = (SI)_{30\text{-ft}}\left(\frac{20g}{60g}\right) = 11,000\left(\frac{20}{60}\right) = 3,667\text{ psi}$$

The allowable stress (S_m) for the PWR spacer at 300°F is 20,000 psi. This results in the following margin of safety:

$$MS = \left(\frac{20,000\text{ psi}}{3,667\text{ psi}}\right) - 1 = +4.45$$

2.6.16.2 BWR Cask Cavity Spacers

Each Class 5 canister is located by one spacer. Class 4 canisters are located by 4 spacers. The lengths of the Class 4 and Class 5 canisters containing BWR fuel are 185.75 and 190.55 in, respectively. To maintain the centers of gravity of these canisters at the required distance from the bottom inner surface of the cask, spacers of 1.5 and 6 inches in length are designed to be placed at the bottom of the cask cavity below the canister bottom.

Table 2.7.3.1-1 Summary of Maximum Canister Pressures During Hypothetical Accident Conditions

Pressure Condition	Canister Internal Pressure (PWR)	Canister Internal Pressure (BWR)
Fire Accident and 100% Rod Failure	74.3 psig	43.8 psig
Pressure Used for Canister Analysis	80 psig	80 psig

Table 2.7.3.1-2 Summary of Maximum Cask Cavity Pressures During Hypothetical Accident Conditions

Pressure Condition	Cask Cavity Internal Pressure (PWR)	Cask Cavity Internal Pressure (BWR)
Fire Accident and 100% Rod Failure	69.3 psig	42.8 psig
Cask Lid Closure Analysis	80 psig	80 psig
Cask Body Finite Element Analysis	150 psig	150 psig

Table 2.7.3.1-3 PWR Canister P_m Stresses 80 psig Internal Pressure Accident Conditions

Section Location	P_m Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
	Sx	Sy	Sz	Sxy	Syz	Sxz			
1	5.7	-4.8	-6.6	-0.9	-0.1	-0.9	12.4	38.4	2.09
2	1.2	0.3	-8.8	1.4	-0.2	-0.8	11.1	38.4	2.46
3	-0.1	2.3	4.2	0	0	0.3	4.3	38.4	7.88
4	-0.1	2.1	4.2	0	0	0.3	4.4	38.4	7.77
5	-0.1	2.1	4.2	0	0	0.3	4.4	38.4	7.74
6	-0.2	2	4.2	0	0	0.3	4.4	38.4	7.69
7	-0.1	2.1	2	0	0.2	0.3	2.4	38.4	14.92
8	-1.1	2.1	0.9	-0.4	0.2	0	3.3	38.4	10.77
9	1.0	1.6	0.2	-0.1	-0.2	-0.3	1.5	38.4	24.57
10	0.6	1.0	-0.6	0.1	0.2	-0.4	1.8	38.4	20.19
11	1.1	-0.2	0.5	0.1	0	0	1.3	38.4	28.50
12	-0.4	-1.4	0.1	-0.4	0	0	1.6	38.4	22.97
13	0	1	0.6	0.1	0	0.1	1	30.7*	29.12
14	-0.2	0	-0.1	0	0	0	0.1	38.4	304.11
15	0.1	0	0.1	0	0	0	0.1	38.4	266.45

* Allowable Stress includes reduction factor for weld (0.8 x Allowable Stress).

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.7.3.1-4 PWR Canister $P_m + P_b$ Stresses 80 psig Internal Pressure Accident Conditions

Section Location	$P_m + P_b$ Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
	Sx	Sy	Sz	Sxy	Syz	Sxz			
1	8.2	20.1	1.4	0.3	0.1	-0.3	18.7	57.5	2.08
2	2.5	-36.8	-16.9	-2.5	-0.2	-1.5	39.7	57.5	0.45
3	1.5	-43.3	-20.4	0.2	-0.4	-3.6	45.4	57.5	0.27
4	-0.1	2.4	4.5	0	0	0.3	4.7	57.5	11.33
5	-0.1	2.1	4.2	0	0	0.3	4.4	57.5	12.09
6	-0.2	2.1	4.4	0	0	0.4	4.6	57.5	11.46
7	-0.2	2.1	4.6	0	0	0.4	4.9	57.5	10.69
8	-0.1	2.4	2.6	-0.1	0.3	0.3	3	57.5	18.39
9	1.4	3	0.3	-0.1	-0.4	-0.4	2.9	57.5	18.63
10	0.7	4.5	0.7	-0.1	-0.1	-1.1	4.9	57.5	10.79
11	0.6	-2.9	-0.4	0.1	0	-0.1	3.5	57.5	15.68
12	-1	-2.5	-0.4	-0.6	0	0.1	2.4	57.5	23.27
13	-1.4	-0.3	-0.2	0.1	0	0.2	1.3	46*	34.38
14	24.7	-2	24.7	-0.1	0.3	-0.1	26.7	57.5	1.15
15	-1.8	0	-1.8	0	0	0	1.8	57.5	31.5

* Allowable Stress includes reduction factor for weld (0.8 x Allowable Stress).

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.6.12.1.

Table 2.7.3.1-5 BWR Canister P_m Stresses 80 psig Internal Pressure Accident Conditions

Section Location	P_m Stresses (ksi)						Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
	Sx	Sy	Sz	Sxy	Syz	Sxz			
1	-1	6.1	2.1	-1.1	0.1	0.1	7.5	38.4	4.15
2	2.6	-4.1	-7.1	-1.3	0	-0.7	10	38.4	2.83
3	1.8	-2.6	-8.2	-0.6	0	-0.7	10.2	38.4	2.76
4	-0.1	2	4.2	0	0	0.3	4.3	38.4	7.91
5	-0.1	2	4.2	0	0	0.3	4.3	38.4	7.95
6	-0.1	2	4.2	0	0	0.3	4.3	38.4	7.95
7	-0.1	2	4.2	0	0	0.3	4.3	38.4	7.94
8	-0.1	2.2	2	-0.1	0.1	0.2	2.4	38.4	14.79
9	-1	2.1	0.9	-0.4	0.1	0	3.3	38.4	10.75
10	-3.8	0.6	0	-0.8	0.1	0	4.7	38.4	7.19
11	1.1	-0.2	0.5	0	0	-0.1	1.3	38.4	28.71
12	-2.4	-1.6	-0.2	-1.1	0	-0.1	2.9	38.4	12.09
13	-0.8	0.5	0.4	-0.1	0	0	1.3	30.72†	22.63
14	1.1	-0.8	1.1	-0.1	-0.1	0	1.9	38.4	18.9
15	-0.2	0	-0.1	0	0	0	0.1	38.4	313.1
16	0.1	0	0.1	0	0	0	0.1	38.4	281.21

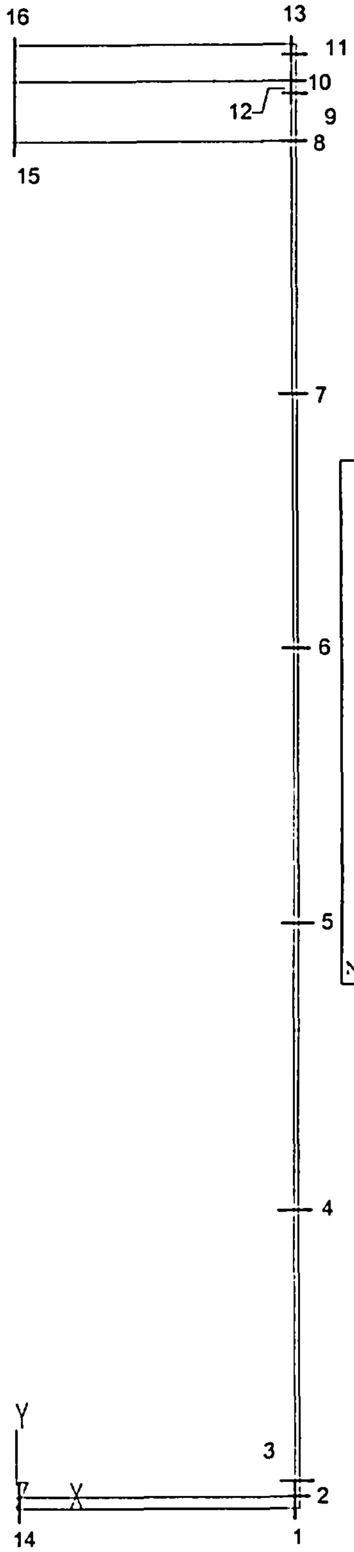
†Allowable Stress includes reduction factor for weld (0.8 x Allowable Stress).

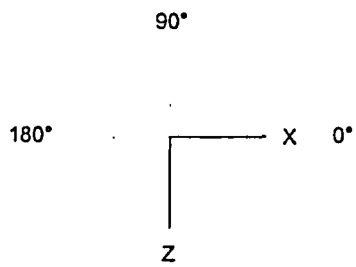
The section stresses presented in the tables are identified by a section number. The minimum margin at each section is presented by denoting the circumferential angle where the minimum margin of safety occurs. A cross section of the canister showing the section numbers is presented in Figure 2.7.7.2-1. Stresses are evaluated at 9° increments around the circumference for each of the locations shown in Figure 2.7.7.2-1. The minimum margin is denoted by an angular location at each section. The canister minimum margins of safety for the evaluated drop conditions are summarized in Table 2.7.7.2-11.

The methodology used to evaluate the stresses for the side-drop are identical to that used for the normal conditions 1-ft side drop for the PWR canister (Section 2.6.12.6). Sections 9, 10, and 11 at the 0° and 9° circumferential positions (see Figure 2.6.12.3-1) are not included in the evaluation. These regions are characterized as a bearing stress since they result from the canister shell bearing against cask inner shell. An evaluation of these bearing stresses is not required for accident conditions. Results for Sections 9, 10, and 11 at angular locations other than 0° and 9° are included in the evaluation.

The allowable stresses presented in the tables are for Type 304L stainless steel. Because the shield lid is constructed of Type 304 stainless steel, which possesses higher allowable stresses, a conservative evaluation results. These allowables are evaluated at 380°F, unless otherwise indicated. Review of the thermal analyses shows that the maximum temperature of the canister is 399°F (Section 3.4.2), which occurs in the center portion of the canister wall (Sections 5 and 6 described in Figure 2.7.7.2-1). The impact of this temperature increase is addressed by evaluating the margins presented at Sections 5 and 6 where the peak temperature occurs. The minimum margin for all the accident cases considered at Sections 5 or 6 is 4.41, which occurs for the 30-ft bottom-corner drop plus internal pressure. The allowable S_m for Type 304L stainless steel is reduced from 16.0 ksi to 15.8 ksi at 400°F. The margin of safety for this case would be reduced to 4.34. Therefore, the increased peak temperature in the center of the canister will have a negligible impact on the presented minimum margins of safety.

Figure 2.7.7.2-1 Identification of the Sections for Evaluating the Linearized Stresses in the PWR Canister





Top View of Axis

Section Coordinates at Z = 0

Axial Section	Node 1 x	Node 1 y	Node 2 x	Node 2 y
1	32.905	0.0	32.905	1.75
2	32.905	1.75	33.53	1.75
3	32.905	2.25	33.53	2.25
4	32.905	34.15	33.53	34.15
5	32.905	66.55	33.53	66.55
6	32.905	98.95	33.53	98.95
7	32.905	131.35	33.53	131.35
8	32.905	163.75	33.53	163.75
9	32.905	170.38	33.53	170.38
10	32.905	170.75	33.53	170.75
11	32.905	173.00	33.53	173.00
12	32.905	170.38	32.905	170.75
13	32.905	173.00	32.905	173.75
14	0.1	0.0	0.1	1.75
15	0.1	163.75	0.1	170.73
16	0.1	170.75	0.1	173.75

Note: Dimensions in inches.

Table 2.7.7.2-1 PWR Canister P_m Stresses - 30-Foot Side-Drop - 45° Basket Orientation

		P_m Stresses (ksi)								
Section Location	**Angle of peak stress location**	**Sx**	**Sy**	**Sz**	**Sxy**	**Syz**	**Sxz**	**SI (ksi)**	**Allow. Stress (ksi)**	**Margin of Safety**
1	0	-20.6	0.4	-12.6	-0.2	-0.3	-1.6	21.3	38.4	0.8
2	0	-15.4	0.4	-12.8	-1.2	-0.9	-0.7	16.3	38.4	1.36
3	0	-4.2	-0.1	-8.9	-0.4	-1.2	-0.9	9.3	38.4	3.11
4	108	-0.2	-2.2	0	2.1	-0.7	0.1	4.8	38.4	7.01
5	9	-2.1	2.1	0.3	0	0	0.4	4.2	38.4	8.03
6	9	-2.1	2.6	0.2	0	-0.1	0.4	4.7	38.4	7.1
7	9	-2.3	2.4	1	0	-0.3	0.5	4.9	38.4	6.9
8	72	0	-0.8	0	-4.5	-1.5	-0.1	9.5	38.4	3.03
9	18	5.2	5.1	0.9	2.7	3	-3.8	11.2	38.4	2.41
10	18	6.2	4.4	-1	-0.2	1.8	-3.1	10.2	38.4	2.76
11	18	6.2	1.8	-1.3	0.1	1.6	-3.7	11.1	38.4	2.46
12	18	3.6	-1.8	-3.6	1.8	0.5	-5.8	14.2	38.4	1.71
13	18	3.3	2.1	-3.9	0.1	0.9	-4.3	11.3	30.7*	1.72
14	0	-2.9	0	1	0	0	-0.1	3.8	38.4	8.98
15	0	-1	0	0.4	-0.1	0	0	1.3	38.4	27.49
16	0	-1.6	0	0.4	0	0	0	2	38.4	18.25

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-2 PWR Canister $P_m + P_b$ Stresses - 30-Foot Side-Drop - 45° Basket Orientation

		$P_m + P_b$ Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-23.9	-0.1	-14.1	0.8	0.1	-1.6	24.1	57.5	1.39
2	0	-17.1	1.1	-10.9	-1.7	-0.9	-1.3	18.8	57.5	2.06
3	45	-3.5	-17.8	-3.6	1.6	1.3	-4.2	18.9	57.5	2.05
4	9	-2.3	0.9	3.6	0.1	0.4	0.9	6.3	57.5	8.19
5	9	-2	2.8	2.4	0	0	0.7	4.9	57.5	10.71
6	9	-2	3.3	2.4	0	-0.1	0.7	5.4	57.5	9.62
7	9	-2.3	3	3	0	-0.3	0.8	5.8	57.5	8.88
8	72	0.1	-0.8	0	-5.5	-1.9	-0.1	11.7	57.5	3.91
9	18	2.6	-1.6	-2.3	1.7	2.1	-5.7	13.8	57.5	3.17
10	18	4.5	-4.2	-4.8	1.6	0.8	-5.1	14.4	57.5	2.98
11	18	7.8	5.5	-0.7	-0.2	2.2	-4.9	13.6	57.5	3.23
12	18	4.7	-3.2	-4.8	1.5	0	-5.7	15.1	57.5	2.81
13	18	7	4.8	-1.8	0	1.8	-4.8	13.4	46*	2.43
14	0	-2.9	0	1	0	0	-0.1	3.8	57.5	13.95
15	0	-1.9	0	-0.6	-0.1	0	0	1.9	57.5	29.9
16	0	-1.2	0	0.9	0	0	0	2	57.5	27.23

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-3 PWR Canister P_m Stresses - 30-Foot Bottom End-Drop - Internal Pressure

		P_m Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	180	0	-2.6	-0.4	0.2	0.1	0	2.6	38.4	13.85
2	180	0.7	-6.3	-1.1	0.3	0.1	0.1	7.1	38.4	4.43
3	180	0.1	-6.9	-1.2	0	0.1	0.1	7	38.4	4.49
4	180	0	-6.3	1.3	0	0	-0.1	7.7	38.4	4.01
5	180	0	-5.8	1.3	0	0	-0.1	7.1	38.4	4.41
6	180	0	-5.2	1.3	0	0	-0.1	6.5	38.4	4.88
7	180	0	-4.6	1.3	0	0	-0.1	6	38.4	5.44
8	81	0.7	-3.1	0.1	0	-0.1	0.1	3.8	38.4	9.03
9	162	-0.6	-1.9	-1.7	0.4	0.1	0.4	1.7	38.4	22.24
10	180	1.5	-1.2	-1.1	-0.3	0	0.2	2.8	38.4	12.7
11	0	-1.8	0.5	-0.9	-0.2	0	0	2.3	38.4	15.39
12	0	0.7	1.9	-0.4	0.3	0.1	-0.1	2.4	38.4	14.98
13	180	0.2	-1.7	-1	0.2	0	0.1	1.9	30.7*	15.08
14	0	0.1	-1.1	0.1	0	0	0	1.2	38.4	30.57
15	171	0.2	-0.1	0.2	0	0	0	0.2	38.4	186.72
16	90	-0.2	0	-0.2	0	0	0	0.2	38.4	223.94

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-4 PWR Canister $P_m + P_b$ Stresses - 30-Foot Bottom End-Drop - Internal Pressure

		$P_m + P_b$ Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	180	0.4	-2.9	-0.2	0.3	0.1	0	3.4	57.5	16.11
2	180	0.4	-9.5	-2.1	0.1	0.1	0.2	9.9	57.5	4.84
3	180	0.1	-8.9	-1.8	-0.1	0.1	0.1	9	57.5	5.39
4	180	0	-6.3	1.3	0	0	-0.1	7.7	57.5	6.49
5	0	0	-5.8	1.3	0	0	0.1	7.1	57.5	7.1
6	180	0	-5.2	1.3	0	0	-0.1	6.5	57.5	7.8
7	180	0	-4.6	1.3	0	0	-0.1	6	57.5	8.64
8	90	0.6	-3.4	0.3	0	-0.2	0	4.1	57.5	13.03
9	135	-1.5	-4.2	-1.5	0.5	0.5	1	3.9	57.5	13.60
10	72	-2.5	-6.2	0.3	-0.1	0.3	-1	6.8	57.5	7.44
11	0	-1	5.1	0.7	-0.3	0	0.1	6.1	57.5	8.48
12	0	2.3	3.4	0.5	1	0.1	-0.1	3.4	57.5	15.77
13	180	2.7	0.6	0.3	0.3	0	0.2	2.4	46.0*	18.25
14	0	0.1	-1.2	0.1	0	0	0	1.3	57.5	43.49
15	81	3.6	0	3.6	0	0	0	3.6	57.5	14.82
16	81	-1.8	0	-1.8	0	0	0	1.8	57.5	31.14

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-5 PWR Canister P_m Stresses - 30-Foot Top End-Drop

		P_m Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-0.4	-5.9	-2.2	0.8	0	-0.1	5.8	38.4	5.65
2	0	-3.8	3.7	5.5	0.9	-0.1	0.6	9.5	38.4	3.03
3	0	-0.8	0.1	7.6	-0.7	0.1	0.6	8.9	38.4	3.31
4	135	0	-2.2	0	0	0	0	2.2	38.4	16.27
5	153	0	-2.8	0	0	0	0	2.8	38.4	12.75
6	153	0	-3.4	0	0	0	0	3.4	38.4	10.43
7	180	0	-3.9	0	0	0	0	3.9	38.4	8.77
8	180	0.1	-3.7	0.1	-0.1	0	0	3.8	38.4	9.07
9	180	0	-2.7	-0.4	-0.1	0	0	2.7	38.4	13.26
10	27	-0.2	-2.6	-0.4	0	0	-0.2	2.6	38.4	14.04
11	144	-0.2	-2.6	-0.3	0	0	0.2	2.5	38.4	14.10
12	153	-0.1	-2.1	-0.2	-0.1	0	0.1	2.1	38.4*	17.26
13	0	0	-2.1	-0.3	0	0	0	2.1	30.7*	13.49
14	90	-0.7	0	-0.7	0.2	-0.4	0	1.1	38.4	35.05
15	153	0	-1	0	0	0	0	1.1	38.4	35.42
16	0	0	-1.1	0	0	0	0	1.2	38.4	31.89

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-6 PWR Canister $P_m + P_b$ Stresses - 30-Foot Top End-Drop

		$P_m + P_b$ Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-4.3	-14.2	0.2	0.1	-0.1	0.2	14.4	57.5	2.99
2	0	-1.9	27.1	13	2	-0.1	1.1	29.4	57.5	0.96
3	0	-1.6	32.5	16.9	-0.1	0	1.4	34.2	57.5	0.68
4	162	0	-2.3	0	0	0	0	2.3	57.5	24.44
5	153	0	-2.8	0	0	0	0	2.8	57.5	19.63
6	171	0	-3.4	0	0	0	0	3.4	57.5	16.14
7	180	0	-3.9	0	0	0	0	3.9	57.5	13.64
8	180	0.3	-3.6	0.1	-0.2	0	0	3.9	57.5	13.71
9	135	-0.3	-3	-0.3	0	0	0.2	3	57.5	18.44
10	0	0	-2.9	-0.5	0	0	0	2.9	57.5	18.63
11	36	-0.2	-2.9	-0.4	0	0	-0.2	2.9	57.5	18.77
12	180	0.2	-2	-0.2	-0.2	0	0	2.2	57.5	25.15
13	0	-0.1	-2.2	-0.3	0	0	0	2.2	46*	20.40
14	90	-20.4	-0.3	-20.4	0.2	-0.4	0	20.2	57.5	1.85
15	81	0.3	-1	0.3	0	0	0	1.3	57.5	44.4
16	0	0.1	-1.1	0.1	0	0	0	1.2	57.5	47.14

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-7 PWR Canister P_m Stresses - 30-Foot Bottom Corner-Drop

		P_m Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-15	-3.3	-6.1	-0.5	-0.1	-1.9	12.1	38.4	2.16
2	18	2.2	-8.7	-1.1	0.3	-0.8	-1.9	11.9	38.4	2.23
3	27	-0.2	-9.3	-2.7	0.6	-0.1	-1.1	9.6	38.4	2.99
4	0	-0.4	-6.9	0.3	0	0.1	0.4	7.4	38.4	4.19
5	180	0	-6.8	-0.2	0	0	0	6.8	38.4	4.68
6	180	0	-6.5	-0.2	0	0	0	6.5	38.4	4.92
7	180	0	-5.8	-0.2	0	0	0	5.8	38.4	5.62
8	54	0.1	-3.5	0.1	-0.8	-0.7	0	4.1	38.4	8.26
9	0	-27.7	1.7	-9.5	-3.1	1.6	-0.2	30.3	38.4	0.27
10	0	-17.4	0	-6.6	-3.4	1.2	-0.5	19	38.4	1.02
11	0	-35	-0.7	-11.4	-1	1.9	-0.3	34.7	38.4	0.1
12	0	-23	-5.1	-7.2	-4.9	1	-1	20.8	38.4	0.84
13	0	-23.9	-5.8	-6.7	-0.9	1.2	-1.8	19.3	30.7*	0.59
14	0	-1.1	-1	0.4	0	0	0	1.5	38.4	24.48
15	0	-0.2	0	0.3	0	0	0	0.5	38.4	81.71
16	0	-0.9	0	0	0	0	0	0.9	38.4	43.06

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-8 PWR Canister $P_m + P_b$ Stresses - 30-Foot Bottom Corner-Drop

		$P_m + P_b$ Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-16.3	-2	-6.2	0.8	0.1	-2	14.8	57.5	2.89
2	18	0.4	-18.8	-3.5	-0.1	-0.1	-2	20	57.5	1.87
3	27	-0.8	-18	-4.6	0.1	-1.1	-2.1	18.2	57.5	2.15
4	0	-0.4	-6.1	2.8	0	0.1	0.7	9	57.5	5.37
5	0	-0.4	-4.8	2.6	0	0	0.6	7.5	57.5	6.64
6	0	-0.5	-3.9	2.6	0	0	0.5	6.6	57.5	7.76
7	0	-0.4	-3.2	2.6	0	0	0.6	5.9	57.5	8.81
8	18	0.4	-2.7	-1.3	1	1.8	-0.7	5	57.5	10.54
9	0	-28.4	7.2	-10.1	-2.6	1.8	0.4	36.2	57.5	0.59
10	0	-17.7	1.9	-8.4	-1	1.8	-0.2	20	57.5	1.88
11	0	-31.3	7.8	-9.7	0.2	1.9	0.5	39.3	57.5	0.46
12	0	-26.7	-6	-9.1	-4.2	1.4	-1.1	22.9	57.5	1.51
13	0	-36.1	-13	-12.5	-2.3	1.6	-0.9	25.4	46*	0.81
14	0	-1	-1	0.5	0	0	0	1.5	57.5	37.12
15	81	3.9	0	4.3	0	0	0	4.3	57.5	12.39
16	0	-2.7	0	-1.9	0	0	0	2.7	57.5	20.31

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-9 PWR Canister P_m Stresses - 30-Foot Top Corner-Drop

		P_m Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	9	-2.1	-7	-4.8	0.7	-1.1	-1	5.9	38.4	5.53
2	0	-38	-1.4	-10.4	-5.2	0.7	-0.2	38.1	38.4	0.01
3	0	-12.1	-2.5	-2.6	-5.3	0.5	-0.3	14.5	38.4	1.65
4	180	0	-2.7	-0.2	0	0	0	2.7	38.4	13.07
5	180	0	-3.5	-0.2	0	0	0	3.5	38.4	9.89
6	180	0	-3.9	-0.2	0	0	0	3.9	38.4	8.82
7	72	0.1	-3.5	0	-0.9	-0.3	0	4.1	38.4	8.39
8	45	0.1	-3.9	0.1	-1.1	-1.2	0.1	5.2	38.4	6.31
9	0	-29	-4	-9.8	-3.5	0.8	-0.1	26.1	38.4	0.47
10	0	-23.3	-8.6	-8.8	-4.8	0.1	-0.4	17.6	38.4	1.18
11	0	-30.7	-13.8	-11.9	-2	0.6	-0.6	19.3	38.4	0.99
12	0	-26.9	-13	-8.8	-6.7	0.2	-1	21.0	38.4	0.83
13	0	-27.4	-16.6	-8.9	-2.3	0.4	-1.5	19.2	30.7*	0.60
14	90	-1.4	0	-0.3	0.1	-0.3	0	1.7	38.4	21.81
15	0	-0.4	-1	0.1	0	0	0	1.1	38.4	33.99
16	0	-0.6	-1.1	0.2	0	0	0	1.3	38.4	29.2

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-10 PWR Canister $P_m + P_b$ Stresses - 30-Foot Top Corner-Drop

		$P_m + P_b$ Stresses (ksi)								
Section Location	Angle of peak stress location	Sx	Sy	Sz	Sxy	Syz	Sxz	SI (ksi)	Allow. Stress (ksi)	Margin of Safety
1	0	-28.1	-15.6	-10.7	-7.5	-0.1	-1.1	21.2	57.5	1.71
2	0	-37.9	17.6	-5.7	-2.1	1.6	0.5	55.8	57.5	0.03
3	180	-1.4	29.4	15.6	0.1	0	-1.3	30.9	57.5	0.86
4	27	0.3	-1.7	-2.1	0	-0.1	-1.4	3.7	57.5	14.66
5	0	-0.4	-0.9	2.6	0	0	0.6	3.6	57.5	15.02
6	0	-0.4	-1.6	2.6	0	-0.1	0.6	4.3	57.5	12.39
7	0	-0.4	-2.5	2.8	0	-0.1	0.7	5.4	57.5	9.58
8	45	0.4	-3.8	0.4	-1.3	-1.6	0.2	6	57.5	8.53
9	0	-30	1.4	-10.5	-2.6	0.8	0.4	31.8	57.5	0.81
10	0	-24	-12.1	-7.7	-8.6	-0.2	-0.7	21.1	57.5	1.73
11	0	-33.7	-17.7	-12.3	-3.5	0.7	-1.2	22.5	57.5	1.56
12	0	-26.3	-14.2	-8.4	-8.5	-0.2	-0.9	22.4	57.5	1.56
13	0	-30.9	-19.8	-10.8	-4.3	0.5	-1.2	21.8	46*	1.11
14	72	-19.1	-0.3	-17.3	0.1	-0.3	0	18.8	57.5	2.06
15	72	-0.2	-0.9	0.4	0	0	0	1.3	57.5	43.02
16	0	-0.6	-1	0.3	0	0	0	1.3	57.5	43.39

* Allowable stress includes a stress reduction factor for the weld: 0.8 x allowable stress.

Note: All of the allowable stress values presented in this table are based on SA240, Type 304L stainless steel at a temperature of 380°F unless otherwise stated. Localized peak temperatures in the central portion of the canister shell reach 408°F—resulting in slightly lower allowable stress values and subsequently slightly lower margins of safety for sections 5 and 6 than those presented in the table. However, this difference is negligible as discussed in Section 2.7.7.2.

Table 2.7.7.2-11 Summary of Minimum Margins of Safety for PWR Canister - 30-Foot Drops

Drop Orientation	Loading Condition	Stress Evaluated	Min. Margin of Safety	Section No.*
Side	30-ft impact (45 degree basket)	P_m	0.8	1
Side	30-ft impact (45 degree basket)	$P_m + P_b$	1.39	1
Bottom end	30-ft impact + pressure (25 psi)	P_m	4.01	4
Bottom end	30-ft impact + pressure (25 psi)	$P_m + P_b$	4.84	2
Top end	30-ft impact	P_m	3.03	2
Top end	30-ft impact	$P_m + P_b$	0.68	3
Bottom Corner	30-ft impact	P_m	0.10	11
Bottom Corner	30-ft impact	$P_m + P_b$	0.46	11
Top Corner	30-ft impact	P_m	0.01	2
Top Corner	30-ft impact	$P_m + P_b$	0.03	2

* See Figure 2.7.7.2-1 for section locations.

2.7.7.3 Canister Buckling Evaluation for 30-Foot End Drop

Code Case N-284-1 [12] of the ASME Boiler and Pressure Vessel Code is used to analyze the PWR canister for the accident condition 30-foot end drop (both top and bottom end drops). The evaluation requirements of Regulatory Guide 7.6, Paragraph C.5, are shown to be satisfied by the results of the buckling interaction equation calculations of Code Case N-284-1. The canister buckling design criteria are described Section 2.1.2.5.3.

The PWR canister for the 30-foot end drop is evaluated for buckling in the same manner as the PWR canister for the 1-foot end drop (see Section 2.6.12.12). The analytical process used for the PWR canister is the same as that described in a step-by-step example presented in Section 2.7.12.3 (for the cask inner shell).

A 60 g deceleration load was used for all the 30-ft drop canister analyses that are presented in Sections 2.7.7.2. The 60 g-load bounds all 30-ft deceleration loads for all other drop angles. The top- and bottom-end drops result in the largest potential for canister shell buckling and, therefore, are the two load cases presented here. The side drop load case is not considered a credible buckling mode of the canister shell and is, therefore, not presented here.

The stress results from the dynamic shell analyses (ANSYS) are screened for the maximum values of the longitudinal compression, circumferential compression, or in-plane shear stresses for the 30-ft drop cases (top- and bottom-end drops) with and without pressure. For each loading case, the largest of each of the three stress components anywhere regardless of location within the PWR canister shell are combined. Combining the maximum stress components in this way produces a conservative, bounding-case buckling evaluation of the PWR canister, one which envelopes all 30-ft PWR canister drop cases including those presented in Tables 2.7.7.2-3 and 2.7.7.2-5.

The geometry parameters used in the PWR canister evaluation are the same as those presented in Table 2.6.12.12-1.

2.7.8 PWR Basket Analysis - Accident Conditions

The PWR fuel basket in the Transportable Storage Canister is designed to contain up to 24 PWR fuel assemblies. The basket structure has a right-circular cylinder configuration and consists of 24 square tubes supported by circular support disks and a circular top and bottom plate that are retained by eight axial tie rods. The number of support disks provided in the basket varies, depending upon the fuel basket class (Class 1, 2, or 3).

The support disks and top and bottom plates are separated and supported by split spacers at the tie rods. The configuration of the basket is shown in Figure 2.6.13-1. Design of the basket and its components is discussed in detail in Chapter 1.0.

The PWR fuel basket is evaluated for hypothetical accident loads in this section (evaluation of the basket for loads under normal conditions of transport is presented in Section 2.6.13). Both stress analyses and buckling evaluations are performed and documented in the subsequent sections. The structural analysis of the basket components is in accordance with the ASME Code, Section III, Division 1, Subsection NG [15]. In addition, the stainless steel/neutron absorber composite fuel tube is evaluated for a postulated impact load.

The fuel tubes are not structural components and are not considered in the basket evaluation. The tie rods and spacers locate and structurally assemble the circular support disks, heat transfer disks, and top and bottom plates to form an integral assembly. The spacers carry the weight of the support disks, heat transfer disks, and endplate and their own weight in the 30-ft end-drop accident loading condition. The end-drop loading condition of the spacers is a classical, closed-form analysis, and the spacers are evaluated independently of the finite element basket model. Two finite element models of a single disk are used to perform the support disk structural evaluation. Figure 2.6.13.2-1 shows the PWR support disk model for the side drop evaluation. For further details of the basket, refer to Section 2.6.13.

2.7.8.1 Stress Evaluation of Support Disk

To determine the structural adequacy of the support disks, 30-ft-drop accident impact loads are evaluated for the worst-case radial orientations of the basket (0°, 18.22°, 26.28°, and 45°). The cask orientations considered are side-drop, end-drop, and oblique drops (0°, 10°, 20°, 23°, 30°, 40°, 50°, 60°, 70°, 75°, 80°, and 88°).

A load equal to the weight of the fuel assembly and fuel tubes multiplied by a 60 *g* amplification factor is applied to the support disk structure to simulate the 30-ft side-drop accident condition. The 60 *g* amplification factor is the design value that envelopes the calculated deceleration values in Section 2.6.7.5 for a 30-ft side-drop accident condition. The fuel assembly loads are transmitted in direct compression through the tube wall to the web structure of each support disk. These loads are transmitted to the canister and to the inner shell of the cask by the support disks, top weldment, and bottom weldment. The support disk configuration is analyzed for four worst-case radial orientations—0°, 18.22°, 26.28°, and 45°—to bound the possible maximum stress cases. The 18.22° orientation is located at the thinnest radial section of the disk perimeter.

For the end-drop condition, the support disk is loaded by the inertia of its own weight multiplied by the 60 *g* end-drop amplification factor.

Two limiting boundary conditions (thermal Case A and B) are considered in the evaluation (See Section 2.6.13.3 for case definition). Note that temperatures in the model are used only to determine material allowables for stress evaluation. However, thermal stresses are considered in the buckling evaluation (Section 2.7.8.3).

The stress evaluation for the support disk is performed according to the ASME Code, Section III, Subsection NG. According to this subsection, linearized stresses of cross sections of the structure are to be compared against the allowable stresses. The allowable stresses for Normal and Accident conditions are taken from Subsection NG as shown below.

	Accident (Level D)
P_m	$0.7\ S_u$
P_m+P_b	$1.0\ S_u$

The allowable limit is $0.7\ S_u$ or $2.4\ S_m$, whichever is less. For the support disk, $2.4\ S_m > 0.7\ S_u$, therefore, $0.7\ S_u$ is limiting.

2.7.8.4 Fuel Tube Analysis

The fuel tube provides a foundation to mount neutron absorber plates within the fuel basket structure. The fuel tube does not serve a structural function relative to the support of the fuel assembly. The fuel tube design is presented in Figure 2.6.13-3. To ensure that the fuel tube remains functional when the cask is subjected to design load conditions, a structural evaluation of the tube is performed for both the end and side-impact load conditions.

2.7.8.4.1 Fuel Tube End Impact Analysis

During the postulated cask end impact, fuel assemblies are supported by the cask bottom for the bottom-end drop and the lid for the top-end drop. The fuel tubes do not carry fuel assembly load. Therefore, evaluation of the fuel tube for the end-impact load is performed by considering the weight of the fuel tube subjected to the cask deceleration carried by the minimum tube cross section. The minimum tube cross section is located at the contact point of the tube with the bottom weldment. From the dimensions of the tube shown in Figure 2.6.13-3, the minimum cross-sectional area is

$$\begin{aligned}\text{Area } &= \text{(thickness)(mean perimeter) } (0.048)\\ &= [(8.8+0.048)4] \; = \; 1.69 \text{ in}^2.\end{aligned}$$

The total bearing load on the tube and neutron absorber during the cask bottom-end impact is 9,180 lb, ($60\,g \times 153$ lb). The maximum compressive and bearing stress in the fuel tube is 5,432 psi (9180/1.69). Limiting the compressive stress level in the tube to the material yield strength ensures that the tube remains in position when the cask is subjected to the postulated end-drop. Type 304 stainless steel yield strength is 19,400 psi at a conservatively high temperature of 500°F for the axial location on the fuel tube that has the minimum cross-section area. Using this criterion to evaluate the tube for the end-drop load, a margin of safety of +2.57 is achieved.

2.7.8.4.2 Fuel Tube Side-Impact Analysis

During the cask side-impact load configuration, the fuel tube is supported by the fuel basket's stainless steel support disks. The fuel basket support disks support the full length of the fuel tube, and are spaced at 4.42 in. apart (which is about one half of the fuel tube width of

8.8 in). Considering the fuel tube subjected to the 60 *g* [1] side-impact deceleration and the 30 support locations provided by the basket support disks, the fuel tube shear stress is

Impact shear load = (60)(1,602)/30 = 3,204 lb

Shear area of tube = (0.048)(8.8)(2) = 0.845 in^2

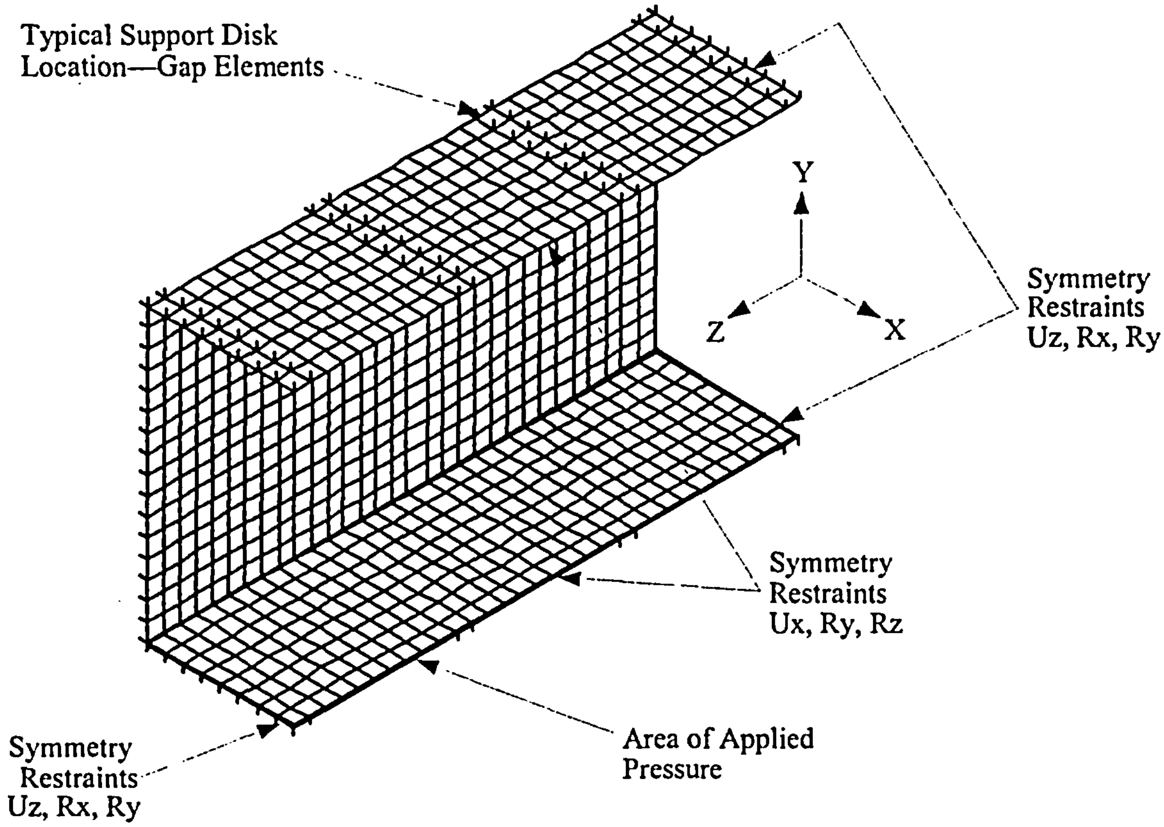
Shear stress of tube = 3,204/0.845 = 3,792 psi.

The yield strength of Type 304 stainless steel at 750°F is 17,300 psi. Using an allowable shear stress equivalent to half the yield strength of the tube wall material, 8,650 psi, results in a large positive margin of safety. The conservative evaluation of the tube loading resulting from its own mass during the side-impact configuration indicates that the tube structure will maintain position and will function.

The load transfer of a fuel assembly to the fuel basket support disk when the cask is subjected to a side impact will be through direct bearing and compression of the distributed load of the fuel assembly through the fuel tube to the support disk web. The analysis considers the fuel assembly load as a distributed pressure on the inside tube surface.

The load transfer of the weight of the fuel assembly to the fuel basket support disk in the side impact is through direct bearing and compression of the distributed load of the fuel assembly through the fuel tube to the support disk web. Two load conditions are considered in the fuel tube evaluation. The first considers the fuel assembly load as a distributed pressure on the inside surface of the fuel tube. The second postulates that the fuel assembly grid is located at the center of the span between the support disks and produces a localized distributed load over the effective area of the grid.

Two different ANSYS finite element models of the tube are developed for these two load conditions since the fuel tube structural performance for either load is nonlinear. As shown in the following, the first model represents a fuel tube section with a length of three spans, i.e., the model is supported at four locations by support disks. The model conservatively considers the fuel tube wall thickness of 0.048 inch as the only material subjected to a distributed pressure load representative of the fuel assembly deceleration of 60g. Fuel assembly stiffness is not considered in the development of the imposed pressure load on the fuel tube.



The tube is modeled with the ANSYS plastic, quadrilateral shell element (SHELL43). The support disks are represented by gap elements (CONTAC52). The outer nodes of the gap elements are fully restrained in all three translational directions. Edge restraints were applied to the model to represent symmetry boundary conditions. The effective load on the fuel tube due to the 60g deceleration of the fuel assembly is applied as a pressure to the inside area of the fuel tube.

The finite element analysis results show that the maximum stress in the tube is 23.8 ksi, which is local to the sections of the tube resting on the support disks. At 750°F the ultimate strength for Type 304 stainless steel is 63.1 ksi. The margin of safety is:

$$MS = \frac{63.1}{23.8} - 1 = +1.65$$

The analysis shows that the maximum total strain is 0.026 inch/inch. Defining the acceptable elastic-plastic response of the stainless steel as one half of the material failure strain of 0.40 inch/inch at 750°F [24], the resulting margin of safety is:

$$MS = \frac{0.40/2}{0.026} - 1 = +\text{Large}$$

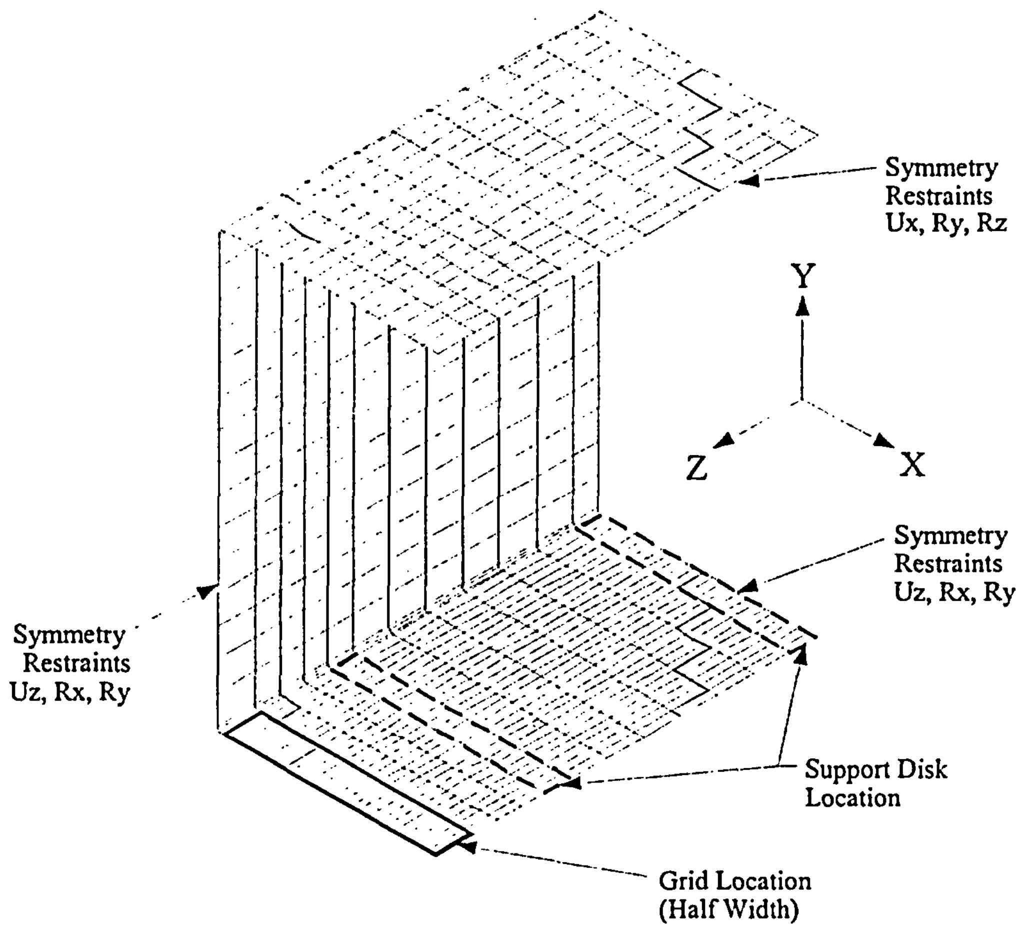
Similarly, the margin of safety for elastic-plastic stress becomes:

$$MS = \frac{63.1 - 17.3}{23.8 - 17.3} - 1 = 6.05$$

where the yield strength of Type 304 stainless steel is 17.3 ksi at 750°F.

The second finite element model is used to evaluate the load condition with the fuel assembly grid located at the center of the span between two support disks. The fuel tube is subjected to a localized distributed load over the effective area of the grid. As shown in the following, the model is a quarter-symmetry periodic section of the fuel tube. As in the finite element model used for the distributed pressure case, this model conservatively considers a fuel tube wall thickness of 0.048 inch. The neutron absorber plate (0.075 in) and stainless steel cover plate (0.018 in) are conservatively not included in the model. The tube wall is modeled with ANSYS SHELL43 elements. The support disks are modeled with CONTAC52 elements.

Based on the Lawrence Livermore evaluation of the fuel rods for a side impact (UCID-21246) [43], the fuel rods and fuel assemblies maintain their structural integrity during the side impact resulting from a cask tip-over accident and the displacement of the fuel tube is limited. The maximum displacement of the fuel tube section between the support disks will not exceed the "thickness" of the grid spacer, which is the distance between the outer surface of the grid and the outer surface of the fuel rod array. When the displacement of the fuel tube reaches the "thickness" of the grid spacer, the fuel rods will be in contact with the inner surface of the fuel tube and the weight of the fuel rods will be transferred through the tube wall to the support disks. Therefore, a bounding load condition for this model is simulated by applying a constant displacement of 0.08 inch in the negative Y direction to the nodes corresponding to the grid location in the model. Note that 0.08 inch displacement bounds all PWR fuel assemblies. It is assumed that the fuel assembly grid spacer is rigid and therefore a constant displacement is conservatively applied.



The finite element analysis results show that the maximum stress in the tube is 38.4 ksi, which is local to the corner of the tube at the grid spacer location of the model close to the side wall of the tube. At 750°F the ultimate strength for Type 304 stainless steel is 63.1 ksi. The margin of safety is:

$$MS = \frac{63.1}{38.4} - 1 = +0.64$$

The analysis shows that the maximum total strain is 0.11 inch/inch. Defining the acceptable elastic-plastic response of the stainless steel as one half of the material failure strain of 0.40 inch/inch at 750°F [24], the resulting margin of safety is:

$$MS = \frac{0.40/2}{0.11} - 1 = 0.82$$

Similarly, the margin of safety for elastic-plastic stress becomes:

$$MS = \frac{63.1 - 17.3}{38.4 - 17.3} - 1 = 1.17$$

where the yield strength of Type 304 stainless steel is 17.3 ksi at 750°F.

Both the maximum total strain and the elastic-plastic stress analyses indicate that the tube position within the support basket is maintained.

Assurance that the neutron absorber remains attached to the fuel tube is evaluated by considering that loads produced by the neutron absorber plate and stainless steel attachment plate, assuming a 60g load, are carried by the attachment plate weld. Total load and resultant stress on the weld are calculated as:

$F_{b/ss} = (g)(\rho)(t)(w)(l)$ Load exerted by neutron absorber/Stainless Steel Attachment Plate

where:

- g = acceleration (g)
- ρ = density of material (lb/in^3) (The density of aluminum (0.098 lb/in^3) is conservatively used for the neutron absorber.
- t = thickness of material (in)
- w = width of material (in)
- l = length of material section (in)

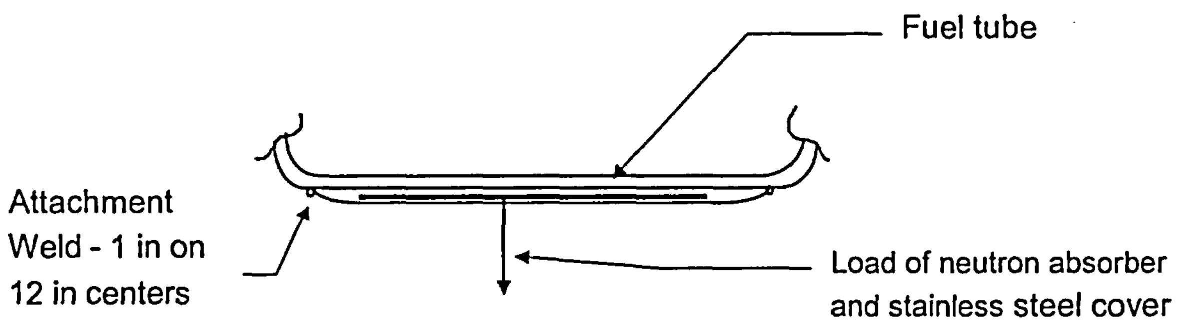
The forces on the weld due to a 12-inch section of neutron absorber (F_b) and a 12-inch section of stainless steel plate (F_{ss}) are:

$$F_b = (60g)(0.098 \text{ lb/in}^3)(0.075 \text{ in})(8.2 \text{ in})(12 \text{ in}) = 43.4 \text{ lbs}$$

$$F_{ss} = (60g)(0.291 \text{ lb/in}^3)(0.018 \text{ in})(8.7 \text{ in})(12 \text{ in}) = 32.8 \text{ lbs}$$

The total load (F_t) on a 1-in attachment weld for a 12-in section is:

$$F_t = 43.4 \text{ lbs} + 32.8 \text{ lbs} = 76.2 \text{ lbs}$$



The resulting weld stress is: $\sigma = P/A = (76.2 \text{ lb}/2) / (1 \text{ in}) (0.018 \text{ in}) = 2{,}117$ psi

Since the weld material is Type 304 stainless steel, the margin of safety (at 750°F) is:

$$MS = \frac{17{,}300}{2{,}117} - 1 = +7.2$$

Therefore, the neutron absorber remains enclosed on each outer surface of the fuel tube wall.

2.7.8.5 Basket Weldment Analysis for 30-Foot End Drop

The responses of the top and the bottom weldment plates of the fuel basket assembly to a 60 *g* accident condition deceleration load are examined. Two finite element models representing the PWR basket top and bottom weldments are constructed for structural evaluation. The structural evaluations are performed at normal condition temperatures; therefore, prior to the structural evaluation portion of the analyses, the steady-state temperature distribution in the top and bottom weldment models is determined by applying fixed temperatures to the outer circular edge and to the node at the intersection of the symmetry planes and then solving for the intermediate temperatures. These fixed temperatures are obtained from the normal conditions thermal analysis with -40°F ambient temperature and maximum heat generation. The material allowable stresses are based on the maximum temperature of the weldments determined for normal conditions with 100°F ambient temperature and maximum heat generation.

During the temperature solution portion of the analyses, ANSYS three-dimensional thermal shell elements (SHELL57) are used to construct the finite element models. During the structural evaluation portion of the analyses, ANSYS three-dimensional, six-degrees-of-freedom, elastic shell elements (SHELL63) in the weldment plate and structural support plate regions are used to construct the finite element models. BEAM4 elements are used to model the top nut/pads. Contact between the structural support plates and the structural support ring (where applicable) are modeled using CONTACT52 elements. The finite element models represent one-quarter sections of the weldments.

The top and bottom weldments are 1.0-in and 1.25 in thick, respectively, and are fabricated from SA-240, Type 304 stainless steel. The top weldment supports its own weight and 24 fuel tubes (without the fuel assemblies) during a top-end drop. Eleven structural support places, eight tie-rod top nuts, and a circumferential ring support the top weldment and its loads during a top-end drop. These structural components are modeled as zero-translation restraints in the direction of the end drop. The finite element models of the top and bottom weldments are presented in Figures 2.6.13.13-1 and 2.6.13.13-2, respectively.

2.7.10 BWR Basket Analysis - Accident Conditions

The BWR fuel basket in the Transportable Storage Canister is designed to contain up to 56 BWR fuel assemblies. The basket structure has a right-circular cylinder configuration and consists of 56 square tubes supported by circular support disks and a circular top and bottom plate that are retained by six axial tie rods. The number of support disks provided in the basket varies, depending upon the fuel basket class (Class 4 or 5). The support disks and top and bottom plates are separated and supported by split spacers at the tie rods. The configuration of the basket is shown in Figure 2.6.15-1. Design of the basket and its components is discussed in detail in Chapter 1.0.

In this section, the BWR fuel basket is evaluated for hypothetical accident loads (evaluation of the basket for normal conditions of transport loads is presented in Section 2.6.15). Both stress analyses and buckling evaluations are performed and documented. The structural analysis of the basket components is in accordance with ASME Code, Section III, Division 1, Subsection NG. In addition, the stainless steel/neutron absorber composite fuel tube is evaluated for a postulated impact load.

The fuel tubes are not structural components and are not considered in the basket evaluation. The tie rods and spacers locate and structurally assemble the circular support disks, heat transfer disks, and top and bottom plates to form an integral assembly. The spacers carry the weight of the support disks, heat transfer disks, and endplate and their own weight in the 30-ft end-drop accident loading condition. The end-drop loading condition of the spacers is a classical, closed-form analysis and the spacers are evaluated independently of the finite element basket model. A finite element model of a single disk is used to evaluate the support disk structural evaluation. Figure 2.6.15-2 shows the support disk cross-section. For further details of the basket refer to Section 2.6.15.

The basket support disk is designed to restrain 56 fuel assemblies, which would nominally fit into a 6.278-inch square slot. Since a populace of BWR fuel assemblies are not expected to fit into the 6.278-inch square, four oversized fuel assemblies slots are specified as 6.478-inch squares. This will reduce the thickness of the ligament at the outer most corner. However, the size of the web (.65 inch) is not changed. Therefore the oversized slots will not affect the buckling calculations, since they pertain to the in-plane and out of plane buckling of the webs. In an inspection of the maximum stresses of the BWR basket, the ligament, which contains the reduction due to the oversized slots, does not appear in the maximum stress summaries. The smallest ligament at the corner is still significantly controlled by the .8-inch ligament. Therefore, the use of oversized holes is not considered to alter the model of the BWR basket which employs a slot size of 6.278 inches.

2.7.10.1 Stress Evaluation of Support Disk

To determine the structural adequacy of the support disks, 30-ft-drop accident side impact loads are evaluated for the worst-case radial orientations of the basket. End-drop impact is also considered.

A load equal to the weight of the fuel and tubes multiplied by a 60 *g* amplification factor is applied to the support disk structure to simulate the 30-ft side-drop accident condition. The 60 *g* amplification factor is the design value that envelopes the calculated deceleration values for a 30-ft side-drop accident condition. The fuel assembly loads are transmitted in direct compression through the tube wall to the web structure of each support disk. These loads are transmitted to the canister and to the inner shell by a conservative number of disks, the top weldment, and the bottom weldment. The support disk configuration is analyzed for five worst-case radial orientations (0, 31.82, 49.46, 77.92, and 90°) to bound the possible maximum stress cases. The 31.82, 49.46, and 77.92° orientations are located at the thinnest radial section of the disk perimeter.

For the end-drop condition, the support disk is loaded by the inertia of its own weight multiplied by the 55 *g* end-drop amplification factor. Thermal Case 4 is the limiting boundary condition (See Section 2.6.15.3 for case definition).

To calculate the stresses in a support disk, the ANSYS computer code is used to perform a finite element analysis. In accordance with the ASME Code, Section III, Subsection NG, the maximum primary membrane stress intensity calculated in the support disk is compared with the allowable stress limit, 0.7 S_u or 2.4 S_m, whichever is less. The material strength is taken at the maximum support disk temperature. For the support disk, 2.4 S_m > 0.7 S_u; therefore, 0.7 S_u is limiting.

Temperature boundary conditions are presented in Section 2.6.13.3.

elements are fully restrained in all three translational directions. Edge restraints were applied to the model to represent symmetry boundary conditions. The effective load on the fuel tube due to the 60g deceleration of the assembly is applied as a pressure to the inside area of the fuel tube.

The finite element analysis results show that the maximum stress in the tube is 19.5 ksi, which is local to the sections of the tube resting on the support disks. At 750°F the ultimate strength for Type 304 stainless steel is 63.1 ksi. The margin of safety is:

$$MS = \frac{63.1}{19.5} - 1 = +2.24$$

The analysis shows that the maximum total strain is 0.0078 in/inch. Defining the acceptable elastic-plastic response of the stainless steel as one half of the material failure strain of 0.40 in/inch. at 750°F [24], the resulting margin of safety is:

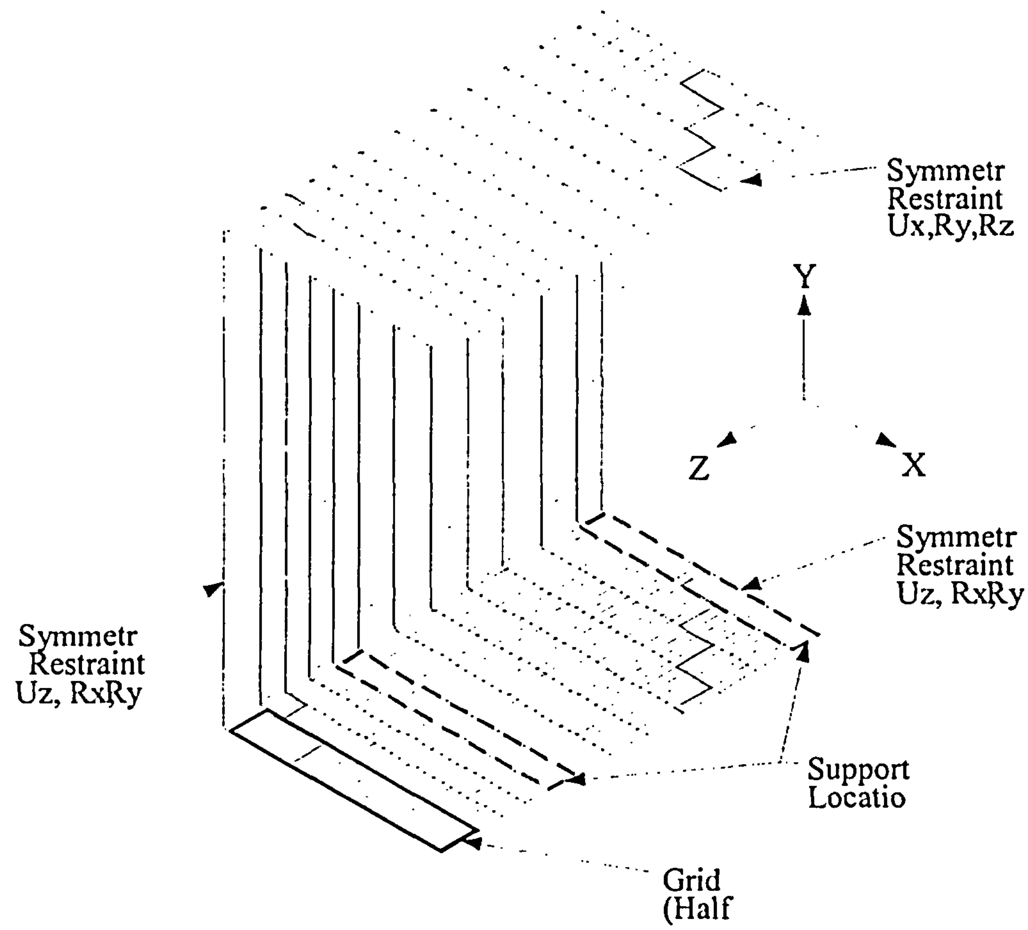
$$MS = \frac{0.40/2}{0.0078} - 1 = +\text{Large}$$

Similarly, the margin of safety for elastic-plastic stress becomes

$$MS = \frac{63.1 - 17.3}{19.5 - 17.3} - 1 = +\text{Large}$$

where the yield strength of Type 304 stainless steel is 17.3 ksi at 750°F.

The second finite element model is used to evaluate the load condition with the fuel assembly grid located at the center of the span between two support disks. The fuel tube is subjected to a localized distributed load over the effective area of the grid. As shown in the following, the model is a quarter-symmetry periodic section of the fuel tube. As in the finite element model used for the distributed pressure case, this model conservatively considers a fuel tube wall thickness of 0.048 inch. The neutron absorber plate (0.135 in) and stainless steel cover plate (0.018 in) are conservatively not included in the model. The tube wall is modeled with ANSYS SHELL43 elements. The support disks are modeled with CONTAC52 elements. A uniform pressure corresponding to the fuel assembly weight with the 60g load is applied to the elements at the grid location of the model. The displacement in the Y direction for the nodes at the grid location of the model are coupled to represent the structural rigidity of the spacer grid.



The finite element analysis results show that the maximum stress in the tube is 38.1 ksi. At 750°F the ultimate strength for Type 304 stainless steel is 63.1 ksi. The margin of safety is:

$$MS = \frac{63.1}{38.1} - 1 = +0.66$$

The analysis shows that the maximum total strain is 0.10 inch/inch. Defining the acceptable elastic-plastic response of the stainless steel as one half of the material failure strain of 0.40 in/in at 750°F [24], the resulting margin of safety is:

$$MS = \frac{0.40/2}{0.10} - 1 = +1.0$$

Similarly, the margin of safety for elastic-plastic stress becomes:

$$MS = \frac{63.1 - 17.3}{38.1 - 17.3} - 1 = +1.2$$

where the yield strength of Type 304 stainless steel is 17.3 ksi at 750°F.

Both the maximum total strain and the elastic-plastic stress analyses indicate that the tube position within the support basket is maintained.

Assurance that the neutron absorber remains attached to the fuel tube is evaluated by considering that loads produced by the neutron absorber plate and stainless steel attachment plate, assuming a 60g load, are carried by the attachment plate weld. Total load and resultant stress on the weld are calculated as:

$F_{b/ss} = (g)(\rho)(t)(w)(l)$ Load exerted by neutron absorber/Stainless Steel Attachment Plate

where:

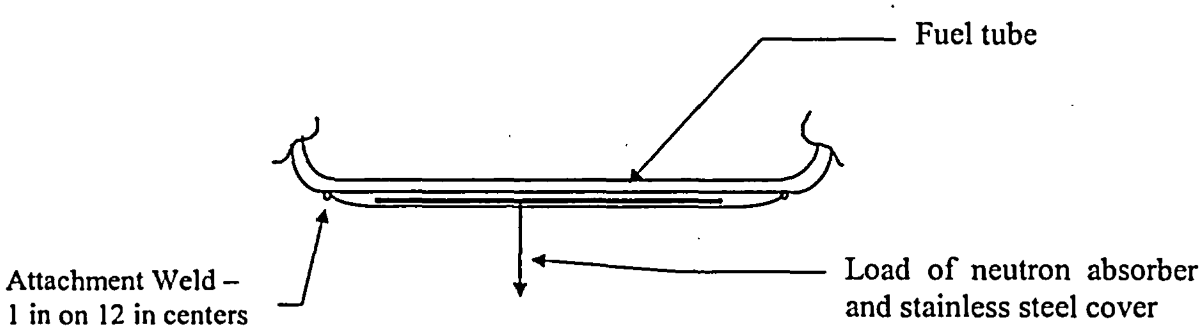
- g = acceleration (g)
- ρ = density of material (lb/in^3) (The density of aluminum (0.098 lb/in^3) is conservatively used for the neutron absorber.
- t = thickness of material (in)
- w = width of material (in)
- l = length of material section (in)

The forces on the weld due to a 12-in section of neutron absorber (F_b) and a 12-in section of stainless steel plate (F_{ss}) are:

F_b = (60g)(0.098 lb/in^3)(0.135 in)(5.45 in)(12 in) = 51.9 lbs.

F_{ss} = (60g)(0.291 lb/in^3)(0.018 in)(5.79 in)(12 in) = 21.8 lbs.

The total load (F_t) on a 1-in attachment for a 12-in section is F_t = 73.7 lbs (51.9 + 21.8) lbs



The resulting weld stress is: $\sigma = P/A = (73.7 \text{ lbs}/2) / (1 \text{ in}) (0.018 \text{ in}) = 2{,}074$ psi

Since the weld material is Type 304 stainless steel, the margin of safety (at 750°F) is:

$$MS = \frac{17{,}300}{2{,}047} - 1 = +7.5$$

Therefore, the neutron absorber remains enclosed on each outer surface of the fuel tube wall.

2.7.10.5 Basket Weldment Analysis for 30-Foot End-Drop

The responses of the top and bottom weldment plates of the fuel basket assembly to a 60 *g* accident condition deceleration load are examined. Two finite element models representing the BWR basket top and bottom weldments are constructed for structural evaluation. The structural evaluations are performed at normal condition temperatures; therefore, prior to the structural evaluation portion of the analyses, the steady-state temperature distribution in the top and bottom weldment models is determined by applying fixed temperatures to the outer circular edge and to the node at the intersection of the symmetry planes. These fixed temperatures are obtained from the normal condition thermal analysis with -40°F ambient temperature and maximum heat generation. The material allowable stresses are based on the maximum temperature of the weldments determined for normal conditions with 100°F ambient temperature and maximum heat generation.

During the temperature solution portion of the analyses, the finite element models are constructed by using ANSYS three-dimensional thermal shell elements (SHELL57). During the structural evaluation portion of the analyses, the finite element models are constructed by using ANSYS three-dimensional, six-degrees-of-freedom, elastic shell elements (SHELL63) in the weldment plate and structural support region. The top nuts/pads are modeled by using BEAM 4 elements. Contact between the structural supports plates and between the structural support ring were modeled by using CONTACT 52 elements. The finite element models represent one-quarter sections of the weldments.

The top and bottom weldments are 1.0 in thick and are fabricated from SA-240, Type 304 stainless steel. The top weldment supports its own weight and 56 fuel tubes (without the fuel assemblies) during a top-end-drop. Eight structural plates, eight tie-rod top nuts, and a

Table 2.11.1.1-1 provides a parametric comparison between the Base Case and the 4 cases evaluated, based on the maximum sectional stresses in the support disk. As shown in the table, the maximum stress in the UMS® basket support disk loaded with 20 standard fuel assemblies and four Maine Yankee fuel cans, including one holding consolidated fuel, is bounded by that for the support disk loaded with the design basis PWR fuel.

Additionally, a support disk analysis is performed for the Maine Yankee fuel configuration (20 standard fuel assemblies, three fuel cans containing spent fuel and one fuel can containing the consolidated fuel assembly), using the two-dimensional PWR support disk model for the governing case (45° basket orientation and thermal condition B) for the side drop condition (Section 2.6.13.6). The loading condition corresponds to Case 1 of the parametric study previously discussed. The analysis results of the P_m and $P_m + P_b$ stresses are summarized in Tables 2.11.1.1-2 and 2.11.1.1-3, respectively. The minimum margins of safety for the P_m and $P_m + P_b$ stresses are + 0.82 and + 0.24, respectively. The minimum margin of safety for the corresponding analysis for the support disk for the UMS® System design basis PWR configuration is +0.79 and +0.19 for P_m and $P_m + P_b$ stresses, respectively (see Tables 2.6.13.6-16 and 2.6.13.6-17). This comparison further substantiates the conclusion of the parametric study based on the normalized stress ratios using a two-dimensional model (Table 2.11.1.1-1).

Since no credit is taken for the structural integrity of the consolidated fuel or damaged fuel inside the fuel can, it is assumed that 100% of the fuel rods fail during an accident. For a Maine Yankee standard 14x14 fuel assembly, the volume of 176 fuel rods (100%) and 5 guide tubes will fill up 103.6 inches of the fuel can (span over 21 support disks) assuming a 50% volume compaction factor. For the consolidated fuel, the volume of 283 rods (100%) and 4 connector rods will fill up 109.6 inches of the fuel can (span over 22 support disks) assuming a 75% compaction factor. The compaction factor of 75% for the consolidated fuel considers that the number of rods in the consolidated fuel is approximately 1.5 times the number of rods in the standard Maine Yankee fuel and these rods are initially more closely spaced.

The corresponding pressure load on the support disk ligament is 15.3 psi for the 100% failed Maine Yankee damaged fuel and 22.5 psi for the consolidated fuel. Since the fuel cans holding damaged fuel and consolidated fuel are limited to the corner locations of the basket, the total load per support disk for this Maine Yankee configuration remains bounded by the total load per support disk for the UMS® System design basis configuration. To demonstrate that there is no adverse impact on the maximum stress of the support disk, the PWR support disk analysis (Section 2.6.13.6) is reperformed for the Maine Yankee configuration (20 standard fuel assemblies, three fuel cans containing 100% failed fuel and one fuel can containing the 100% failed consolidated fuel) for the governing case of the side drop condition (45° basket drop orientation and thermal condition B). The analysis results indicate the minimum margins of safety for the P_m and $P_m + P_b$ stresses are +0.80 and +0.23, respectively. The minimum margin of safety for the corresponding analysis for the support disk for the UMS® System design basis PWR configuration is +0.79 and +0.19 for the P_m and $P_m + P_b$ stresses, respectively (Tables 2.6.13.6-16 and 2.6.13.6-17). Therefore, the maximum stress in the support disk for the Maine Yankee configuration, assuming 100% rod failure of the damaged and consolidated fuel in the fuel cans, is bounded by the maximum stress in the support disk calculated for the UMS® design basis fuel.

2.11.1.1.1 Maine Yankee Fuel Can

The Maine Yankee fuel can, shown in Drawings 412-501 and 412-502, is provided in two configurations to accommodate Maine Yankee damaged fuel. The fuel can fits within a standard PWR basket fuel tube. The primary function of the Maine Yankee fuel can is to confine the fuel material within the can to minimize the potential for dispersal of the fuel material into the canister cavity volume.

The Maine Yankee fuel can is designed to hold an intact fuel assembly, a damaged fuel assembly, a fuel assembly with a burnup between 45,000 and 50,000 MWD/MTU and having a cladding oxidation layer thickness greater than 80 microns, or consolidated fuel in the Maine Yankee fuel inventory.

Both configurations of the fuel can are a square cross-section tube made of Type 304 stainless steel with a total length of 162.8 inches. The can walls are 0.048-inch thick sheet (18 gauge). In one configuration, the minimum internal width of the can is 8.52 inches. The corresponding dimension of the second configuration is 8.32 inches. The smaller cross-section allows the use of the fuel can in a basket in which the corner fuel loading positions of the bottom weldment are not enlarged. The bottom of the can is a 0.63-inch thick plate. Four holes in the plates, screened with a Type 304 stainless steel wire screen (250 openings/inch x 250 openings/inch mesh), permit water to be drained from the can during loading operations. Since the bottom surface of the fuel can rests on the canister bottom plate, additional slots are machined in the fuel can (extending from the holes to the side of the bottom assembly) to allow the water to be drained from the can. At the top of the can, the wall thickness is increased to 0.15 inch to permit the can to be handled. Slots in the top assembly side plates allow the use of a handling tool to lift the can and contents. To confine the contents within the can, the top assembly consists of a 0.88-inch thick plate with screened drain holes identical to those in the bottom plate. Once the can is loaded, the can and contents are inserted into the basket, where the can may be supported by the sides of the fuel assembly tube, which are backed by the structural support disks. Alternately, the empty fuel can may be placed in the basket prior to having the designated contents inserted in the fuel can.

The major physical design parameters of the Maine Yankee fuel can are provided in Table 2.11.1.1-4.

Structural evaluation of the Maine Yankee fuel can is shown below. The end drop and side drop conditions (both normal and accident conditions of transport) are considered in the evaluation. For conservatism, the fuel can configuration with the smaller internal width is used in the following analyses.

End Drop Conditions

For the bottom end drop, the top assembly (lid), the side plates, and the tube body act against the bottom assembly. For the top end drop, the bottom assembly, tube body, and side plates act against the top assembly. Because the top assembly is heavier, the bottom end drop is the governing case for tube body compression. The can contents bear against the bottom assembly through which the loads are transferred to the TSC bottom plate.

The Maine Yankee fuel can tube body is subjected to compressive stresses. Under normal operating conditions, the tube is evaluated for a 20g acceleration. This approach addresses the transport condition 1-foot drop and bounds the storage deadweight and handling condition, including a 10% dynamic load factor. The compressive load (P) on the tube is the combined weight of the lid, side plates, and tube body times 20:

$$P = (17.89 \text{ lb} + 6.57 \text{ lb} + 78.77 \text{ lb}) \times 20 = 2{,}064.6 \text{ lb; use } 3{,}000 \text{ lb for evaluation.}$$

The compressive stress (S_c) in the tube body is:

$$S_c = \frac{P}{A} = \frac{3{,}000 \text{ lb}}{1.674 \text{ in}^2} = 1{,}792 \text{ psi}$$

where:

$$A = 8.42^2 - 8.32^2 = 1.674 \text{ in}^2$$

The margin of safety (MS) is then:

$$MS = \frac{S_m}{S_c} - 1 = \frac{16{,}700 \text{ psi}}{1{,}792 \text{ psi}} - 1 = +8.3 \text{ for normal operating conditions at } 600°F.$$

Under accident conditions, the tube is evaluated for a 60g acceleration.

The compressive load (P) is:

$$P = (17.89 \text{ lb} + 6.57 \text{ lb} + 78.77 \text{ lb}) \times 60g = 6{,}193.8 \text{ lb; use } 8{,}500 \text{ lb for evaluation.}$$

The compressive stress (S_c) in the tube body is:

$$S_c = \frac{P}{A} = \frac{8{,}500 \text{ lb}}{1.674 \text{ in}^2} = 5{,}078 \text{ psi}$$

where the margin of safety (MS) is then:

$$MS = \frac{0.7S_u}{S_c} - 1 = \frac{0.7(63{,}300) \text{ psi}}{5{,}078 \text{ psi}} - 1 = +7.7 \text{ for accident conditions at } 600°F.$$

The tube is evaluated using the Euler formula to determine the critical buckling load (P_{cr}):

$$P_{cr} = \frac{\pi^2 EI}{L_e^2} = \frac{\pi^2(25.2 \times 10^6)(19.55)}{(157.8)^2} = 1.95 \times 10^5 \text{ lb}$$

where:

$E = 25.2 \times 10^6$ psi

$I = \dfrac{8.42^4 - 8.32^4}{12} = 19.55 \text{ in}^4$

L_e = tube body length (157.8 in)

Because the maximum compressive load (8,500 lb under the accident condition) is much less than the critical buckling load (1.95×10^5 lb), the tube has adequate resistance to buckling.

The lid is analyzed for compressive stresses in a top-end drop where compressive loads are transferred through the lid structure to the TSC shield lid. The compressive load (P) is the weight of the fuel assembly plus the weight of the lid (18.01 lb; use 30 lb for analysis) times the appropriate acceleration factor.

Case 1: The Maine Yankee fuel can contents is in an intact (although damaged) Maine Yankee fuel assembly, a CF-1 fuel rod storage insert, or a consolidated fuel assembly. The compressive load for Case 1 acts directly through the support ring and the lift tee, which are directly in line with the axis of the upper end fitting posts in the top-end drop configuration.

Case 2: The Maine Yankee fuel can contents is a fuel rod storage insert with a 3/4 – 10 threaded rod that transfers the compressive load to the center of the lid directly in line with the lift tee axis.

For Case 1, the contents weight is conservatively analyzed as the consolidated fuel weight (2,100 lb); Case 2 considers the heaviest standard Maine Yankee fuel assembly (1,300 lb).

Note: Because the lid thickness is greater than the free space between the top and the Maine Yankee fuel can and the bottom of the TSC shield lid, the lid cannot become disengaged from the can.

Case 1:

For normal operating conditions, the compressive stress (σ_c) is:

$$\sigma_c = \frac{P}{A} = \frac{2130\,(20)\text{ lb}}{7.66\text{ in}^2} = 5{,}561\text{ psi} \qquad \text{(using 30 lb for lid weight)}$$

where A is the combined cross-sectional area of the support ring and the lift tee:

$$A = \frac{\pi}{4}\left(\left(6.63^2 - 6.07^2\right) + 1.625^2\right) = 7.66\text{ in}^2$$

The margin of safety (MS) is:

$$MS = \frac{S_m}{\sigma_c} - 1 = \frac{16{,}700 \text{ psi}}{5{,}561 \text{ psi}} - 1 = +2.0 \text{(normal operating condition)}$$

For accident conditions, the compressive stress (σ_c) is:

$$\sigma_c = \frac{P}{A} = \frac{2130(60)}{7.66} = 16{,}684 \text{ psi}$$

The margin of safety (MS) is:

$$MS = \frac{0.7S_u}{\sigma_c} - 1 = \frac{0.7(63{,}300 \text{ psi})}{16{,}684 \text{ psi}} - 1 = +1.66 \text{ (accident condition)}$$

Case 2:

For normal operating conditions, the compressive stress (σ_c) is:

$$\sigma_c = \frac{P}{A} = \frac{1330(20) \text{ lb}}{2.07 \text{ in}^2} = 12{,}850 \text{ psi} \qquad \text{(using 30 lb for lid weight)}$$

where A is the cross-sectional area of the lift tee:

$$A = \frac{\pi}{4}(1.625)^2 = 2.07 \text{ in}^2$$

The margin of safety (MS) is:

$$MS = \frac{S_m}{\sigma_c} - 1 = \frac{16{,}700 \text{ psi}}{12{,}850 \text{ psi}} - 1 = +0.30 \text{ (normal operating condition)}$$

For accident conditions, the compressive stress (σ_c) is:

$$\sigma_c = \frac{P}{A} = \frac{1330(60)}{2.07} = 38{,}551 \text{ psi}$$

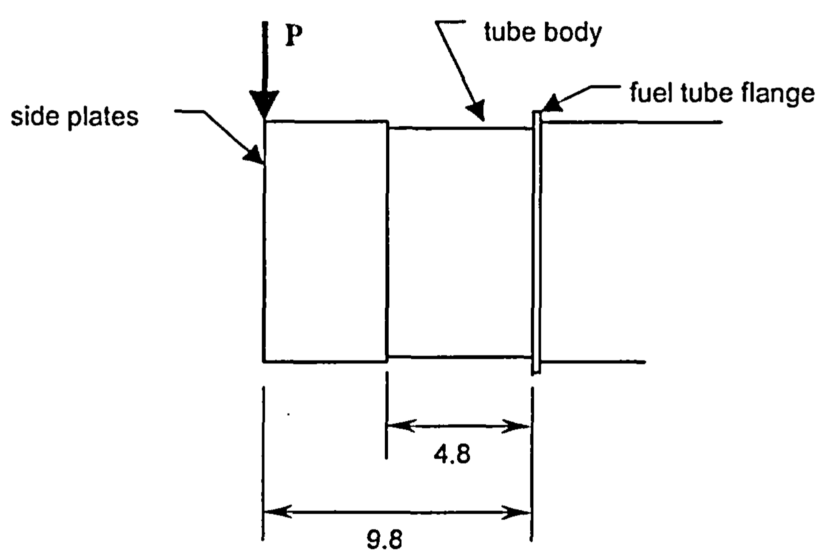
The margin of safety (MS) is:

$$MS = \frac{0.7S_u}{\sigma_c} - 1 = \frac{0.7(63{,}300 \text{ psi})}{38{,}551 \text{ psi}} - 1 = +0.15 \text{ (accident condition)}$$

Side Drop Conditions

The majority of the tube body is contained within the fuel tube in the basket assembly. Because both the tube body and the fuel tube have square cross-sections, they will be in full contact (for 153.0 inches longitudinally) during the side drop and no significant bending stress will be introduced into the tube body. The last 4.8 inches of the body tube and the 5.0-inch length of the side plates will be unsupported past the fuel tube flange in the side drop configuration.

The tube body will be evaluated as a cantilevered beam with the combined weight (P) of the overhanging tube body, top assembly, and side plates multiplied by the appropriate deceleration factor and, conservatively, concentrated at the top end of the side plates.



Normal condition (one-foot drop):

The maximum bending stress (f_b) is determined as follows:

$$f_b = \frac{M_{max}c}{I} = \frac{6{,}860(4.21)}{19.55} \cong 1{,}477 \text{ psi}$$

where:

M_{max} = $Pg \times L = 35(20)(9.8) = 6{,}860$ lb·in.

P = 35 lb; (side plates, 6.57 lb + tube body (0.5 lb/in. × 4.8 in. = 2.4) + top assembly, 17.89 lb, equals 26.86 lb; use 35 lb for this analysis.)

g = 20 (normal condition)

L = 9.8 in. (the total overhung length of the tube body and end plates)

c = 8.42/2 = 4.21 in.

$$I = \frac{bh^3 - b_i h_i^3}{12} = \frac{8.42^4 - 8.32^4}{12} = 19.55 \text{ in}^4$$

The shear stress (τ) is:

$$\tau = \frac{Pg}{A} = \frac{35(20)}{1.674} \cong 418 \text{ psi}$$

where:

$$A = 8.42^2 - 8.32^2 = 1.674 \text{ in}^2$$

$$\sigma_1, \sigma_2 = \frac{1}{2}\left(f_b \pm \sqrt{f_b^2 + 4\tau^2}\right) = \frac{1}{2}\left(1{,}477 \pm \sqrt{1{,}477^2 + 4(418)^2}\right) = 1{,}587 \text{ psi and } -110 \text{ psi}$$

The stress intensity (σ_{max}) = $|\sigma_1 - \sigma_2|$ = 1,697 psi

The margin of safety (MS) is:

$$MS = \frac{1.5S_m}{\sigma_{max}} - 1 = \frac{1.5(16{,}700)\ \text{psi}}{1{,}697\ \text{psi}} - 1 = +14 \text{ for the normal condition (20g acceleration)}$$

Accident condition (30-foot drop):

The maximum bending stress (f_b) is determined as follows:

$$f_b = \frac{M_{max}c}{I} = \frac{20{,}580(4.21)}{19.55} = 4{,}432\ \text{psi}$$

where:

M_{max} = $P g \times L = 35(60)(9.8) = 20{,}580$ lb·in.

g = 60 (accident condition)

The shear stress (τ) is:

$$\tau = \frac{Pg}{A} = \frac{35(60)}{1.674} = 1{,}254\ \text{psi}$$

$$\sigma_1, \sigma_2 = \frac{1}{2}\left(f_b \pm \sqrt{f_b^2 + 4\tau^2}\right) = \frac{1}{2}\left(4{,}432 \pm \sqrt{4{,}432^2 + 4(1{,}254)^2}\right) = 4{,}762\ \text{psi and } -330\ \text{psi}$$

The stress intensity (σ_{max}) = $|\sigma_1 - \sigma_2|$ = 5,092 psi

The margin of safety (MS) is:

$$MS = \frac{1.0\ S_u}{\sigma_{max}} - 1 = \frac{1.0(63{,}300)}{5{,}092} - 1 = +11.4 \text{ for the accident condition (60g acceleration)}$$

Side Drop – Consolidated Fuel

The fuel can is evaluated using the same method as in the previous section with the additional uniformly distributed weight (w) of the consolidated fuel.

Normal condition (1-foot drop):

The maximum bending stress (f_b) is determined as follows:

$$f_b = \frac{M_{max}c}{I} = \frac{17{,}494(4.21)}{19.55} \cong 3{,}767 \text{ psi}$$

where:

$$M_{max} = \left(PL + \frac{w(L-2.35)^2}{2}\right)(20g) = \left(35(9.8) + \frac{19.16(9.8-2.35)^2}{2}\right)(20g)$$

$$= 17{,}494 \text{ lb} \cdot \text{in}$$

2.35 in. = the distance from the top of the side plate to the bottom of the lid assembly

$$w = \frac{2{,}100 \text{ lb}}{109.6 \text{ in}} = 19.16 \text{ lb/in.}$$

2,100 lb = the consolidated fuel weight

P = 35 lb; (side plates, 6.57 lb + tube body (0.5 lb/in. × 4.8 in. = 2.4) + top assembly, 17.89 lb = 26.86 lb; use 35 lb for this analysis.)

The shear stress (τ) is:

$$\tau = \frac{(P + w(L - 2.35))g}{A} = \frac{(35 + 19.16(9.8 - 2.35))20}{1.674} \cong 2{,}124 \text{ psi}$$

$$\sigma_1, \sigma_2 = \frac{1}{2}\left(f_b \pm \sqrt{f_b^2 + 4\tau^2}\right) = \frac{1}{2}\left(3{,}767 \pm \sqrt{3{,}767^2 + 4(2{,}124)^2}\right) = 4{,}723 \text{ psi and } -956 \text{ psi}$$

The stress intensity (σ_{max}) = $|\sigma_1 - \sigma_2|$ = 5,679 psi

The margin of safety (MS) is:

$$MS = \frac{1.5S_m}{\sigma_{max}} - 1 = \frac{1.5(16{,}700) \text{ psi}}{5{,}679 \text{ psi}} - 1 = +3.4 \text{ for the normal condition (20g acceleration)}$$

Accident condition (30-foot drop):

The maximum bending stress (f_b) is determined as follows:

$$f_b = \frac{M_{max} c}{I} = \frac{52{,}483(4.21)}{19.55} = 11{,}302 \text{ psi}$$

where:

$$M_{max} = \left(PL + \frac{w(L - 2.35)^2}{2}\right)(60g) = \left(35(9.8) + \frac{19.16(9.8 - 2.35)^2}{2}\right)(60g) = 52{,}483 \text{ lb} \cdot \text{in}$$

The shear stress (τ) is:

$$\tau = \frac{(P + w(L - 2.35))g}{A} = \frac{(35 + 19.16(9.8 - 2.35))60}{1.674} \cong 6{,}371 \text{ psi}$$

g = 60 (accident condition)

$$\sigma_1, \sigma_2 = \frac{1}{2}\left(f_b \pm \sqrt{f_b^2 + 4\tau^2}\right) = \frac{1}{2}\left(11{,}302 \pm \sqrt{11{,}302^2 + 4(6{,}371)^2}\right) = 14{,}167 \text{ psi and } -2{,}865 \text{ psi}$$

The stress intensity (σ_{max}) = $|\sigma_1 - \sigma_2|$ = 17,032 psi

The margin of safety (MS) is:

$$MS = \frac{1.0\ S_u}{\sigma_{max}} - 1 = \frac{1.0(63{,}300)}{17{,}032} - 1 = +2.72 \text{ for the accident condition (60g acceleration)}$$

The welds joining the tube body to the side plates are full penetration welds (Type III NG-3352.3). Per Table NG-3352-1, the weld quality factor (n) for a Type III weld with visual surface inspection is 0.5.

The margin of safety (MS) for the welds is:

$$MS = \frac{n \cdot 1.5 \cdot S_m}{\sigma_{max}} - 1 = \frac{0.5(1.5)(16{,}700 \text{ psi})}{5{,}679 \text{ psi}} - 1 = +1.21 \text{ (normal condition)}$$

$$MS = \frac{n \cdot 1.0 \cdot S_u}{\sigma_{max}} - 1 = \frac{0.5(1.0)(63{,}300 \text{ psi})}{17{,}032 \text{ psi}} - 1 = +0.86 \text{ (accident condition)}$$

<u>100% Failed Fuel Analysis</u>

Accident Conditions:

Both configurations of the Maine Yankee fuel can may hold 100% failed/damaged fuel or consolidated fuel. An evaluation is performed to demonstrate that the fuel can maintains its integrity during a tip-over accident for this condition.

Both configurations of the fuel can are designed to hold either Maine Yankee standard fuel assemblies (1300 lb) or consolidated fuel assemblies (2100 lb). For 100% failed fuel, the pressure load applied to the fuel can is:

standard fuel: $$P_S = \frac{1300}{8.52 \times 103.6} = 1.47 \text{ psi}$$

consolidated fuel: $$P_C = \frac{2100}{8.52 \times 109.6} = 2.25 \text{ psi}$$

where:

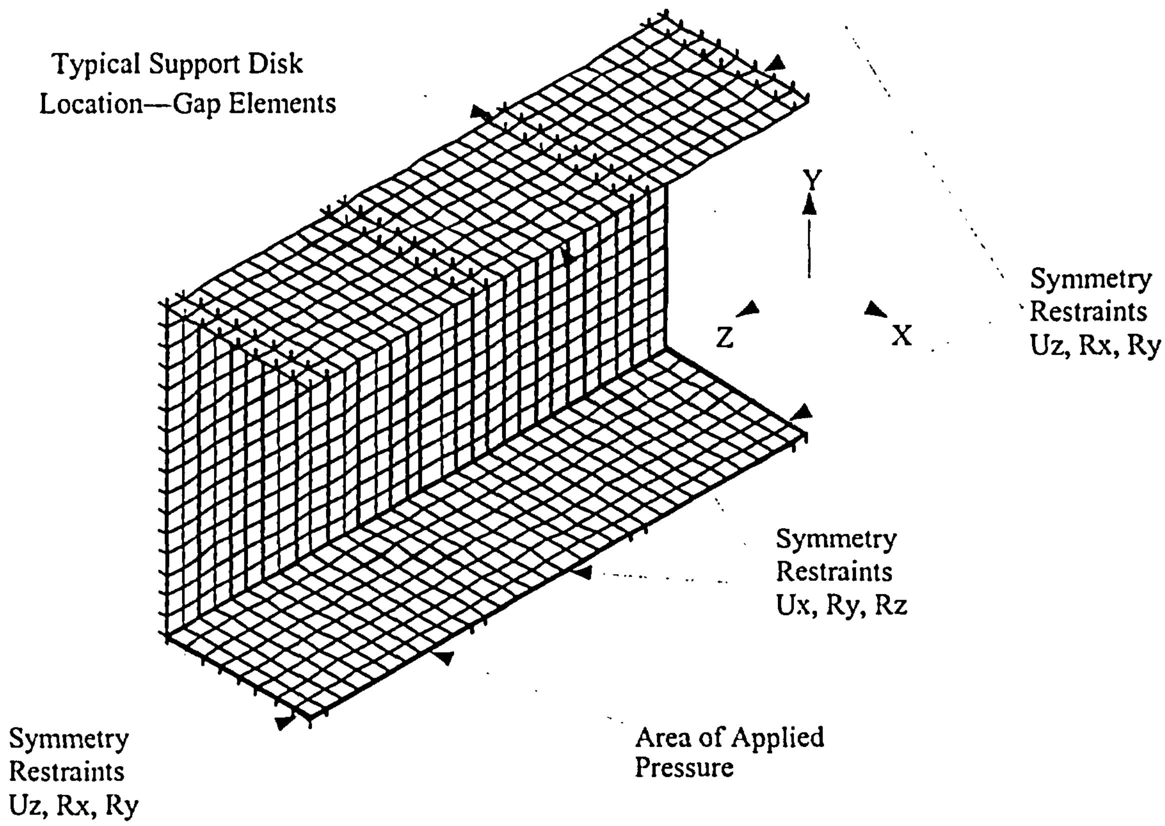
1300 lbs	= Maine Yankee standard fuel weight
2100 lbs	= maximum consolidated fuel weight
8.52 in	= inside width of fuel can
103.6 in	= height occupied by 100% failed standard fuel
109.6 in	= height occupied by 100% failed consolidated fuel

Therefore, the bounding pressure load on the fuel can is the consolidated fuel, 2.25 psi, multiplied by 60g (135 psi).

An ANSYS model of the Maine Yankee fuel can (8.57 in × 8.57 in) is constructed to evaluate the fuel can for a 60g loading. Note that 8.57 in is the dimension of the fuel can based on the centerlines of its side walls.

It should be noted that the fuel tube, the neutron absorber plate and its cover are not included in the model. Therefore, the fuel can analysis is conservative.

The ANSYS model is comprised of shell elements to model the deformation of the sides of the fuel can between the support disks. While there are two bounding dimensions of 8.57 in and 8.32 in, the 8.57-in length would correspond to the largest unsupported span (from side to side) between the support disks. The use of the larger span (of 8.57 in) would result in the stresses and deformation in the model, which would bound the stresses and deformation associated with a smaller distance (of 8.32 inches).



The finite element analysis results show that the maximum stress in the fuel can is 25.4 ksi, which is local to the sections of the tube resting on the support disks. At 750°F, the ultimate strength for Type 304 stainless steel is 63.1 ksi. The margin of safety is:

$$MS = \frac{63.1}{25.4} - 1 = +1.48$$

The analysis shows that the maximum total strain is 0.050 inch/inch (see Figure A-1). Defining the acceptable elastic-plastic response of the stainless steel as one-half of the material failure strain of 0.40 inch/inch at 750°F, the resulting margin of safety is:

Table 2.11.1.1-3 $P_m + P_b$ Stresses for Support Disk—1-Foot Side Drop, 45° Orientation, Thermal Case B, Structural Case 1

Section	Sx (ksi)	Sy (ksi)	Sxy (ksi)	Stress Intensity (ksi)	Allowable Stress (ksi)	Margin of Safety
37	-38.5	-45.1	12	54.2	67.5	0.24
21	-44.9	-38.5	12	54.1	67.5	0.25
23	33.4	36.6	10.2	45.3	67.5	0.49
35	36.5	33.4	10.1	45.2	67.5	0.49
34	-40.7	-41.2	3.2	44.2	67.5	0.53
20	-41	-40.8	3.2	44.1	67.5	0.53
4	37.9	41.6	3	43.3	67.5	0.56
1	41.6	37.9	3	43.3	67.5	0.56
112	-18.1	-42	3.7	42.5	67.5	0.59
111	-41.6	-18	3.6	42.2	67.5	0.6
51	30.9	34.8	9	42.1	67.5	0.6
7	34.6	31.1	9.1	42	67.5	0.61
2	-37.8	-37.2	2.6	40.1	67.5	0.68
3	-37.2	-37.8	2.6	40.1	67.5	0.68
49	-30.8	-31	8.6	39.6	67.5	0.71
9	-30.9	-30.9	8.7	39.5	67.5	0.71
64	-31	-30.4	8.2	38.9	67.5	0.73
95	-30.1	-31.2	8.2	38.8	67.5	0.74
63	-30.2	-30.7	8.3	38.8	67.5	0.74
96	-30.4	-30.5	8.3	38.8	67.5	0.74
120	0.2	-34.9	5.5	36.7	67.5	0.84
114	-34.8	0.2	5.4	36.6	67.5	0.84
42	-18.9	-33	7.6	36.3	67.5	0.86
26	-32.9	-18.7	7.5	36.1	67.5	0.87
6	32.1	33.1	1.6	34.3	67.5	0.97
48	32.9	32.3	1.6	34.2	67.5	0.98
36	-4	-32	-4.1	32.6	67.5	1.07
22	-31.7	-3.7	-4.2	32.4	67.5	1.09
80	25	25	6.5	31.5	67.5	1.14
79	24.7	25.2	6.5	31.5	67.5	1.14
72	-18	-25.2	8.8	31.1	67.5	1.17
98	-25	-17.9	8.7	30.8	67.5	1.19
40	-9.7	-29.6	4.8	30.7	67.5	1.2
28	-29.3	-9.5	4.7	30.4	67.5	1.22
108	7.8	28.1	6.3	29.9	67.5	1.26
75	13.4	19.9	-12.3	29.4	67.5	1.3
39	-18.8	-28	1.6	28.3	67.5	1.39
25	-27.9	-18.6	1.6	28.1	67.5	1.4
123	-14.5	-18.3	-11.1	27.6	67.5	1.44
115	-12.4	-27.6	-0.3	27.6	67.5	1.44

Table 2.11.1.1-4 Major Physical Design Parameters of the Maine Yankee Fuel Can

Parameter	**Value**
Overall Length (in.)	162.8
Inside Cross Section (in.)	8.5 × 8.5 or 8.3 × 8.3
Outside Cross Section (in.) [1]	8.6 × 8.6 or 8.4 × 8.4
Can Wall Thickness	18 Gauge (0.048 in.)
Internal Cavity Length (in.)	160.0
Empty Weight (nominal) (lbs.)	130

Note [1] The top of the Maine Yankee Fuel Can is located above the top weldment of the fuel basket when it is installed. The outside top cross-section is 8.82 × 8.82 in. at the top 4.5 inches to allow for lid engagement and fuel can lifting.

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Table 3.2-14 Gaps Within the Universal Transport Cask

Gap Location	**Gap (in)**	
	Cask with PWR Fuel Canister	**Cask with BWR Fuel Canister**
Gap between support disk and canister shell	0.155	0.155
Gap between canister and inner shell	0.275	0.275
Gap between lead gamma shield and inner shell	0.015	0.015
Gap between heat transfer disk and canister shell	0.280	0.315
Gap between canister bottom plate and top of spacer	0.125	0.25
Gap between bottom forging and spacer	*	0.25
Gap between spacer and canister bottom plate	0.125	0.25

* Only the base disk of the spacer is modeled in the PWR cask analysis. The cylindrical shells attached to the base disk are neglected.

Table 3.2-15 Thermal Properties of METAMIC

Property (units)	**Value at Temperature**		
	77°F	**212°F**	**482°F**
Conductivity (Btu/hr-in-°F)	4.54	4.42	4.64
Specific Heat (Btu/lbm-°F)	0.2207	0.2412	0.2938
Density (lbm/in^3)	0.094		

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the cask (the sections of the cask body covered by the impact limiters are modeled as adiabatic). The three-dimensional finite element model for the cask loaded with PWR fuel is described in Section 3.4.1.1.1. The three-dimensional finite element model for the cask loaded with BWR fuel is described in Section 3.4.1.2.1.

The models of the cask/internal components (both PWR and BWR) are constructed of ANSYS three-dimensional, solid brick, thermal conduction elements (SOLID70) to model heat conduction/combined conduction and thermal radiation, as well as two-node thermal radiation link elements (LINK31) to model thermal radiation. The analyses of the cask models correspond to steady-state conditions.

In the three-dimensional cask models, the fuel assemblies are modeled as homogeneous regions with effective temperature-dependent thermal conductivity. The effective thermal conductivity of the fuel region in the plane perpendicular to the major axis of the cask is determined for each fuel (PWR and BWR) by using two-dimensional finite element models representing the cross-section of a single fuel assembly. The two-dimensional finite element models of the fuel assemblies consist of the UO_2 fuel pellets; Zircaloy cladding; and gas between the fuel pellets and cladding and between the fuel rods (fuel pellet/cladding). Heat generation rates (multiplied by the respective peaking factors for each fuel) are applied to the elements representing the UO_2 and an isothermal temperature condition is applied to the edges of the model representing the outer surfaces of the fuel assembly. The effective conductivity of the fuel assembly is then calculated by determining the maximum temperature in the fuel and using a closed form expression for a square with uniform heat generation. The two-dimensional finite element model of the PWR fuel is also described in Section 3.4.1.1.2. The two-dimensional finite element model of the BWR fuel is also described in Section 3.4.1.2.2.

The models of the fuel assemblies are constructed of ANSYS two-dimensional thermal elements (PLANE55) to model heat conduction and two-node thermal radiation link elements (LINK31) to model thermal radiation. The analyses of the fuel assemblies models are steady-state.

Additionally, the fuel tube walls and neutron absorber plate are modeled in the three-dimensional cask models as homogeneous regions by using effective thermal conductivity properties. The effective thermal conductivity of the fuel tube walls and neutron absorber plate is determined for each fuel tube (PWR and BWR) by using two-dimensional finite element models representing the cross-section of a typical fuel tube. The two dimensional models of the fuel tube walls and neutron absorber plate consist of the stainless steel tube wall; the neutron absorber sheet, which is composed of a sheet of boron sandwiched between aluminum sheets; the stainless steel sheet covering the neutron absorber plate; and the gaps separating these components. A heat flux is applied to the inner face of the composite tube wall while a temperature is applied to the outer face. The change in temperature is then used to calculate the effective thermal conductivity. This method treats the thermal resistance of the different layers as being in series. The effective thermal conductivity for heat condition parallel to the axis of the cask is computed as a weighted average based on the thickness of each layer. The two-dimensional finite element model of the PWR fuel tube is described in Section 3.4.1.1.3. The two-dimensional finite element model of the BWR fuel tube is described in Section 3.4.1.2.3.

The models of the tube wall and neutron absorber plate are constructed of ANSYS two-dimensional thermal elements (PLANE55) to model heat conduction and two-node thermal radiation link elements (LINK31) to model thermal radiation. The analyses of the fuel tube and neutron absorber plate models are steady-state.

A separate thermal analysis from the cask models is performed to determine the volumetric average temperature of the cask impact limiters. The impact limiters are not explicitly modeled in the cask thermal analyses previously discussed—the cask surfaces covered by the impact limiters are modeled as adiabatic. The impact limiter thermal model consists of an axis-symmetric finite element model of one impact limiter, the cask lid, the cask upper forging, the fire block inside the impact limiter shell, and the gap between the cask upper forging and the impact limiter.

3.4.1.1 Analytical Models: Cask with PWR Fuel Canister

The thermal analysis of the cask transporting PWR fuel uses three finite element ANSYS models as previously described. A three-dimensional model is employed to evaluate the cask in a horizontal position with the basket in contact with the canister, which, in turn, is in contact with the cask inner shell. The fuel regions and the fuel tubes with neutron absorber plates in this model are modeled by using effective conductivities. The effective conductivity of the fuel is determined by a second model, which is a detailed two-dimensional thermal model of the fuel assembly. The effective conductivities of the fuel tube wall and neutron absorber plate are calculated by using a third model, which is a two-dimensional thermal model of the fuel tube. The three ANSYS thermal models are described in the following paragraphs.

3.4.1.1.1 Three-Dimensional Cask Model: Cask with PWR Fuel Canister

The three dimensional Universal Transport Cask model is a half-symmetry finite element model constructed by using ANSYS Revision 5.5. The model considers the fuel assemblies, fuel tubes, stainless steel support disks, aluminum heat transfer disks, canister shell, lids and bottom plate, spacers at the bottom of the canister, cask inner shell, lead, outer shell, neutron shield, and neutron shield shell. The gaps between the individual components are also considered. The ANSYS model is shown in Figure 3.4-1. As shown in Figure 3.4-1, the internal cavity of the canister contains the active fuel region: the top and bottom end fittings of the fuel assemblies, fuel tubes enclosing the fuel assemblies and the top and bottom end fittings, and the bottom weldment.

The gas inside the canister is modeled as helium. The gas inside the cask cavity is modeled as helium, because the cavity will be backfilled with helium following fuel loading prior to transport. The finite element model is constructed of ANSYS three-dimensional, solid brick, thermal conduction elements (SOLID70) to model heat conduction/combined conduction and thermal radiation and two-node thermal radiation link elements (LINK31) to model thermal radiation. The principal gaps applied to the model are shown in Figure 3.1-1 and described in Section 3.2.2.3. In establishing these gaps, the differential thermal expansion between the components is considered. The gap values selected are conservative.

Because the canister is in the horizontal position during transport, the elements for the canister shell are shifted downwards to simulate contact with the inner shell of the cask. Similarly, the support disks and the heat transfer disks are shifted downward to simulate contact with the canister shell. As shown in Figure 3.1-1, a 2-degree contact is considered for the gaps between the canister shell and the cask inner shell and between the support disk and the canister shell. At the 2-degree contact region in the model, an element 0.005-inch thick (in the radial direction) is modeled between the elements of the canister shell and cask inner shell, and between the elements for the support disk and canister shell. To simulate the contact condition, a conductivity of 100 Btu/hr-in-°F is assumed for the element. The value of conductivity used has a negligible effect on the thermal analysis results, since the thermal resistance across the element is negligible compared to the thermal resistance of the canister shell or the cask inner shell because the thickness of the element is only 0.005 inch. The aluminum heat transfer disks are assumed to have only a line contact with the canister shell because the heat transfer disks are not subjected to any loads other than their own weight.

To account for differential thermal expansion, gaps within the model are adjusted on the basis of temperature and defined physical contact conditions. Solar insolance and ambient temperature conditions are applied to the neutron shield shell when appropriate. Insolance is used at the exterior surface of the cask and is based on the amount of insolation required by 10 CFR 71 to be applied over a 12-hr period evaluated in the steady state (applied over 24 hr simulating 12-hr period of solar exposure and 12-hr period of no solar exposure). The heat flux resulting from insolation on a curved surface is calculated as follows:

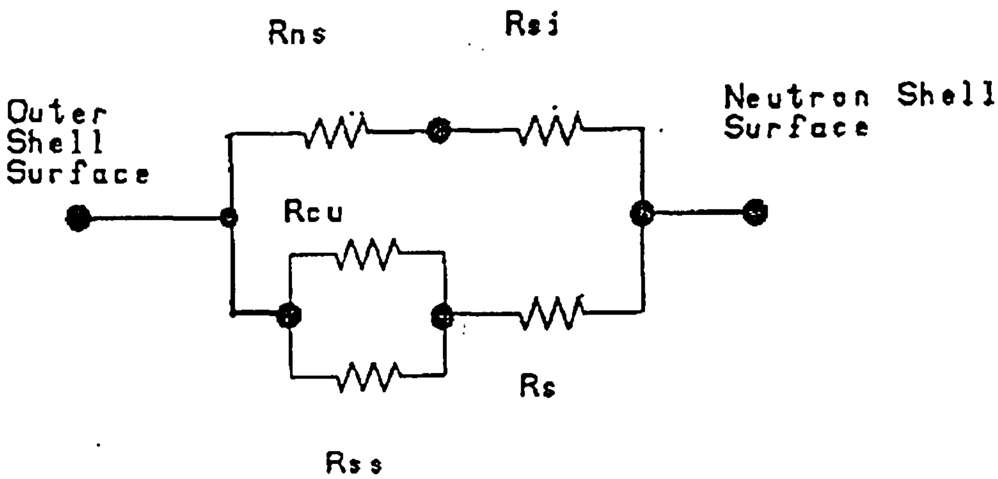
$$1475 \frac{\text{Btu}}{12\ \text{hr - ft}^2} \times \frac{12\ \text{hr}}{24\ \text{hr}} \times \frac{1\ \text{ft}^2}{144\ \text{in}^2} = 0.427\ \text{Btu/hr-in}^2.$$

Multiplying this value by the emissivity of the cask surface, $\varepsilon = 0.36$, gives a heat flux resulting from insolance on curved surfaces of 0.154 Btu/hr-in^2. Using the same method and a heat flux of 2,950 Btu/12 hr-ft^2 (0.853 Btu/hr-in^2) gives a heat flux resulting from insolance on flat surfaces of 0.307 Btu/hr-in^2. Applying one-half of the required 12-hr insolance over a 24-hr period to achieve a steady state solution, as has been done previously in transport cask licensing, is conservative.

The model is analyzed to determine the maximum temperatures for the basket, canister, cask shells, radial shielding, and surface conditions under normal conditions of transport. All material properties are shown in Tables 3.2-1 through 3.2-13.

The fuel regions (inside tubes) are modeled as homogeneous regions with effective conductivities, determined by the two-dimensional fuel model as described in Section 3.4.1.1.2. The fuel assembly tube and the neutron absorber plate, including gaps on both sides of the neutron absorber sheet and the gap between the stainless steel cladding for neutron absorber and disk, are modeled as one element thick with effective conductivities, as established by using the two-dimensional tube model discussed in Section 3.4.1.1.3. Only the spacer plate is modeled with the spacer concentric cylinders. Therefore, only conduction through the helium (modeled using SOLID70 elements) and radiation from the spacer plate to the cask bottom (modeled using LINK31 thermal radiation links) are conservatively modeled.

The neutron shield of the Universal Transport Cask, consisting of NS-4-FR, steel, and Cu/SS fins, is also modeled with effective conductivities. The radial neutron shield effective conductivity is calculated using an electrical resistance analogy. The equivalent circuit corresponding to Cu/SS, fin, NS-4-FR and silicon foam is shown below.



Rns = NS-4-FR material

Rsi = silicon foam between NS-4-FR and neutron shield shell

Rcu = 6 mm copper plate

Rss = 8 mm stainless steel

Rs = stainless steel connection to neutron shield shell

The axial conductivity, specific heat, and density are calculated on the basis of a weighted average of the axial cross sectional area and property. Conductivity of the neutron shield material NS-4-FR (0.031 Btu/hr-inch-°F) is used as the conductivity in the circumferential direction. The effective thermal conductivities for the neutron shield are:

Temperature	100°F	225°F	350°F
Radial Conductivity (Btu/hr in °F)	0.380	0.382	0.383
Axial Conductivity (Btu/hr in °F)	0.425	0.424	0.421
Specific heat (Btu/hr in °F)	0.39	0.39	0.39
Density (lbm/in^3)	0.0589	0.0589	0.0589

In the model, radiation heat transfer is considered from the top of the fuel region to the bottom surface of the canister shield lid, from the bottom of the fuel region to the top surface of the canister bottom plate, and from the exterior surfaces of the fuel tubes to the inner surface of the canister shell. This radiation is modeled by using LINK31 radiation elements. Radiation across gaps in the model is described in Section 3.2.2.3 and 3.2.2.4.

Radiation at the neutron shield shell surface to ambient is combined with the convection effect by using the method described in Section 3.2.2.2. The convection heat transfer coefficient is calculated on the basis of the formula shown in Section 3.2.3. Effective emissivities are used for all radiation calculations, with the form factor taken to be unity. Effective emissivity is computed by using the following formula [9] based on corresponding material emissivities:

$$\varepsilon_{eff} = 1/(1/\varepsilon_1 + 1/\varepsilon_2 - 1)$$

Solar insolance is applied to the neutron shield shell surface for the "Hot" condition (ambient temperature = 100°F). A cosine distribution is considered for the heat flux since the cask side surface is subjected to maximum insolation at the top and minimum (zero) insolation at the bottom while in the horizontal position. The heat flux is determined based on the average value of 0.154 Btu/hr-in^2 for the curved surface discussed previously.

Volumetric heat generation (Btu/hr-inch^3) is applied to the active fuel region on the basis of a total heat load of 20 kW, with an active fuel rod length of 144 inches, and an axial power distribution as shown in Figure 3.4-2. While CE 14x14 has a shorter fuel length of 128 inches, Volumetric heat generation based on the design heat load of 20 kW with a peaking factor of 1.1 is applied to the fuel pellets. The temperature at the boundary of the model is constrained to be uniform. The effective conductivity is determined on the basis of the heat generated and the temperature difference from the center of the model to its edge. The temperature-dependent effective properties are established by using different boundary temperatures. The effective conductivity in the axial direction of the fuel assembly is calculated on the basis of a weighted average of the axial cross sectional area.

3.4.1.1.3 Two-Dimensional Fuel Tube Model: PWR Fuel

The effective conductivity of the fuel tube and neutron absorber plate, which is used in the three-dimensional canister model, is determined by the two-dimensional fuel tube model. As shown in Figure 3.4-4, this model includes the fuel tube, the neutron absorber plate (including the core matrix sandwiched by aluminum claddings), gaps on both sides of the neutron absorber plate, and a gap between the stainless steel cladding for the neutron absorber plate and the support disk or heat transfer disk. The neutron absorber plate in the PWR fuel tube is composed of 62.34% B_4C and 37.66% aluminum.

ANSYS PLANE55 conduction elements and LINK31 radiation elements are used to construct the model, which consists of eight layers of conduction elements and six radiation elements that are defined at the gaps (two per gap). The thickness of the model (x-direction) is the distance measured from the inside dimension of the fuel tube to the inside dimension of the slot in the support disk (assuming that the fuel tube is located at the center of the disk slot). The tolerance of the neutron absorber plate core thickness, 0.003 inch, is used as the gap size for both sides of the neutron absorber plate. The model height is defined to be the same dimension as the model thickness.

A heat flux is applied at the left side of the model and the temperature at the right boundary of the model is constrained. The heat flux is determined on the basis of design heat load of 20 kW with a peaking factor of 1.1. The maximum temperature of the model (at the left boundary where the heat flux is applied) is calculated by using ANSYS. The effective conductivity through the thickness of the tube is determined by using the following equation:

$$q = K_{eff}(A/L)\,\Delta T, \text{ or}$$
$$K_{eff} = qL/(A\,\Delta T)$$

where:

q = heat rate applied to inner surface of fuel tube (Btu/hr)
A = area (in^2)
L = thickness of composite tube model (in)
ΔT = temperature difference across the model (°F)
K_{eff} = effective conductivity (Btu/hr-in-°F).

The temperature-dependent conductivity for heat conduction through the wall (K_{eff}) is determined by varying the temperature constraint at the boundary of the model and then re-solving for the temperature difference. The effective conductivity for heat conduction parallel to the axis of the cask body or in the plane of the tube wall is calculated on the basis of the weighted average of the thickness and conductivity of the individual layers.

3.4.1.2 Analytical Models: Cask with BWR Fuel Canister

The finite element ANSYS models used in the thermal analysis of the cask transporting BWR fuel are similar to those used in the thermal analysis of the cask with PWR fuel canister discussed in previous sections. A three-dimensional model is employed to evaluate the cask in a horizontal position with the basket in contact with the canister, which, in turn, is in contact with the cask inner shell. The fuel regions and the fuel tubes with neutron absorber plates are modeled by using effective conductivities. A detailed two-dimensional thermal model of the fuel assembly is used to determine the effective conductivity of the fuel. A two-dimensional thermal model of the fuel tube is used to calculate the effective conductivities of the fuel tube wall and neutron absorber plate. Another two-dimensional thermal model for the fuel tube is used to calculate the effective conductivity of the fuel tube wall with no neutron absorber plate present. These four ANSYS thermal models are described in the following sections.

3.4.1.2.1 Three-Dimensional Cask Model: Cask with BWR Fuel Canister

The three dimensional Universal Transport Cask model is a half-symmetry finite element model constructed by using ANSYS Revision 5.5. The model considers the fuel assemblies, fuel tubes, stainless steel support disks, aluminum heat transfer disks, canister shell, lids and bottom plate, spacers at the bottom of the canister, cask inner shell, lead, outer shell, neutron shield, and neutron shield shell. The ANSYS model is shown in Figure 3.4-5. As shown in the figure, the internal cavity of the canister contains the active fuel region: the top and bottom fittings of the fuel assemblies, fuel tubes enclosing the top and bottom fittings, and the first stainless steel support.

For the BWR configuration, the gas inside the canister and the cask cavity is modeled as helium because the cavity will be backfilled with helium prior to transport. Conduction and radiation are modeled by using ANSYS "SOLID70" and "LINK31" elements, respectively. The principal gaps applied to the model are shown in Figure 3.1-2 and are described in Section 3.2.2.3. In establishing these gaps, the differential thermal expansion between the components is considered.

Because the canister is in horizontal position during transport, the elements for the canister shell are shifted downwards to simulate contact with the inner shell of the cask. Similarly, the support disks and the heat transfer disks are shifted downward to simulate contact with the canister shell. As shown in Figure 3.1-2, a 2-degree contact is considered for the gaps between the canister shell and the cask inner shell and between the support disk and the canister shell. This contact is simulated by using appropriate conductivity (100 Btu/hr-inch-°F) for elements at the contact locations. The aluminum heat transfer disks are assumed to have only a line contact with the canister shell because the heat transfer disks are not subjected to any loads other than their own weight.

To account for differential expansion, gaps within the model are adjusted on the basis of temperature and defined physical contact conditions. Solar insolance and ambient temperature conditions are applied to the neutron shield shell when appropriate. Insolance is used at the exterior surface of the cask and is based on the amount of insolation required by 10 CFR 71 to be applied over a 12-hr period evaluated in the steady state (applied over 24 hr simulating 12-hr period of solar exposure and 12-hr period of no solar exposure). The heat flux resulting from insolation on a curved surface is calculated as follows:

$$1475\frac{\text{Btu}}{12\ \text{hr - ft}^2} \times \frac{12\ \text{hr}}{24\ \text{hr}} \times \frac{1\ \text{ft}^2}{144\ \text{in}^2} = 0.427\ \text{Btu/hr-in}^2$$

Multiplying this value by the emissivity of the cask surface, $\epsilon = 0.36$, gives a heat flux resulting from insolance on curved surfaces of 0.154 Btu/hr-in^2. Using the same method and a heat flux of

2,950 Btu/12 hr-ft^2 (0.853 Btu/hr-in^2), gives a heat flux resulting from insolance on flat surfaces of 0.307 Btu/hr-in^2.

The model is analyzed to determine the maximum temperatures for the basket, canister, cask shells, radial shielding, and surface conditions under normal conditions of transport. All material properties are shown in Tables 3.2-1 through 3.2-13.

The fuel regions (inside tubes) are modeled as homogeneous regions with effective conductivities determined by the two dimensional fuel model as described in Section 3.4.1.2.2. All sides of the BWR fuel tubes do not contain the neutron absorber plate. Therefore, two different two-dimensional BWR fuel tube models are analyzed to establish the effective conductivities used in the three dimensional analysis of the cask with BWR fuel. The models consist of the neutron absorber plate (where applicable), including gas gaps on both sides of the neutron absorber sheet (where applicable), and the gap between the stainless steel cladding for the neutron absorber and the support disks and heat transfer disks. These models are discussed in Section 3.4.1.2.3.

The radial neutron shield of the transport cask for the BWR configuration is identical to PWR configuration. The modeling of the radial neutron shield is described in Section 3.4.1.1.

In the model, radiation heat transfer is considered from the top of the fuel region to the bottom surface of the canister shield lid, from the bottom of the fuel region to the top surface of the canister bottom plate, and from the exterior surfaces of the fuel tubes to the inner surface of the canister shell. This radiation is modeled by using LINK31 radiation elements. Radiation across gaps in the model is described in Sections 3.2.2.3 and 3.2.2.4.

Radiation at the neutron shield shell surface to ambient is combined with the convection effect by using the method described in Section 3.2.2.2. The convection heat transfer coefficient is calculated on the basis of the formula shown in Section 3.2.3. Effective emissivities are used for all radiation calculations, with the form factor taken to be unity. Effective emissivity is computed by using the following formula [9] based on corresponding material emissivities:

$$\varepsilon_{eff} = 1 / (1/\varepsilon_1 + 1/\varepsilon_2 - 1)$$

Solar insolance is applied to the neutron shield shell surface for the "Hot" condition (ambient temperature = 100°F). A value of 0.154 Btu/hr-inch^2 is used as the heat flux at the neutron shield shell surface on the basis of the 1,475 Btu/hr-ft^2 heat flux for a curved surface. Calculation of the heat flux resulting from insolation on a curved surface is discussed earlier in this section.

Volumetric heat generation (Btu/hr-inch^3) is applied to the active fuel region on the basis of a total heat load of 16 kW, a shortest active fuel rod length of 144 inches, and an axial power with a peaking factor of 1.22 as shown in Figure 3.4-6.

3.4.1.2.2 Two-Dimensional Fuel Assembly Model: BWR Fuel

The effective conductivity of the fuel is determined by a detailed two-dimensional finite element thermal model of the BWR 9x9 fuel assembly. Taking advantage of the symmetry of the cross-section of the fuel, the finite element model represents a one-quarter section of the fuel. The model includes the fuel pellets, cladding, gas between the fuel rods, and gas occupying the gap between the fuel pellets and cladding. Modes of heat transfer modeled include conduction and radiation between individual fuel rods for the steady-state condition. The model is shown in Figure 3.4-7. Thermal analyses of the other BWR fuel assemblies (i.e., 7x7 and 8x8) are performed; however, because the BWR 9x9 fuel assembly results in the lowest effective thermal conductivities, only the analysis of that fuel assembly is presented in this section.

ANSYS PLANE55 conduction elements and LINK31 radiation elements are used in the model, which includes a total of 20.25 fuel rods (representing a total of 81 fuel rods for the full cross-section). Each fuel rod consists of the pellet, Zircaloy cladding, and a gap between the pellet and clad. The gas in the gap between the pellet and clad, as well as the gas between the fuel rods, is modeled as helium. Radiation elements are defined between rods and from rods to the boundary of the model (inside surface of the fuel tube). Radiation effect at the gaps between the pellet and clad is conservatively ignored. Effective emissivities are determined by using the formula shown in Section 3.4.1.1.1.

The effective conductivity for the fuel is determined by using a two-step procedure. Using the fuel assembly model, a uniform temperature is applied to the exterior of the model (see Figure 3.4-7) in conjunction with the volumetric heat generation. From this analysis, the maximum temperature located at the center of the fuel assembly is determined. This maximum temperature occurs at the corner of the model, which represents the center of the entire fuel assembly.

A Sandia National Laboratory Report [10] defines an expression for use in determining the maximum temperature of a square cross section of an isotropic homogeneous fuel with uniform volumetric heat generation. At the boundary of this square cross section, the temperature is constrained to be uniform. The expression for the maximum temperature is given by:

$$T_c = T_e + 0.29468 \frac{Q a^2}{K_{eff}}$$

where:

- T_c = temperature at center of fuel (°F)
- T_e = temperature applied at exterior of fuel (°F)
- Q = volumetric heat generation rate (Btu/hr-in^3)
- a = half-length of square cross section of fuel (inch)
- K_{eff} = effective thermal conductivity for isotropic homogeneous fuel material (Btu/hr-in-°F).

Using the maximum temperature, located at the center of the fuel, from the detailed fuel assembly model, the preceding expression is used to determine the K_{eff} for an isotropic homogeneous representation of the fuel assembly.

Volumetric heat generation based on the design heat load of 16 kW with a peaking factor of 1.22 is applied to the fuel pellets. The temperature at the boundary of the model is constrained to be uniform. The effective conductivity is determined on the basis of the heat generated and the temperature difference from the center of the model to its edge. The temperature-dependent effective properties are established by using different boundary temperatures. The effective conductivity in the axial direction of the fuel assembly is calculated on the basis of the material area ratio.

3.4.1.2.3 Two-Dimensional Fuel Tube Models: BWR Fuel

The fuel tubes in the BWR fuel basket differ from those in the PWR fuel basket in that not all sides of the fuel tubes contain neutron absorber. Therefore, two effective conductivity models are necessary—one fuel tube model with the neutron absorber plate (a total of 10 layers of materials) and another fuel tube model with a gas gap replacing the neutron absorber plate (a total of 4 layers of materials). Additionally, the neutron absorber plate in the BWR fuel tube is composed of 16.46% B_4C and 83.54% aluminum, whereas the neutron absorber plate in the PWR fuel tube is composed of a 62.34%—37.66% composition of B_4C and aluminum.

The effective conductivity of the fuel tube and neutron absorber plate, which is used in the three-dimensional canister model, is determined by a two-dimensional fuel tube model. As shown in Figure 3.4-8, this model includes the fuel channel, gas gaps between the fuel channel and fuel tube. the fuel tube, the neutron absorber plate (including the core matrix sandwiched by aluminum claddings), gas gaps on both sides of the neutron absorber plate, and a gas gap between the stainless steel cladding for the neutron absorber plate and the support disk or heat transfer disk.

Additionally, the effective conductivity of the fuel tube without the neutron absorber plate, which is used in the three-dimensional canister model, is determined by another two-dimensional fuel tube model. As shown in Figure 3.4-9, this model includes the fuel channel, gas gaps between the fuel channel and stainless steel fuel tube, the fuel tube, and a gas gap between the stainless steel cladding and the support disk or heat transfer disk.

ANSYS PLANE55 conduction elements and LINK31 radiation elements are used to construct the models. The model with the neutron absorber plate consists of 10 layers of conduction elements and 8 radiation elements that are defined at the gas gaps (two per gap). The model without the neutron absorber plate consists of four layers of conduction elements and four radiation elements that are defined at the gas gaps (two per gap). The thickness of the models (x-direction) is the distance measured from the inside dimension of the fuel channel to the inside dimension of the slot in the support disk (assuming that the fuel tube is located at the center of the disk slot). In the model containing the neutron absorber plate, the tolerance of the neutron absorber plate core thickness, 0.0045 inch, is used as the gap size for both sides of the neutron absorber plate. The height of the models is defined to be the same dimension as the thickness of the models.

In each analysis, a heat flux is applied at the left side of the model and the temperature at the right boundary of the model is constrained. The heat flux is determined on the basis of the design heat load of 16 kW with a peaking factor of 1.22. The maximum temperature of the model (at the left boundary) and the temperature difference (ΔT) across the model are calculated by using ANSYS. The effective conductivity is determined by using the following formula:

$$q = K_{eff}(A/L)\,\Delta T$$

or

$$K_{eff} = qL/(A\,\Delta T)$$

where:

q = heat rate applied to inner surface of fuel tube (Btu/hr)
A = area (in^2)
L = thickness of composite tube model (in)
ΔT = temperature difference across the model (°F)
K_{eff} = effective conductivity (Btu/hr-in-°F).

The temperature-dependent conductivity (K_{eff}) in each analysis is determined by varying the temperature constraint at the boundary of the model and then re-solving for the temperature difference. The effective conductivity for the parallel path is calculated on the basis of area ratio of material.

3.4.1.3 Cask Impact Limiter Thermal Model

As described in Sections 3.4.1.1 and 3.4.1.2, the cask impact limiters are not explicitly modeled in the 3D cask models. In these models, the cask ends enclosed by the impact limiters are modeled as being adiabatic surfaces. The cask impact limiters are evaluated thermally for normal operating conditions in this section. Specifically, the volumetric average temperature of the redwood material in the cask impact limiters is calculated using an ANSYS finite element model. Taking advantage of the symmetrical geometry of the cask impact limiters about the major axis of the cask, the finite element model is an axisymmetric representation of one of the impact limiters with the cask oriented in a horizontal position. This represents the orientation of the impact limiters during normal transport. The cask impact limiter thermal model is shown in Figure 3.4-10.

The finite element model of the cask impact limiter is constructed of PLANE55 axisymmetric thermal elements, and radiation and conduction heat transfer across air gaps within the model are accounted for using effective thermal conductivity properties for air using the method described in Section 3.2.2.3. Air gaps are modeled between the cask and impact limiter based upon nominal dimensions. Additionally, a 0.125-in thick layer of Fiberfrax® Ceramic Fiber Paper is modeled between the impact limiter redwood and the cask mating surface of the impact limiter. A heat flux of 0.13 Btu/h-in², which represents the package contents, is applied to the interior surface of the cask lid. This heat flux is obtained from the thermal results for the 3D cask model with the PWR canister and air as the canister cover gas (described in Section 3.4.1.1) by conservatively assuming the heat transfer rate to the cask lid is equal to the heat transfer rate to the canister shield lid.

Heat fluxes representing the normal conditions solar heat loads are applied to the cylindrical and vertical flat end surfaces of the impact limiter as shown in Figure 3.4-10. The solar heat flux applied to the vertical flat surfaces of the impact limiter 0.0769 Btu/h-in² model (which is in the normal transport orientation) are calculated in the same manner described in Section 3.4.1.1.1 using the prescribed solar heat flux value of 737 Btu/12-hr-ft². A solar heat flux of 0.154 Btu/hr-in² is applied to the cylindrical portions of the cask and impact limiter modeled.

A steady-state heat transfer analysis is performed using the ANSYS model described in this Section. The volumetric average temperature of the cask impact limiter redwood material (T_{avg}) is calculated from the results of the thermal steady state analysis.

3.4.1.4 Personnel Barrier Thermal Model

According to 10 CFR 71.43(g), a package must be designed, constructed, and prepared for transport such that in still air at 100°F and shade, no accessible surface of the package has a temperature exceeding 185°F in an exclusive use shipment. Compliance with 10 CFR 71.43(g) is demonstrated by performing a computational fluid dynamics (CFD) analysis on a finite element model of the air between the cask surface (i.e., neutron shield shell) and the personnel barrier using ANSYS/FLOTRAN. The finite element model is constructed of two-dimensional FLUID141 elements and is presented in Figure 3.4-11.

Because of geometrical symmetry, only one-half of the cask and the air around the cask is modeled. In addition to the natural convection of the air, thermal radiation heat transfer from the cask outer surface to the personnel barrier is considered in this model. It is conservative to only model the air between the cask surface and the personnel barrier because it results in a higher air velocity and more heat is carried to the top of the personnel barrier. Along the centerline of the model, the horizontal velocity component is specified to be zero. The nodes at the location of the personnel barrier (except the top side) are conservatively defined as wall conditions (Velocity = 0) to force all of the heat out from the top of the barrier. At the inlet (bottom side of the model), the pressure is set to atmospheric pressure with the temperature constrained to 100°F. The portion of the model corresponding to the cask surface constrains both the horizontal and vertical components of the velocity to be zero.

The cask and personnel barrier are not explicitly modeled in this analysis—only the air surrounding the cask is modeled. It is conservative that the personnel barrier is not explicitly modeled because it will not have a temperature greater than the temperature of the air in contact with it. The temperatures of nodes in the model that correspond to the air adjacent to the cask surface are constrained as boundary conditions of the model. The temperature is considered to be linearly distributed, with the bottom and top temperatures equal to 267°F and 244°F, respectively.

Since the personnel barrier is not explicitly modeled, its temperature is considered to be the temperature of the air at coordinates that correspond the location of the personnel barrier surface. The maximum temperature of the personnel barrier occurs at the top most location at the centerline of the model. The temperatures at key points from the analysis using the model described above are shown in Figure 3.4-12.

3.4.1.5 Test Model

The methods previously described have been used in previous transport cask licensing and are sufficient to show that the Universal Transport Cask meets the criteria set forth in Section 3.4. Therefore, no thermal test model is created.

3.4.2 Maximum Temperatures

Using the thermal models described in Sections 3.4.1.1 and 3.4.1.2, temperatures for the PWR and BWR cask body, canister, basket, and fuel rod cladding are determined for three normal conditions of transport: (1) maximum decay heat, 100°F ambient temperature, and solar insolance; (2) maximum decay heat, -40°F ambient temperature, and no insolance; and (3) no decay heat, -40°F ambient temperature, and no insolance. The maximum temperatures of the principal PWR and BWR cask components, canister, basket components, and fuel rod cladding are shown in Tables 3.4-1 and 3.4-2 for the first two environmental conditions listed above. For the third environmental

Figure 3.4-8 Two-Dimensional BWR Fuel Tube (with neutron absorber) Model

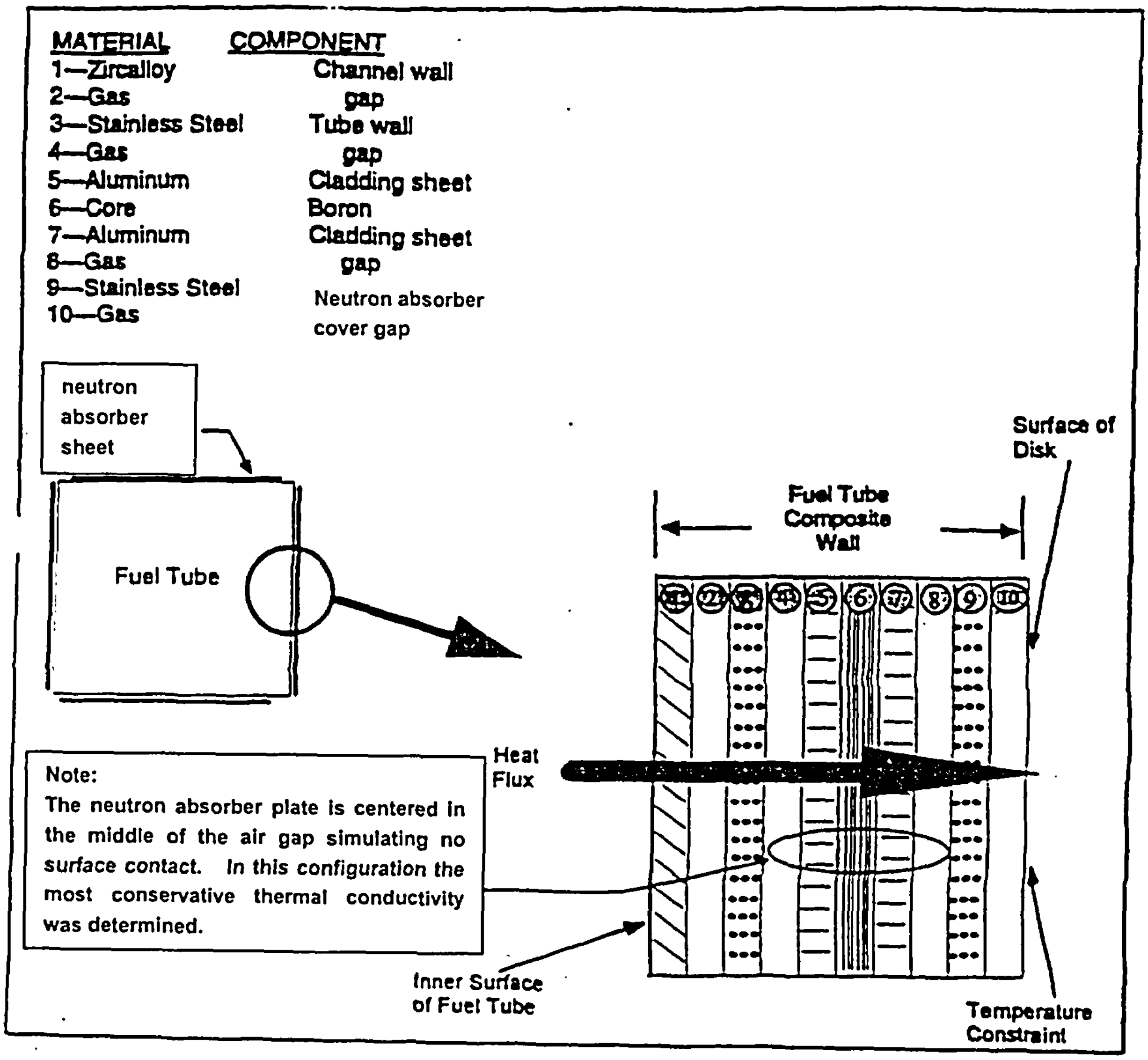
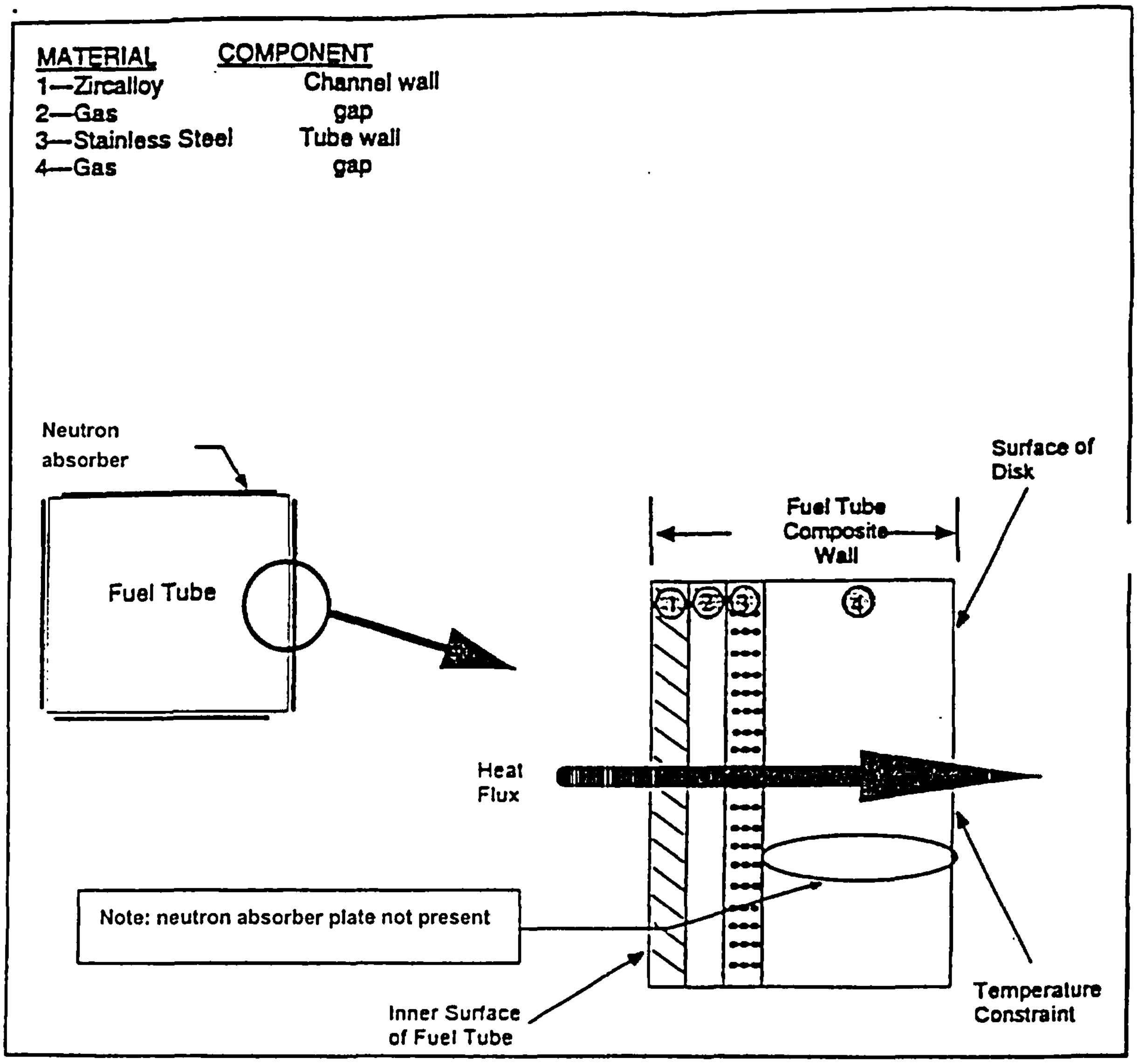


Figure 3.4-9 Two-Dimensional BWR Fuel Tube (without neutron absorber) Model



3.6 Thermal Evaluation for Site Specific Contents

3.6.1 Maine Yankee Site Specific Contents

The standard spent fuel assembly for the Maine Yankee site is the Combustion Engineering (CE) 14x14 fuel assembly. Fuel of the same design has also been supplied by Westinghouse and by Exxon. The standard 14x14 fuel assembly is included in the population of the design basis PWR fuel assemblies for the UMS Transport System (see Table 1.2.5). The maximum decay heat for the Maine Yankee fuel is limited to the design basis heat load for the PWR fuels (20 kW total, or 0.83 kW per assembly). This heat load is bounded by the thermal evaluations in Sections 3.4 and 3.5 for the normal conditions of transport and hypothetical accident conditions, respectively.

The Maine Yankee site specific fuels and GTCC waste are described in Sections 1.3.1.1.1 and 1.3.1.1.2, respectively.

The thermal evaluations of the Maine Yankee site specific fuels and the GTCC waste are provided in Sections 3.6.1.1 and 3.6.1.2, respectively.

Preferential loading of the Maine Yankee site-specific fuel assemblies is governed by the standard fuel inventory requirement presented in the Approved Contents and Design Features for the NAC-UMS® System in Chapter 12 of the Final Safety Analysis Report (FSAR) for the UMS® Universal Storage System, Docket Number 72-1015. Loading fuel assemblies for storage with a cool time of less than 7 years requires a preferential loading arrangement with shorter-cooled fuel placed at the canister interior locations. The corresponding thermal evaluation for the transport system is shown in Section 3.4.2.1. Maine Yankee site-specific preferential loading patterns placing high heat load (1.05 or 0.958 kW) fuel in basket peripheral locations, as allowed in Chapter 12 of the UMS® Universal Storage System FSAR, are not applicable for the transport system. All fuel assemblies loaded in the transport cask must meet the standard configuration transport minimum allowable heat load limits and cool time tables. As such, a transportable storage canister loaded under the Maine Yankee site-specific high heat load preferential loading option will require additional cool time for the peripheral assemblies to meet the transport cask cool time requirements shown in Table 1.3.1-2 (also Table 5.5.1.1-10). This assures that a loaded canister will meet all thermal and shielding limits for transport.

Some Maine Yankee site-specific fuel has a burnup greater than 45,000 MWD/MTU, but less than 50,000 MWD/MTU. Loading of these fuel assemblies is subject to preferential loading in peripheral positions of the basket.

3.6.1.1 Spent Fuel

The Maine Yankee site specific fuels included in this evaluation are:

1. Consolidated fuel rod lattices consisting of a 17x17 lattice fabricated with 17x17 grids, 4 stainless steel support rods and stainless steel end fittings. One of these lattices contains 283 fuel rods and 2 vacancies. The other contains 172 fuel rods, with the remaining locations either empty or containing stainless steel dummy rods.
2. Standard fuel assemblies with a Control Element Assembly (CEA) inserted in each one.
3. Standard fuel assemblies that have been repaired by removing damaged fuel rods and replacing them with stainless steel dummy rods, solid zirconium rods, or 1.95 wt % enriched fuel rods.
4. Standard fuel assemblies that have had the burnable poison rods removed and replaced with hollow Zircaloy tubes.
5. Standard fuel assemblies with in-core instrument thimble assemblies stored in the center guide tube.
6. Standard fuel assemblies that are designed with variable enrichment (radial) and axial blankets.
7. Standard fuel assemblies that have fuel rods removed.
8. Fuel assemblies with damaged fuel rods.

The thermal evaluations of these site specific fuels are provided below. The maximum heat load per assembly is limited to the design basis heat load (0.83 kW) for all Maine Yankee site specific fuels.

1. Consolidated Fuel

There are two (2) consolidated fuel lattices (pseudo assemblies). The maximum decay heat of each consolidated fuel assembly is 0.279 kW. The heat load of the consolidated fuel lattice with 283 fuel pins is bounded by the design basis PWR fuel assembly, since its heat load is only one-third (0.279/0.83) of the design basis heat load.

7. Standard fuel assemblies that have fuel rods removed from the lattice.

There is one fuel assembly that has 107 rods removed. This fuel assembly has a heat load of 70 watts (only 8% of the design basis heat load of 0.83 kW). For the rest of fuel assemblies that have fuel rods removed from the lattice, the maximum number of removed fuel rods is 14, which is 8% (14/176) of the total number of rods in one fuel assembly. The maximum heat load for any one of these fuel assemblies is conservatively determined to be 0.63 kW. This heat load is 24% less than the design basis heat load of 0.83 kW. Therefore, the thermal performance for the configuration that contains standard fuel assemblies bounds that of the fuel assemblies with removed rods.

8. Damaged Fuel Assemblies

Damaged fuel assemblies are standard fuel assemblies with fuel rods that have known or suspected cladding defects greater than hairline cracks or pinhole leaks. Each damaged fuel assembly will be placed in one of the two configurations of the Maine Yankee fuel can. The primary function of the fuel can is to confine fuel material within the can and to facilitate handling and retrievability. The Maine Yankee fuel can is shown in Drawings 412-501 and 412-502. The placement of the loaded fuel cans is restricted by operating procedures and/or Technical Specifications to loading into the four fuel tube positions at the periphery of the fuel basket as shown in Figure 3.6.1.1-4. The heat load for each damaged fuel assembly is limited to the design basis heat load of 0.833 kW (20 kW/24).

A steady-state thermal analysis is performed using the three-dimensional cask model described in Section 3.4.1.1.1 simulating 100% failure of the damaged fuel rods held in the Maine Yankee fuel can. The canister is assumed to contain twenty (20) design basis PWR fuel assemblies and damaged fuel assemblies in fuel cans in each of the four corner positions.

A debris compaction length of 104 inches is considered in the analysis based on the volume of fuel rods and a 50% compaction of the debris. Additionally, this 104-inch debris region is assumed to be located at the center of the active fuel region of the design basis PWR fuel assemblies, as shown in Figure 3.6.1.1-4. The entire heat load for a single fuel assembly (i.e., 0.833 kW) is considered to be concentrated in the debris region. The effective thermal conductivities for the design basis PWR fuel assembly (Section 3.4.1.1.2) are used for the debris region. This is conservative, since the debris (100% failed rods) is expected to have a higher density (better conduction) and more surface area (better radiation) than an intact fuel assembly. In addition, the thermal conductivity of helium is used for the remainder of the active fuel length. Boundary conditions corresponding to normal transport are used at the outer surface of the cask (see Section 3.4.1.1.1). The results of the steady-state thermal analysis for 100% fuel rod, fuel cladding and guide tube failure are:

Description	Maximum Temperature (°F)			
	Fuel Cladding	Damaged Fuel	Support Disk	Heat Transfer Disk
Configuration with damaged fuel loaded in four basket corner locations	682	633	618	614
Design basis PWR fuel	673	N/A	608	605
Allowable	750	N/A	650	700

As shown by the previous data, the maximum temperatures for the fuel cladding, damaged fuel assembly, support disks, and heat transfer disks for the configuration with damaged fuel loaded in four (4) basket corner locations are within the allowable temperature range. Additionally, the maximum temperature of the support disk remains bounded by that used in the structural analyses of the fuel basket.

The effect of the compaction of the damaged fuel is most significant for the interior of the basket, and this effect is determined to be 10 °F, as shown in the table above. For the cask body closure lid seal, the effect of the damaged fuel is expected to be insignificant, since the transportable storage canister shield and structural lids, representing a thickness of 10 inches of steel, separate the fuel from the cask body closure lid seals. The canister lids act to spread any concentration of heat from the damaged fuel. The port cover seals are even more remote from the damaged fuel than the cask body lid seals and, therefore, are not considered to be affected by the damaged fuel.

Damaged high burnup fuel must be loaded into one of two configurations of Maine Yankee damaged fuel cans. Consistent with the containment analysis, a basket release fraction of 20% is applied. This release fraction accounts for up to 12 high burnup assemblies, including up to four classified as damaged. Applying this release fraction to the pressure evaluation in Section 3.4.4.1 yields a normal conditions cask pressure of 15.61 psig, calculated using B&W 17x17 Mark C fuel assembly parameters.

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Mixture A_2 values are determined for gas, volatile, fine, and crud mixtures and are then combined for a total cask mixture A_2 value. Tables 4.2-2 and 4.2-3 provide the source term and A_2 values per group for PWR and BWR cask systems release rate calculations.

Maximum Allowable Leak Rates

On the basis of the methodology discussed above, the maximum allowable leak rates for the casks containing standard or high burnup PWR and BWR standard fuel under normal conditions of transport are calculated to be 5.5×10^{-6} and 1.3×10^{-5} ref cm^3/sec, respectively (Table 4.2-4).

The maximum allowable release rates are more restrictive for the cask containing high burnup damaged PWR assemblies because of the conservative assumption of a higher failure rate. The bounding case containment analysis loading assumed is, therefore, 12 intact standard assemblies failing at 3%, 8 high burnup assemblies failing at 4.5%, and 4 high burnup assemblies failing at 50%. The 4 high burnup assemblies failing at 50% are assumed to be located in damaged fuel cans. This configuration is bounded by the 20% average release fraction applied to a full canister load of high burnup assemblies.

4.2.1.2 Correlation of Allowable Leak Rates to Air Standard

The volumetric gas leak rate is independent of transport cask pressure and temperature. The maximum allowable release must be correlated with air standard leak rates, which depend on gas temperatures, pressures, and leakage path length and diameter. This correlation requires calculation of the capillary opening diameter through which the flow occurs. Depending on pressure and condition of the flow, a combination of continuum and molecular flow occurs.

Continuum flow and molecular flow equations are obtained from NUREG/CR-6487, Section 2. Both continuum and molecular flow rate equations presented below are adjusted to upstream flow rate in accordance with NUREG/CR-6487 and ANSI N14.5-1997.

The continuum volumetric flow rate of the gas (cm^3/sec), L_c, is given by:

$$L_c = \frac{2.48x10^6 D^4}{a\mu}(P_u - P_d) * \frac{P_a}{P_u} = F_c * (P_u - P_d) * \frac{P_a}{P_u}$$

where:

F_c	=	coefficient for continuum flow [cm^3/atm-s]
D	=	capillary diameter [cm]
a	=	capillary length [cm]
μ	=	fluid viscosity [cP]
P_u	=	upstream pressure [atm] - pressure inside containment
P_d	=	downstream pressure [atm] - pressure outside containment

and, the molecular volumetric flow rate of the gas (cm^3/sec), L_m, is given by:

$$L_m = \frac{3.81x10^3 D^3 \sqrt{\frac{T}{M}}}{aP_a}(P_u - P_d) * \frac{P_a}{P_u} = F_m * (P_u - P_d) * \frac{P_a}{P_u}$$

where:

L_m	=	is the volumetric flow rate of gas at P_a [cm^3/sec]
F_m	=	is the coefficient for molecular flow [cm^3/atm-s]
D	=	is the capillary diameter [cm]
T	=	is the gas temperature [K]
M	=	is the gas molecular weight [g/mole]
P_a	=	is the average pressure $(P_u+P_d)/2$ [atm]
P_u	=	is the upstream pressure [atm]
P_d	=	is the downstream pressure [atm].
a	=	capillary diameter [cm]

For this analysis, the gas temperature used for molecular flow analysis is identical to the upstream temperature. Pressures and temperatures for PWR and BWR system normal operating conditions are summarized in Table 4.2-5. Based on the pressure, temperature and allowable leakage rate (L_N) the capillary diameter of the leak is determined. The calculated capillary diameter is then used to determine the air standard leak rate and helium test leak rate. Air standard condition leak rates are determined for air leaking from 1 atmosphere to 0.01

4.5.1 Containment Evaluation for Site Specific Contents

4.5.1.1 Containment Evaluation for Maine Yankee Contents

Pressure and radionuclide content of the Maine Yankee 14×14 fuel assemblies are bounded by the larger B&W 15×15 assembly employed in the containment evaluations presented in Sections 4.2 and 4.3. The larger fission mass of the B&W assembly produces higher fission gas inventories for a fixed burnup. The Maine Yankee fuel assemblies, with non-fuel components or in consolidated or damaged form (up to four consolidated or damaged assemblies per canister) displaces less free volume than the B&W fuel assembly forming the design basis for the containment analysis, and, therefore, results in lower pressures at a fixed decay heat.

Maine Yankee fuel with up to 50,000 MWD/MTU may be loaded in the transportable storage canister. High burnup fuel must be loaded in the outer fuel loading positions of the basket. The PWR basket has 24 fuel loading positions, including 12 outer positions.

The PWR containment analysis in Section 4.2.1 assumes 4 PWR (high burnup) fuel assemblies failing at 100%, 8 high burnup fuel assemblies failing at 4.5%, and the remaining 12 assemblies failing at 3%. This results in 20% of the fuel rods failing in normal conditions and bounds the presence of four Maine Yankee damaged fuel cans of either configuration (see Drawings 412-501 and 412-502) in the basket. The PWR leak rate calculation is based on the higher failure fraction.

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Chapter 5

5.1 Discussion and Results

The radiation protection provided by the Universal Transport Cask is in the form of solid multiwalled shielding materials that completely surround the fuel. These shielding materials include steel and lead for gamma shielding and a borated polymer (NS-4-FR) for neutron shielding. The multiwalled arrangement of steel and lead in the cask provides an optimal gamma shield. The NS-4-FR neutron shielding material, with a hydrogen density close to that of water, moderates neutrons and facilitates their capture in boron.

The multiwalled shielding arrangement is employed in both radial and axial shields. The configuration of the radial gamma shielding in the cask body is a 2.0 in thick stainless steel inner shell and a 2.75 in thick stainless steel outer shell with a 2.75 in lead-filled annulus between the two. The radial neutron shield is arranged around the outer steel shell with a 4.5 in thick NS-4-FR layer, which is covered by a 0.25 in thick stainless steel neutron shield shell. The bottom of the cask contains a steel/NS-4-FR/steel shield arrangement in which the two stainless steel components provide a total of 9.25 in of gamma shielding with a 1 in layer of NS-4-FR neutron shielding between them. The top of the cask provides additional shielding in the form of a 6.50 in thick stainless steel closure lid.

The Universal Transport Cask is designed to accommodate a variety of fuel assembly types. Because assembly lengths vary, fuel assemblies are segregated into five distinct classes, three for PWR fuel and two for BWR fuel accommodated by five classes of canisters. The canister designs differ only in their internal cavity length and basket structure. To accommodate the shorter canister classes, a spacer assembly is placed beneath the canister to ensure proper canister positioning within the cask cavity. For each reactor type, the shielding analysis develops bounding dose rates for a specific design basis fuel assembly type and its associated canister.

These design basis fuel assemblies are determined on the basis of the results of one-dimensional shielding analyses conducted for a number of candidate assembly designs. These candidate assembly types are selected on the basis of their radiation source terms as determined by detailed SAS2H isotopic depletion calculations performed for each assembly. Representative PWR and BWR fuel assembly designs are selected for the source term analysis on the basis of initial uranium loading and non-fuel hardware compositions and masses. Hence, the following analytical procedure is used to identify the design basis PWR and BWR fuel assemblies. First, among all assembly types for which the Universal Transport Cask is intended, those assemblies expected to have the highest source terms are first identified on the basis of initial loading of heavy metal and other factors. Then, detailed source descriptions of these assemblies are developed by using the SCALE SAS2H code [4]. To identify the bounding PWR and BWR assemblies, the resulting source descriptions are employed in one-dimensional shielding calculations. Full three-dimensional analysis of the resulting design basis assemblies is then conducted to establish licensing basis dose rates.

5.1.1 Fuel Assembly Classification

5.1.1.1 PWR Fuel Assembly Classes

The Universal Transport Cask is designed to transport up to 24 intact PWR design basis fuel assemblies. As discussed in Chapters 1.0 and 6.0, the PWR fuel assemblies to be transported in the cask are compiled into three classes on the basis of similarity of their lengths. Of the PWR assemblies to be transported in the cask, the following four are identified as representative assemblies on the basis of their computed radiation source terms:

- Westinghouse 15×15 Std (Class 1)
- Westinghouse 17×17 Std (Class 1)
- Babcock & Wilcox 15×15 Mark B (Class 2)
- Combustion Engineering 16×16 System 80 (Class 3)

These assemblies constitute the candidate design basis PWR fuel assemblies for the shielding analysis of the cask. One-dimensional shielding calculations are performed for each to identify a single assembly type, which is then selected as the design basis assembly for a subsequent detailed three-dimensional shielding analysis. The candidate PWR fuel assemblies are analyzed on the basis of an assumed initial enrichment of 3.7 wt % ^{235}U, a burnup of 45,000 MWD/MTU, and a cooling time of 10 years. The initial enrichment assumed in the shielding analysis is significantly less than the criticality analysis design basis value of 4.2 wt % so that the calculated neutron source rate bounds that of lower enrichment fuel which may reach the design basis burnup of 45,000 MWD/MTU. This assumption produces a neutron source that is 29% higher than that calculated assuming a 4.2 wt % ^{235}U initial enrichment.

5.5.1.1.4.4 Consolidated Fuel

There are two consolidated fuel lattices intended for shipment in the Universal Transport Cask. The lattices house fuel rods taken from assemblies as shown in Table 5.5.1.1-6. The consolidated fuel rods have decayed for over twenty years and do not represent a significant shielding issue.

A limiting cool time analysis is conducted by identifying a fuel assembly description analyzed in the loading table analysis which bounds the parameters of the fuel rods in the consolidated fuel lattices. The parameters of those fuel rods are shown in Table 5.5.1.1-17. The CE14x14 fuel at 30,000 MWD/MTU and 1.9 wt % enrichment represents a bounding assembly type since it has a significantly higher burnup and a lower enrichment than the original assemblies. This fuel requires six years cool time before it can be loaded in the transport cask as shown in Table 5.5.1.1-10. The consolidated fuel has been cooled for at least 24 years. For container CN-1 lattice, one can immediately conclude that dose rates are bounded by the limiting fuel.

However, the CN-10 lattice contains significantly more fuel rods than an intact assembly. Neglecting the mitigating effects of additional self-shielding, this configuration is addressed by comparing the radiation source strength of the limiting fuel at six and 24 years cool time. Conservatively assuming that all fuel rods present in CN-10 are at the limiting conditions of 30,000 MWD/MTU and 1.9 wt %, the ratio of the source rate in the CN-10 to the source rate in the limiting fuel assembly is shown to be less than one for each source type in Table 5.5.1.1-18. For each source type, the ratio is computed as:

Ratio = (Num Rods in CN-10)(Source Rate at 24 Yr) / (Num Rods in F/A)(Source Rate at 6 Yr)

Hence, CN-10 is also bounded by the limiting case and the consolidated fuel is eligible for shipment in the transport cask as of January 1, 2001.

5.5.1.1.4.5 Damaged Fuel

To provide minimum cool times for Maine Yankee damaged fuel inserted in one of two configurations of the Maine Yankee fuel cans (see Drawings 412-501 and 412-502) in the four corner locations of the basket, an analysis is performed that determines, for any given enrichment and burnup combination, the minimum cool time required for dose rates to fall below the design basis values for these locations. The analysis models the source term for combinations of enrichment, burnup, and cool time based on SAS2H results. The dose rate evaluation is made on the basis of computed three-dimensional dose rates that explicitly consider the effects of radiation spectrum and cask shielding properties. The analysis considers the migration of damaged fuel from the active fuel region into the upper end-fitting and upper plenum assembly regions.

5.5.1.1.4.5.1 Damaged Fuel Loading Table Analysis

The loading table analysis extends the applicability of the initial 10-year-cooled, 45,000 MWD/MTU PWR design basis shielding evaluation by providing minimum cool times for 30,000 to 50,000 MWD/MTU burned fuel assemblies in increments of 5,000 MWD/MTU. In addition to the burnup range, the loading table evaluation includes minimum initial enrichment limits ranging from 1.9 to 3.7 wt % ^{235}U in 0.2 wt % ^{235}U increments.

A complete set of source spectra for the design basis Maine Yankee CE 14×14 fuel assembly is computed using the SAS2H code at various initial enrichment, burnup, and cool times representative of the fuel inventory intended for shipment. Next, the damaged fuel material descriptions are computed for the upper end-fitting and upper plenum assembly regions. The volume of void space in each region is calculated and is then assumed completely filled with UO_2. Thus, 56% of the assembly fuel mass is assumed to migrate into the upper assembly region with no reduction in fuel modeled over the active fuel length.

With the damaged fuel defined, gamma and neutron source spectra for the four corner basket locations are constructed based on the mass of UO_2 in each fuel assembly region for seven sources: active fuel gamma; active fuel neutron; active fuel hardware; upper end-fitting gamma; upper end-fitting neutron; upper plenum gamma; and upper plenum neutron.

Because of the migration of the fuel out of the active fuel region, the one-dimensional dose response approach outlined in Section 5.4.3.1 cannot be used. Therefore, a three-dimensional dose response methodology is used to generate the large number of dose rates required. Thus, seven sets of three-dimensional response cases are run to generate the groupwise contribution to dose rates at the dose rate locations of interest.

For each enrichment, burnup, cool time, and source region, the product of the normalized source spectrum and the response spectrum is multiplied by the total source to calculate the dose rates at the detector locations of interest. The dose rates from all sources are then summed. With the

Chapter 6

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6.0 CRITICALITY EVALUATION

This chapter documents the criticality evaluation of the Universal Transport Cask package with PWR and BWR payloads. The results demonstrate that the cask package design meets the criticality requirements of IAEA Safety Series No. 6 [2] and of 10 CFR 71 sections 71.55 and 71.59 [1]. For the cask containing either PWR or BWR payload, the value of the transport index for nuclear criticality control is determined to be zero and thus meets the requirements of 10 CFR 71.59. Therefore, an infinite number of packages remain subcritical during normal conditions of transport and hypothetical accident conditions. The transport index based on radiation is determined in Chapter 5.0.

6.1 Discussion and Results

The Universal Transport Cask is designed to safely transport 24 intact PWR fuel assemblies with an initial enrichment of 4.2 wt % ^{235}U or 56 intact BWR fuel assemblies 4.0 wt % ^{235}U. Primarily on the basis of their lengths and cross sections, the fuel assemblies are sorted into classes. Three classes of PWR fuel assemblies and two classes of BWR fuel assemblies are evaluated for transport. Five Transportable Storage Canister assemblies of different lengths and configuration transport the PWR fuel assemblies and the BWR fuel assemblies. The canister assembly includes a fuel basket within which fuel is loaded.

Criticality control in the PWR basket is achieved by using a flux trap principle. Individual fuel assemblies are surrounded by a neutron absorber and four neutron absorber sheets and are separated by a gap that is filled with water during hypothetical accident conditions when the canister is flooded. Fast neutrons escaping one fuel assembly are moderated in the gap between the assemblies and absorbed by the neutron poison surrounding the assemblies. The flux trap spacing is maintained by the baskets stainless steel support disks which separate individual fuel assembly tubes. Alternating stainless steel disks and aluminum heat transfer disks are placed axially at intervals determined by thermal and structural constraints. The PWR basket design includes 30, 32, or 34 support disks and 29, 31, or 33 heat transfer disks, respectively, depending upon the three fuel basket classes. The minimum loading of the neutron absorber sheets in the PWR fuel tubes is 0.025 g ^{10}B/cm^2. Steel cladding holds the neutron absorber sheets in place.

Individual fuel assemblies in the BWR basket are separated from adjacent fuel assemblies by a water gap and a single poison sheet. Although it does not form a flux trap during accident conditions this type of arrangement also absorbs thermal neutrons in the poison sheet. Given the smaller amount of fissile material in BWR assemblies compared with PWR assemblies, the single poison sheet arrangement of the BWR basket provides criticality control at a cask neutron multiplication factor (k_s) below 0.95. The assembly spacing is maintained by carbon steel disks separating individual fuel assembly tubes placed axially at intervals determined by thermal and structural constraints. Each BWR basket design includes 40 or 41 support disks, depending upon the fuel basket class. The BWR basket design also includes 17 aluminum heat transfer disks. Of the total 56 fuel tubes in each BWR basket, 42 tubes contain neutron absorber sheets on two sides of the tubes; 11 tubes contain neutron absorber sheets on one side; and the remaining 3 tubes contain no neutron absorber. 95 neutron absorber sheets are sufficient to provide one sheet between any two adjacent fuel tubes. The minimum loading of the neutron absorber sheets in the BWR tubes is 0.011 g $^{10}B/cm^2$.

The SCALE 4.3 Criticality Safety Analysis Sequence (CSAS) [3, 4] is used to perform the Universal Transport Cask criticality analysis. This sequence includes KENO-Va [5] (Petrie) Monte Carlo analysis to determine k_{eff} under normal and accident conditions. The 27-group ENDF/B-IV neutron cross-section library [6] is used in all calculations, including those used to evaluate the sensitivity of the package to a range of moderator densities and center-to-center spacings. The most reactive PWR and BWR fuel assemblies, in their respective basket configuration, are used in the criticality calculations for the cask. The most reactive PWR assemblies are Westinghouse 17x17 OFA and the most reactive BWR fuel assemblies are Exxon/ANF (Ex/ANF) 9×9 with 79 fuel rods (see Section 6.4.1.2 for detailed discussion). These assemblies bound, respectively, all PWR (Classes 1-3) and BWR (Classes 4-5) fuel assemblies to be transported (see Table 6.2-1), as demonstrated in Section 6.4.1.2.

The MONK8a (AEA Technology) [20] Monte Carlo Program for Nuclear Criticality Safety Analysis is used to evaluate the change in reactivity as a result of the Universal Transport Cask top end drop accident scenario. Evaluation of this scenario is reported in Section 6.4.5.

The results of the criticality analyses are presented in Section 6.4. The values are summarized in Table 6.1-1.

Table 6.1-1 Summary of Criticality Analysis Results

Condition	PWR (Most Reactive Assembly Westinghouse 17×17 OFA)		BWR (Most Reactive Assembly Exxon/ANF 9×9)	
	$k_{eff} \pm \sigma$	k_s	$k_{eff} \pm \sigma$	k_s
Normal conditions:				
Wet-Inside and Outside-Fuel Intact (Single Cask)*	0.9247±0.0009	0.9387	0.9055 ± 0.0008	0.9196
Dry Inside and Optimum Moderation Outside Fuel Intact (Cask Array)	0.3988 ± 0.0007	0.4128	0.4005 ± 0.0008	0.4146
Hypothetical Accident Conditions (100% Fuel Failure):				
Wet Inside and Outside - 100% Fuel Failure (Cask Array)	0.9333 ± 0.0009	0.9475	0.9357 ± 0.0008	0.9497

* Cask is loaded dry and transported dry. This set added to satisfy 10CFR71.55.

Conservatisms contained in these analyses are as follows.

1. Fuel assembly with maximum uranium loading (95% theoretical density).
2. 75% of the nominal ^{10}B loading in the neutron absorber.
3. Infinite array of casks in the x-y plane.
4. Infinite fuel length with no inclusion of end leakage effects.
5. No structural material present in the assembly.
6. No dissolved boron in the cask cavity or surrounding loading or storage area.
7. No credit taken for fuel burnup or for the buildup of fission product neutron absorbers.
8. Water inside fuel rod cladding, i.e., 100% fuel failure and water intrusion under accident conditions.
9. No control components in PWR assemblies; no burnable poison in PWR or BWR assemblies.

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6.2 Package Fuel Loading

The Universal Transport Cask is designed to transport one of five Transportable Storage Canisters of different lengths. Each canister class accommodates one of three classes of PWR fuel assemblies or one of two classes of BWR fuel assemblies. The classification of the fuel assemblies is based primarily on fuel assembly length and cross section. The classes of major fuel assemblies to be transported in the cask and their characteristics are shown in Tables 6.2-1 (PWR) and 6.2-2 (BWR). Limiting fuel axial dimensions for each class are provided in Table 6.2-3.

Table 6.2-1 PWR Fuel Assembly Characteristics (Zirc-4 Clad)

Fuel Class	Vendor	Array	Version	Max MTU	No of Fuel Rods	Pitch (in)	Rod Dia. (in)	Clad Thick (in)	Pellet Dia (in)	Active Length (in)
1	CE	14 x 14	Std.	0.4037	176	0.5800	0.440	0.0280	0.3765	137.0
1	CE	14 x 14	Ft Cal.	0.3772	176	0.5800	0.440	0.0280	0.3765	128.0
1	CE	15 x 15	Palis.	0.4317	216	0.5500	0.418	0.0260	0.3580	132.0
1	CE	16 x 16	Lucie 2	0.4025	236	0.5060	0.382	0.0250	0.3250	136.7
1	Ex/ANF	14 x 14	WE	0.3689	179	0.5560	0.424	0.0300	0.3505	142.0
1	Ex/ANF	14 x 14	CE	0.3814	176	0.5800	0.440	0.0310	0.3700	134.0
1	Ex/ANF	14 x 14	Praire Isl.	0.3741	179	0.5560	0.417	0.0300	0.3505	144.0
1	Ex/ANF	15 x 15	WE	0.4410	204	0.5630	0.424	0.0300	0.3565	144.0
1	Ex/ANF	15 x 15	Palis	0.4310	216	0.5500	0.417	0.0300	0.3580	131.8
1	Ex/ANF	17 x 17	WE	0.4123	264	0.4960	0.360	0.0250	0.3030	144.0
1	WE	14 x 14	Std/ZCA	0.4144	179	0.5560	0.422	0.0225	0.3674	145.2
1	WE	14 x 14	OFA	0.3612	179	0.5560	0.400	0.0243	0.3444	144.0
1	WE	14 x 14	Std/ZCB	0.4144	179	0.5560	0.422	0.0225	0.3674	145.2
1	WE	14 x 14	CE Model	0.4115	176	0.5800	0.440	0.0260	0.3805	136.7
1	WE	15 x 15	Std	0.4646	204	0.5630	0.422	0.0242	0.3659	144.0
1	WE	15 x 15	Std/ZC	0.4646	204	0.5630	0.422	0.0242	0.3659	144.0
1	WE	15 x 15	OFA	0.4646	204	0.5630	0.422	0.0242	0.3659	144.0
1	WE	17 x 17	Std	0.4671	264	0.4960	0.374	0.0225	0.3225	144.0
1	WE	17 x 17	OFA	0.4282	264	0.4960	0.360	0.0225	0.3088	144.0
1	WE	17 x 17	Vant 5	0.4282	264	0.4960	0.360	0.0225	0.3088	144.0
2	B&W	15 x 15	Mark B	0.4807	208	0.5680	0.430	0.0265	0.3686	144.0
2	B&W	15 x 15	Mark BZ	0.4807	208	0.5680	0.430	0.0265	0.3686	144.0
2	B&W	17 x 17	Mark C	0.4658	264	0.5020	0.379	0.0240	0.3232	143.0
3	CE	16 x 16	Sono 2&3	0.4417	236	0.5060	0.382	0.0250	0.3250	150.0
3	CE	16 x 16	ANO2	0.4417	236	0.5060	0.382	0.0250	0.3250	150.0
3	CE	16 x 16	SYS80	0.4417	236	0.5060	0.382	0.0250	0.3250	150.0

- No fuel assembly structural materials (e.g., spacer grids) are included in the active fuel region (except for the fuel assembly channels in the BWR case). Eliminating the structural materials simplifies model construction significantly. Removing parasitic absorbers and increasing the effective H/U ratio in the normally under-moderated assembly increases reactivity. Evaluation of the reactivity impact for a variety of channel dimensions in the BWR most reactive assembly analysis demonstrates that the impact of the channel material on cask criticality is not statistically significant. Removal of the channel on the most reactive assembly (Ex/ANF 9x9) resulted in k_{eff} decrease of 0.001 from 0.872 to 0.871 with a Monte Carlo uncertainty of 0.001.

- Fuel assembly neutron poisons, e.g., gadolinium rods (BWR), are excluded from the analysis, thereby substantially increasing assembly reactivity of the unburned assembly.

- The array for all KENO-Va analyses is axially infinite, i.e., no axial leakage.

- Geometric tolerances and mechanical perturbations (fuel movement in tube, tube movement in the disk opening, and combined fuel and tube movement) are analyzed to arrive at the highest reactivity basket configuration. PWR system geometric tolerances and mechanical perturbations are initially evaluated by using an "infinite array" of tubes in the basket model. An "infinite array" of tubes is produced by modeling mirrored boundary conditions in the x-y plane and a single fuel tube surrounded by the basket structure out to one half the web width. A basket-in-canister model taking into account any positive biases determined from the single-tube-in-basket model is the "worst case," highest reactivity, transport cask configuration. BWR geometric tolerances and mechanical perturbations are directly evaluated by a basket-in-cask model.

- Fuel assembly cladding is intact. For normal operating conditions, no water is present in the gap between fuel pellet and clad. For hypothetical accident conditions, water is present in the pellet-to-clad gap. Because the cask is shown not to fail structurally under normal or accident conditions and the presence of water in the pellet-to-clad gap requires failure of the sealed canister and fuel in addition to failure of the cask, the assumption of water in the pellet-to-clad gap for accident analysis is extremely conservative.

- Full-density moderator is water at standard temperature and pressure (293°K and 0.9982 g/cm^3)

- Fuel, cladding, and structural materials are at 293°K.

- ^{10}B density is reduced to 75% in accordance with 10 CFR 71 licensing guidance and requirements provided in the "Standard Review Plan for Dry Cask Storage Systems" (NUREG-1536) [11].

- The basket will retain their structure and will not show any significant permanent deformation during normal or accident conditions.

- The basket-in-transport-cask model for the KENO-Va neutron shield dimensions for the account for radial neutron shield expansions space (1/8 in. modeled as void) and an equivalent volume neutron shield and neutron shield shell thickness.

- In the MONK models for the top-end-drop accident condition, all fuel rods in each assembly are shifted to the top of the assembly, the fuel within these rods are shifted up half the height of the plenum, and each assembly is shifted up until it is in contact with the lid, while the toleranced basket remains in contact with the canister bottom plate. Section 6.4.5 provides detailed end-drop calculations that demonstrate that this model employed a conservative active fuel exposure.

6.3.3 Description of Calculational Models

The Universal Transport Cask PWR KENO-Va model is derived from a cylindrical segment of the cask at the active fuel region. The model is a stack of four slices containing one aluminum disk, two identical water regions, and one steel disk region (stack is aluminum, water, steel, water). The basket is modeled in each slice and contains 24 design basis PWR fuel assemblies at 4.2 wt% ^{235}U enrichment and fuel density corresponding to a 95% theoretical fuel density. The fuel pin array is explicitly modeled in each of the 24 possible locations. Each basket slice is surrounded by the cask body shielding regions of steel, lead, steel, NS4FR and steel. Each cask slice is surrounded by a cuboid. The four slices are stacked into the KENO global unit.

The KENO-Va model for the cask containing BWR fuel is also derived from a cylindrical segment of the cask at the active fuel region. The model is a stack of four slices, one at the carbon steel disk elevation and thickness, one at the aluminum disk elevation and thickness, and two composed of the water space between disks. The basket is modeled in each slice and contains 56 design basis BWR fuel assemblies at 4.00 wt% ^{235}U enrichment and fuel density corresponding to a 95% theoretical fuel density. The fuel pin array is explicitly modeled in each

6.4 Criticality Calculation

6.4.1 Calculational or Experimental Method

As discussed earlier, criticality analysis of the Universal Transport Cask involves identification of fuel arrays for analysis, determination of most reactive PWR and BWR assemblies, and cask criticality analysis. Detailed discussion follows.

6.4.1.1 Determination of Fuel Arrays for Criticality Analysis

As shown previously, the maximum values for physical dimensions, cross sections, and weights vary among the fuel assemblies. Therefore, qualitatively determining one enveloping assembly for the Universal Transport Cask criticality analysis is difficult. Thus, a set of standard fuel arrays in the basket configuration is selected and modeled with KENO-Va. The selected standard PWR and BWR assemblies qualitatively bound other assemblies in their sub classes and are as follows.

PWR Fuel Assemblies

- B&W 15x15 Mark B
- B&W 15x15 Mark BZ
- B&W 17x17 Mark C
- CE 14x14 Standard
- CE 14x14 Ft. Calhoun
- CE 14x14 Palisades
- CE 14 x14 Lucie 2
- CE 16x16 System 80
- CE 16x16 San Onofre 2&3
- CE 16x16 ANO2
- Westinghouse 14x14 Std/ZCA
- Westinghouse 14x14 Std/ZCB
- Westinghouse 14x14 OFA
- Westinghouse 14x14 (CE)
- Westinghouse 15x15 Std
- Westinghouse 15x15 Std/ZC
- Westinghouse 15x15 OFA
- Westinghouse 17x17
- Westinghouse 17x17 Vant5
- Westinghouse 17x17 OFA
- Ex/ANF 14x14 (CE)
- Ex/ANF 14x14 (WE)
- Ex/ANF 14x14 (Praire Isl.)
- Ex/ANF 15x15 (WE)
- Ex/ANF 15x15 (Palisades)
- Ex/ANF 17x17 (WE)

BWR Fuel Assemblies

- Ex/ANF 7x7 GE
- Ex/ANF 8x8 JP-3
- Ex/ANF 8x8 JP-4, 5
- ExANF 9x9 JP-3
- ExANF 9x9 JP4, 5
- ExAnf 9x9 JP4, 5
- GE 7x7 GE-2a
- GE 7x7 GE-2b
- GE 7x8 GE-2b
- GE 7x7 GE-2
- GE 7X7 GE-3
- GE 7X7 GE-3a
- GE 7X7 GE-3b
- GE 8x8 GE-4a
- GE 8x8 GE-4b
- GE 8X8 GE-5
- GE 8X8 GE-5
- GE 8X8 GE-6 (prep)
- GE 8x8 GE-6 (prep)
- GE 8x8 GE-7 (barr)
- GE 8x8 GE-7 (barr)
- GE 8x8 GE-8
- Ge 8x8 GE-10
- GE 8x8 GE-10
- GE 9x9 GE-11
- GE 9x9 GE-11

6.4.1.2 Most Reactive Fuel Assembly Determination

To determine the most reactive assembly within each type of fuel, a KENO-Va calculation is performed for the PWR and BWR fuel assemblies identified in Section 6.4.1.1. The calculated k_{eff} values for the various classes of fuel are given in Table 6.4-1 (located at the end of this section). The model for the PWR and the BWR fuel assembly types is discussed in the following paragraphs. On the basis of this analysis, the Westinghouse 17x17 OFA fuel assembly is determined to be the most reactive PWR fuel assembly. The Ex/ANF 9 x 9 fuel assembly is determined to be the most reactive BWR fuel assembly.

6.4.1.2.1 Most Reactive PWR Assembly Analysis

The most reactive assembly analysis is based on a single assembly model. The assembly is in the PWR basket surrounded by the steel tube, four neutron absorber sheets, neutron absorber cover sheets, water to disk gap and steel, aluminum or water disk material. For the most reactive assembly analysis, the assembly is centered in the tube and the tube centered in the disk opening. Web thickness of 1.5, 1.0 and 0.875 in. is present in the PWR basket. Web thickness is assumed to have minimal impact on the most reactive assembly analysis. Therefore, the analysis is performed for a web thickness of 1.0 inch.

To simplify modeling, three basket slices are made at the active fuel elevation: one at the stainless steel disk elevation and thickness, one at the aluminum disk elevations and thickness, and one at the water gap between disks. By stacking four of the slices (water, steel, water, and aluminum) on top of one another and periodically reflecting the disk stack, an axially infinite fuel-assembly-in-basket model is built. Building an axially infinite model eliminates axial leakage.

With the exception of the axial (z) length, identical KENO-Va units are constructed for fuel pins, guide/instrument tubes, and neutron absorber sheets in the water and disk slice. Neutron absorber sheet KENO-Va units are required, one sheet running parallel to the x plane, and one for the y plane for disk and water elevations. Axial dimensions for these units are made equal to either the water gap between disks or the disk heights (stainless steel disk and aluminum disk). In this analysis, all unit cells, except for the global unit, are centered on themselves, which implies symmetric upper and lower z elevation bounds.

After establishing fuel pin, guide tube, instrument tubes and neutron absorber sheet KENO-Va units, the fuel assembly arrays are constructed. The fuel assembly array, composed of fuel pins and guide/instrument tubes, is surrounded by a water gap, the fuel tube, and a water gap equal in x, y dimensions to the exterior of the neutron absorber sheet. The neutron absorber sheets are placed as holes into the water cuboid surrounding the tube. The cuboid containing the neutron absorber sheets is then surrounded by a thin encapsulating shell and a water cuboid out to the disk opening. Surrounding the disk opening cuboid is either water or disk material out to one half the web thickness (in this case 0.5 in. of material). The fuel tube is centered in the disk opening and the assembly is centered in the tube.

The three complete fuel assembly/basket units are axially stacked in the GLOBAL unit, with mirrored boundary conditions in the x, y plane to model an infinite array of tubes in the disk. An axially infinite model is created by using periodic boundary conditions on the top and bottom of the global KENO-Va unit.

Calculated values of k_{eff} for the PWR assemblies selected for most reactive assembly analysis are listed in Table 6.4-1 (located at the end of this section). The table includes data for assemblies with water in the fuel-pellet-to-cladding gap and for assemblies with no water in the gap. Also included is a Δk between the dry and wet cases. k_{eff} values in Table 6.4-1 are for a representative 1.0" flux trap, a ^{10}B areal density of 0.02 g/cm^2 and infinite array of tubes in disk and therefore k_{eff} exceed 0.95 for a number of the assemblies analyzed. However bias and uncertainty adjusted k_{eff} values for all assemblies are below 0.95 in the UMS transport cask.

Table 6.4-1 results are based on a web width of 1.0 in. The basket centerline web thickness is 1.5 in. To assure that the most reactive assembly calculation applies to the whole basket and to verify that web spacing does not impact results, Table 6.4-2 (located at the end of this section) is generated to include reactivity data for the highest reactivity assemblies in a 1.5-in. web.

From the 1.0-in. web, dry gap analysis, the Westinghouse 15x15 fuel assembly has a 0.0005 higher k_{eff} than the Westinghouse. 17x17 OFA assembly. However, given the 0.001 Monte Carlo uncertainty associated with the k_{eff} values calculated, no statistically significant difference exists between the k_{eff} values. The 1.5-in. web analysis results in a statistically significantly higher k_{eff} for the Westinghouse 17x17 OFA assembly than for the Westinghouse 15x15 assembly, a Δk_{eff} of +0.005.

6.4.1.2.2 Most Reactive BWR Assembly Analysis

The most reactive assembly analysis is based on the full cask model. Assemblies in the BWR basket are surrounded by the assembly channel, channel-to-tube gap, steel fuel tube, neutron absorber sheet and neutron absorber cover sheet on applicable sides of the tube, water-to-disk gap, and steel and aluminum disk material. For the most reactive assembly analysis, the assembly is centered in the tube and the tube centered in the disk opening. To simplify modeling, three basket slices are made at the active fuel elevation: one at the carbon steel disk elevation and thickness, one at the aluminum disk elevation and thickness, and one at the water gap between disk elevation and thickness. Each of the disks containing the fuel tubes is surrounded by the canister shell and transport cask radial shields. By stacking the three cask slices on top of one another and periodically reflecting the stack, an axially infinite cask model is built. Building an axially infinite model eliminates axial leakage. Into each of the basket slices the 56 disk openings are inserted as KENO-Va HOLE's. Each of the disk openings contain a KENO-Va HOLE representing the fuel tube which in turn has the fuel assembly, including channel, inserted as a HOLE. This modeling approach allows simple component movement, fuel tube or fuel assembly, by simply modifying the HOLE origin coordinate.

Calculated values of k_{eff} for the BWR assemblies selected for analysis of the most reactive assembly are provided in Table 6.4-3 (located at the end of this section). The table includes data for with no water in the pellet-to-clad gap. As can be seen from the table, the most reactive is the Ex/ANF 9x9 fuel assembly with 79 fuel pins and 2 water rods. It is statistically significantly more reactive than any of the other BWR assemblies analyzed, therefore no "wet" gap cases were analyzed.

6.4.1.3 Universal Transport Cask Criticality Analysis

The KENO-Va models employed in the Universal Transport Cask criticality analysis are built on those developed in the most reactive assembly calculations (See Section 6.4.1.2). The transport cask criticality analysis is performed in three steps.

1. Resolution of the criticality impact of mechanical perturbations and geometric tolerances on the basis of a fuel tube-in-basket model (PWR) and basket-in-cask-model (BWR) using the most reactive assembly.
2. Preparation of a basket-in-cask model (PWR) to evaluate the reactivity variation between normal and worst-case configuration. (A BWR basket-in-cask model having been constructed in step 1 for the most reactive assembly analysis.)
3. Evaluation of k_{eff} and k_s for a single cask and for an array of casks on the basis of the worst-case configured cask basket under normal and accident conditions.

Construction of the cask criticality models for normal and accident conditions involves modifications to moderator compositions, cask spacing, material in the gap between fuel pellet and clad, and cask neutron shield material description.

6.4.1.3.1 Universal Transport Cask Containing PWR Fuel

Mechanical Perturbations and Geometric Tolerance: Fuel Tube in PWR Basket Unit Cell Model

Because of the gaps between the fuel assembly and the fuel tube, and between fuel tube and disk opening, a certain amount of mechanical perturbation to the system is possible. In addition, manufacturing tolerances in the basket cause variation in the gaps and basket disk hole positions. The criticality impact of such mechanical variations is evaluated with a KENO-Va model of the PWR basket unit cell. The following mechanical perturbations and geometric tolerances are evaluated:

a. Fuel assembly movement in the tube,
b. Fuel tube movement in the disk opening,
c. Variation in the basket tube opening,
d. Variation in disk opening, and
e. Variation in positioning of the disk opening,

Fuel assembly movement in the tube is based on the physical limits of the inside envelope of the tube and the width of the fuel assembly array. For the design basis fuel, the maximum movement within the tube is ± 0.184 in. (0.468cm). As a result of PWR basket tube symmetry, only one movement direction requires analysis. Fuel assembly movement is bounded by shifting the fuel assembly to the upper right-hand corner of the basket tube. This corner movement maximizes the reactivity impact of movement in one direction.

Similarly, movement of the fuel tube is maximized by shifting to the upper right hand corner of the basket disk opening. The maximum tube movement in the basket disk opening is ± 0.095 in. (0.242cm). The tube outer neutron absorber sheet, and neutron absorber cover sheet dimensions are moved based on the inner tube dimension plus the relevant material thickness.

Both the fuel assembly movement and the fuel tube movement are analyzed with periodic and mirrored boundary conditions. The periodic boundarsy condition approximates a shift of all assemblies/fuel tubes in the basket to one side. The mirrored boundary approximates clusters of four assemblies or fuel tubes moved towards a central location.

- BWR fuel rods are either tie rods connecting the top and bottom nozzles, or are rods manufactured with an external spring between the top of the fuel rod and the top nozzle tie plate. For this evaluation, all external springs are ignored. Therefore, all BWR fuel rods are allowed to shift axially into contact with the top tie plate.
- Within BWR fuel rods, the fuel is assumed to shift upward into the plenum region. Each plenum region contains a plenum spring. Detailed structural analyses have shown that during a 60g top end impact, the BWR plenum spring will compress and rebound 1.729 inches. The fuel material in the rods is assumed to shift and remain in contact with the compressed plenum spring. A review of plenum length and spring data for various rod designs indicates a minimum of 13% of the BWR plenum space is occupied by a solid height plenum spring. The final height of the plenum spring is calculated from the sum of the solid height of the spring and a spring rebound height of 1.729 inches.
- Detailed structural analyses of the BWR assembly have also shown that during a 60g top end impact, the lifting bail will deform. The maximum BWR bail deformation was calculated to be 2.371 inches.

Therefore, spacing from the assembly top to the active fuel region is controlled by the top end-fitting height, the fuel rod end-plug height and the distance the active fuel moves into the top plenum. In the case of BWR rods, the end-plug height includes only the portion of the plug below the tie plate when the fuel rod is shifted up. The distance between the top of the fuel assembly and the active fuel region for the bounding (minimum offset) fuel types in each canister class is presented in Table 6.4-19. Also included in Table 6.4-19 is the Class 5 Exxon/ANF 9x9 assembly, since this assembly represents the maximum reactivity radial lattice geometry.

In the third stage of the evaluation, the maximum active fuel exposure (or minimum coverage) for each fuel type is determined by simply subtracting the active fuel offset from the neutron absorber offset. A positive value indicates active fuel is exposed (i.e., neutron absorber does not cover the entire active fuel region).

As shown in in Table 6.4-19, the maximum lengths of exposed BWR fuel result for the Exxon/ANF 9x9 and GE 8x8 BWR fuel assemblies at 4.312 inches. For further conservatism in the criticality analysis, the active fuel exposure length is increased to 7.625 inches for BWR fuel assemblies.

As previously mentioned, the maximum length of exposed fuel is not obtained from the BWR fuel assembly defined as having the maximum reactivity in Section 6.4. The maximum reactivity

BWR assembly documented in the SAR is the UMS® Class 5 Exxon/ANF 9x9 (79 fuel rod) assembly for BWR canisters. Therefore, rather than analyzing each fuel type with its specific exposed fuel height, the evaluated exposed fuel height of 7.625 inches (BWR) is applied to the Class 5 Exxon/ANF 9x9 BWR assembly.

To model the 7.625-inch exposed fuel length for the Class 5 Exxon/ANF 9 x 9 BWR fuel assembly criticality evaluation, a number of modifications are made to the nominal (unshifted) fuel and basket model.

- Fuel assemblies are shifted to the canister lid.
- Fuel rods are spaced from the top tie plate by the external spring.
- The active fuel is moved to the midpoint of the plenum.
- The top-nozzle height is reduced by 4.7 inches.
- The BWR neutron absorber sheet is reduced by 3.009 inches.

Evaluation of PWR System Top End Impact

Axial shifting of the contents of the Transportable Storage Canister (TSC) occurs as a result of a top end impact load condition for the transport cask containing a loaded TSC. In this scenario of contents shifting, the fuel assembly and the basket shift upward to contact the canister lid. The distance between the canister lid and the neutron absorber sheets, which are attached to the fuel tubes, and the distance between the top of the fuel assembly and the active fuel region are required to establish the height of active fuel exposed beyond the neutron absorber for any given assembly. Exposure of the active fuel in any specific fuel type occurs if the minimum distance between the top of the assembly and the top of the active fuel region is less than the maximum distance from the canister lid to the top of the neutron absorber sheet. The exposed fuel height evaluation is performed for each PWR fuel assembly type that is proposed to be loaded into the UMS® canister. The calculation is divided into three stages: calculation of the neutron absorber offset, determination of the active fuel offset, and calculation of the fuel exposure.

In stage one, the maximum distance between the top of the neutron absorber sheet and the canister lid is determined for each UMS® PWR canister class. The maximum distance provides the greatest fuel exposure, when considering a shifted fuel assembly. This distance depends on the canister class specific weldment, basket, tube and neutron absorber lengths; the relative location of the neutron absorber on the fuel tube; and tolerances associated with the basket components. The maximum distances for a PWR basket shifted to the canister lid appear in Table 6.4-19.

In the second stage of the analysis, the minimum distances between the canister lid and the fuel assembly, and between the top of the fuel assembly and the active fuel region are determined for each PWR fuel type. Since the fuel assembly is shifted to contact the canister lid, the distance between the lid and the fuel assembly is always zero (no credit is taken for any offset produced by the PWR leaf springs). The active fuel shifting condition in the fuel assembly assumes that:

- In PWR fuel assemblies, where a space exists between the fuel rod end-cap and the end-fitting, the fuel rods are shifted within the grid until contact is made with the top end-fitting (zero gap).
- Within the PWR fuel rods, the active fuel is assumed to shift upward into the plenum region. Each plenum region contains a spring. Detailed structural analysis has shown that during a 60 g top-end impact, the PWR spring will compress and rebound a minimum of 2.39 inches. The fuel material in the rods is assumed to shift and remain in contact with the fully compressed plenum spring. A review of plenum length and spring data for various rod designs indicates a minimum of 31% of the PWR plenum space is occupied by a solid height plenum spring. The 2.39-in spring rebound is added to the compressed spring height.
- Detailed structural analyses of the PWR assembly have shown that during a 60g top end impact, no significant damage to the top end-fitting (i.e., no height reduction) occurs.

Therefore, spacing from the assembly top to the active fuel region is controlled by the end-fitting height, the fuel rod end-plug height and the distance the active fuel moves into the top plenum. The distance between the top of the fuel assembly and the active fuel region for typical fuel types in each canister class is presented in Table 6.4-19. Also included in Table 6.4-19 is the Westinghouse 17x17 OFA assembly, since this assembly represents the maximum reactivity radial lattice geometry.

In the third stage of the evaluation, the maximum active fuel exposure (or minimum coverage) for each fuel type is determined by simply subtracting the active fuel offset from the neutron absorber offset. A positive value indicates active fuel is exposed (i.e., neutron absorber does not cover the entire active fuel region), while a negative value indicates full active fuel coverage and additional coverage to that extent.

As shown in Table 6.4-19, the maximum lengths of exposed PWR fuel result for the Westinghouse 15x15 PWR fuel assembly at 0.782 inch. For further conservatism in the criticality analysis, the active fuel exposure length is increased to 4.52 inches for PWR fuel assemblies.

As previously mentioned, the maximum length of exposed fuel is not obtained from the PWR fuel assembly defined as having the maximum reactivity in Section 6.4. The maximum reactivity PWR assembly documented in the SAR is the Westinghouse 17x17 OFA assembly for PWR canisters. Therefore, rather than analyzing each fuel type with its specific exposed fuel height, the evaluated exposed fuel height of 4.52 inches (PWR) is applied to the Westinghouse 17x17 OFA PWR assembly.

To model the 4.52-inch exposed fuel length for the Westinghouse 17x17 OFA PWR fuel assembly criticality evaluation, a number of modifications are made to the nominal (unshifted) fuel and basket model.

- Fuel assemblies are shifted to the canister lid.
- Fuel rods are shifted to the top end-fitting.
- The active fuel is moved to the midpoint of the plenum.
- The top end-fitting height is reduced by 1 inch.
- The PWR neutron absorber sheet is reduced by 0.815 inch.
- Basket is located at the canister bottom.

Fuel Assembly Minimum Intact Hardware Dimension Limits

Based on limiting the exposed height of active fuel to 4.52 inches for the PWR fuel assemblies and to 7.625 inches for the BWR fuel assemblies, intact fuel assembly hardware limits are defined to assure compliance with the safety basis of the analysis. These limits consider zero PWR top end-fitting deformation, a PWR plenum spring rebound height of 2.36 inches, 2.371 inches of BWR top end-fitting (lifting bail) deformation and a BWR plenum spring rebound height of 1.729 inches. The limits for each UMS® canister class containing PWR fuel are calculated by subtracting the sum of the exposed fuel height (4.52 in) and the plenum spring rebound (2.39 in) from the distance between the canister lid and the top of the neutron absorber. The limits for each UMS® canister class containing BWR fuel are calculated by subtracting the sum of the height of exposed fuel, 7.625 inches, and the plenum spring rebound height, 1.729 inches, from the sum of the lifting bail deformation, 2.371 inches, and the distance between the canister lid and the top of the neutron absorber. These resulting limits are provided in Table 6.4-20.

Each minimum axial assembly dimension is a generic limit that all fuel types loaded into a particular can's class shall meet. Compliance with these limits will ensure that the exposed fuel heights evaluated and found to result in a subcritical system will not be exceeded. For PWR fuel, the minimum intact assembly hardware dimension above the active fuel shall be calculated by summing the top end-fitting height, the top end cap height, and the solid height of the plenum spring. For BWR fuel, the minimum axial assembly dimension above the active fuel shall be calculated by summing the intact top end-fitting height, the portion of the top end-cap height below the tie plate when the fuel rod is shifted up, and the solid height of the plenum spring. Tolerances on these components shall be conservatively considered when calculating the subject dimension.

Evaluation of Bottom End Axial Fuel Shifting

Similar to the top end evaluation, a bounding hypothetical axial fuel-shifting condition is considered in which all of the fuel rods are shifted to the bottom of each assembly. For PWR fuel assemblies with a lower plenum, the fuel within every rod is assumed to shift downward to contact a fully compressed plenum spring. Each fuel assembly is assumed to remain in contact with the canister bottom plate. The basket dimensions used assume conservative tolerances, and the basket is conservatively assumed to be shifted upward to contact the canister shield lid. This bounding axial shifting scenario results in the maximum distance from the canister bottom plate to the lower end of the neutron absorber panels. For all UMS® PWR canister classes, this distance is limited to 5.22 inches. For all UMS® BWR canister classes, the distance is limited to 8.19 inches. However, all PWR and BWR fuel assembly types have rod bottom end caps, tie plates and/or components of the bottom end-fitting/nozzle that will not deform to a total height of less than 0.7 inches. Consequently, the top end axial fuel shifting condition, which considers exposed fuel lengths of 4.52 inches for PWR fuel and 7.625 inches for BWR fuel, bounds the bottom end axial fuel shifting condition.

End Impact Accident Condition Effect on System Reactivity

The bounding PWR system end impact event does not significantly affect the reactivity of the system. Therefore, poison sheet coverage is adequate for all allowed PWR fuel contents of the UMS® system. The bounding BWR end impact event increases the reactivity of the system. This increase in reactivity, a Δk_{eff} of 0.0249, is added to the most reactive accident condition system reactivity, $k_{eff} \pm 2\sigma$, of 0.9108 ± 0.0008 as determined in Section 6.4.3.3, to establish a maximum BWR system reactivity, $k_{eff} \pm 2\sigma$, of 0.9357 ± 0.0008. This value is less than the USL of 0.9426 identified in Section 6.5.5. Including code bias, code bias uncertainty, and statistical uncertainty

(2σ) in accordance with Equation 6 in Section 6.5.3, the resulting system k_s of 0.9497 is less than 0.95. Thus, poison sheet coverage is adequate for all allowed BWR fuel contents of the UMS® system.

6.4.6 Regulatory Compliance

The licensing requirements for criticality analyses are provided in 10 CFR 71.55 and 10 CFR 71.59 for shipment of radioactive material.

10 CFR 71.55 and 10 CFR 71.59 require that the fissile material package be subcritical under any credible condition, e.g., optimum interior/exterior moderation and reflection and credible configuration of the material. A criticality transport index is to be assigned to the fissile material package. This transport index must be based on the number of packages (casks in this context) remaining subcritical in an array configuration.

Additional requirements imposed include the reduction in poison plate ^{10}B from 100 to 75 percent and water in the pellet-to-cladding gap.

Table 6.4-19 Transport Cask Top End Impact Bounding Exposed Fuel Heights

Fuel Type[1]	Canister Class	Neutron Absorber Offset (in)	Fuel Offset (in)	Calculated Exposed Fuel Height (in)	Evaluated Exposed Fuel Height (in)
WE 15x15	1	8.89	8.108	0.782	4.52 [2]
WE 17x17 OFA	1	8.89	8.686	0.204	4.52
B&W 15x15	2	10.99	12.679	-1.689	4.52 [2]
CE16x16 (SYS 80)	3	7.39	15.566	-8.176	4.52 [2]
Ex/ANF 9x9	4	12.76	8.448	4.312	7.625 [3]
Ex/ANF 9x9	5	12.76	8.458	4.302	7.625
GE 8x8	5	12.76	8.448	4.312	7.625 [3]

1 Typical fuel types loaded into the particular canister class. Fuel may be loaded into any canister class if minimum hardware limits listed in Table 6.4-20 are met.

2 Evaluated using maximum reactivity UMS® Class 1 WE 17x17 OFA fuel.

3 Evaluated using maximum reactivity UMS® Class 5 Ex/ANF 9x9 fuel.

Table 6.4-20 Fuel Assembly Minimum Intact Hardware Dimension Limits

UMS® Canister Class	1	2	3	4	5
Neutron Absorber Offset (in)	8.89	10.99	7.39	12.76	12.76
Evaluated Exposed Fuel Height (in)	4.52	4.52	4.52	7.625	7.625
Top End Fitting Deformation (in)	0	0	0	2.371	2.371
Plenum Spring Rebound Height (in)	2.39	2.39	2.39	1.729	1.729
Minimum Intact Hardware Dimension Limit (in) [1]	1.98	4.08	0.48	5.777	5.777

1 See Section 6.4.5 for details on how these minium dimensions are calculated

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loading restriction, the Westinghouse 17 x 17 OFA fuel criticality evaluation is bounding.

6.6.1.1.8 Damaged Fuel and Fuel Debris in the Maine Yankee Fuel Can

Damaged fuel assemblies are placed in one of two configurations of the Maine Yankee fuel can prior to loading in the basket (see Drawings 412-501 and 412-502). Both configurations of the the Maine Yankee fuel can have screened openings in the baseplate and the lid to permit drainage, vacuum drying and inerting of the can. This evaluation conservatively considers 100% of the fuel rods in the fuel can as damaged. For conservatism, the fuel can configuration with the larger internal width is used in these analyses.

Fuel debris must be loaded in a rod or tube structure that is subsequently loaded into one of two configurations of the Maine Yankee fuel can. The mass of fuel debris placed in the rod or tube is restricted to the mass equivalent of a fuel rod of an intact fuel assembly.

The Maine Yankee spent fuel inventory includes fuel assemblies with fuel rods inserted in the guide tubes of the assembly. If the integrity of the cladding of the fuel rods in the guide tubes cannot be ascertained, then those fuel rods are assumed to be damaged.

Damaged Fuel Evaluation

All of the spent fuel classified as damaged and all of the spent fuel not in its original lattice are stored in one of two configurations of the Maine Yankee fuel can. This fuel is analyzed using a 100% fuel rod failure assumption. The screened fuel can is designed to preclude the release of pellets and gross particulates into the canister cavity. Evaluation of the canister with four Maine Yankee fuel cans containing CE 14×14 fuel assemblies that have up to 176 damaged fuel rods, or consolidated fuel consisting of up to 289 fuel rods, considers 100% dispersal of the fuel from these rods within the fuel can. Either configuration of the Maine Yankee fuel can is restricted to loading in one of the four corner positions of the basket.

All loose fuel in each analysis is modeled as a homogeneous mixture of fuel and water, of which the volume fractions of the fuel versus the water are varied from 0-100%. By varying the fuel fraction up to 100%, this evaluation addresses fuel masses significantly larger than those available in a standard or consolidated fuel assembly. First, loose fuel from damaged fuel rods within a fuel assembly is evaluated between the remaining rods of the most reactive missing rod array. The results of this analysis, provided in Table 6.6.1.1-9, show a slight decrease in the reactivity of the system. Adding fuel to the already optimized H/U ratio of the bounding missing rod array reduces the reactivity of the system as this effectively returns the system to an undermoderated state. Second, loose fuel is considered above and below the active fuel region of this most reactive missing rod array. This analysis is performed within a finite cask model. The results of this study, provided in Table 6.6.1.1-10, show that any possible mixture combination of fuel and water above and below the active fuel region and, hence, above and below the BORAL sheet coverage, will not significantly increase the reactivity of the system beyond that of the missing rod array. Loose fuel is also considered to replace all contents of the Maine Yankee fuel can with the internal square dimension of 8.52 inches in each four corner fuel tube location. As shown in Table 6.6.1.1-11, the results of this study, which include modeling of the Maine Yankee fuel can with the internal square dimension of 8.52 inches, show that any mixture of fuel and water within this cavity will not significantly increase the reactivity of the system beyond that of the missing rod array.

Damaged fuel within the fuel can may also result from a loss of integrity of a consolidated fuel assembly. As described in Section 6.6.1.1.7, the consolidated assembly missing rod study shows that a potentially higher reactivity heterogeneous configuration does not increase the overall reactivity of the system beyond that of loading 24 Westinghouse 17×17 OFA assemblies when this configuration is restricted to the four corner locations. The homogeneous mixture study of loose fuel and water replacing the contents of the Maine Yankee fuel can having an internal square dimension of 8.52 inches (in each of the four corner fuel tube locations) considers more fuel than is present in the 289 fuel rod consolidated assembly. This study shows that a homogeneous mixture at an optimal H/U ratio within the fuel can also does not affect the reactivity of the system.

Preferential flooding during the transport cask hypothetical accident flooding could result in different moderator densities existing in the transportable storage canister (canister) cavity and damaged fuel can cavity. To investigate the impact of preferential flooding of the canister and damaged fuel can cavity, various moderator densities were evaluated in the damaged fuel can while retaining a fully flooded canister, and vice versa. As shown in Table 6.6.1.1-12, any reduction in moderator density in either the canister or damaged fuel can will result in reduced system reactivities.

The transport cask loaded with the Westinghouse 17×17 OFA fuel assemblies is subcritical. Therefore, it is inherent that a statistically equivalent, or less reactive, canister loading of four Maine Yankee fuel cans containing assemblies with up to 176 damaged rods, or consolidated assemblies with up to 289 rods and 20 of the most reactive Maine Yankee fuel assemblies, is also subcritical. Therefore, assemblies with up to 176 damaged rods and consolidated assemblies with up to 289 rods are allowable contents as long as they are loaded into one of two configurations of the Maine Yankee damaged fuel cans.

Fuel Debris Evaluation

Prior to loading fuel debris into one of the two configurations of the screened Maine Yankee fuel can, fuel debris must be placed into a rod type structure. Placing the debris into rods confines the spent nuclear material to a known volume and allows the fuel debris to be treated identically to the damaged fuel for criticality analysis.

Based on the discussion presented in Section 6.6.1.1.1, the maximum k_s of the UMS® canister with fuel debris will be less than 0.95, including associated uncertainty and bias.

6.6.1.1.9 Fuel Assemblies with Start-up Sources or Other Non-Fuel Components Inserted in a Guide Tube

Maine Yankee fuel assemblies are evaluated for criticality safety with components inserted in the center or corner guide tubes of the fuel assembly. These components include start-up sources, Control Element Assembly (CEA) fingertips, and a 24-inch ICI segment. Start-up sources are inserted in the center guide tube. The CEA fingertips and ICI segment must be inserted in a corner guide tube that is closed at the bottom end of the assembly.

Assemblies with Start-up Sources

Maine Yankee has three Pu-Be sources and two Sb-Be sources that will be installed in the center guide tubes of 14×14 assemblies that subsequently must be loaded in one of the four corner fuel positions of the basket. Each source is designed to fit in the center guide tube of an assembly. All five of these start-up sources contain Sb-Be pellets, which are 50% Be by volume. The moderation potential of the beryllium is evaluated to ensure that this material will not increase the reactivity of the system beyond that reported for the accident condition. The antimony (Sb) content is insignificant and is not considered. The start-up source is assumed to remain within the center guide tube for all conditions. The base case infinite height model used for comparison is the bounding Maine Yankee fuel assembly with 24 empty rod positions as reported in Table 6.6.1.1-6. The center guide tube of this model is filled with 50% water and 50% beryllium. The analysis assumes that assemblies with start-up sources are loaded in all four corner fuel positions of the basket. This configuration, resulting in a system reactivity, $k_{eff} \pm \sigma$ of 0.91085 ± 0.00087, shows that loading Sb-Be sources or the used Pu-Be sources into the center guide tubes of the assemblies in the four corner locations of the basket does not significantly change the reactivity of the system.

One of the three Pu-Be sources was never irradiated. Analysis of this source is equivalent to assuming that the spent Pu-Be sources are fresh. The unused source consists of two capsules that have a total of 1.4 grams of plutonium. All of this material is conservatively assumed to be in one capsule and is modeled as ^{239}Pu. The diameter of this capsule is 0.270 inch and its length is 9.75 inches. This corresponds to a capsule volume of approximately 9.148 cubic centimeters. Thus, the 1.4 grams of ^{239}Pu occupies ~0.77% of the volume at a density of 19.84 g/cc. This material composition is then conservatively assumed to fill the entire center guide tube, which models considerably more ^{239}Pu than is actually present within the Pu-Be source. The remaining volume of the guide tube is analyzed at various fractions of Be, water and/or void to ensure that any combination of these materials is considered. The results of these analyses, provided in Table 6.6.1.1-13, show that loading a fresh Pu-Be start-up source into the center guide tube of each of the four corner assemblies does not significantly change the reactivity of the system.

Fuel Assemblies with Inserted CEA Fingertips or ICI Segment

Maine Yankee fuel assemblies may have CEA fingertips or an ICI segment inserted in one of the four corner guide tubes of a 14×14 assembly. The ICI segment is approximately 24 inches long. These components do not contain any fissile material or moderating material. Therefore, it is conservative to ignore these components, as they displace moderator when the basket is flooded, reducing reactivity.

6.6.1.1.10 Transport Cask Top End Drop Event

The exposed fuel evaluation performed for the design basis WE 17x17 OFA fuel in Section 6.4.5 bounds that of the less reactive Maine Yankee fuel.

6.6.1.1.11 Maine Yankee Criticality Results and Fuel Loading Restrictions

The criticality analyses for the Maine Yankee site specific fuel demonstrates that the UMS® basket loaded with these fuel assemblies results in a system that is less reactive than loading the basket with the Westinghouse 17 x 17 OFA fuel assemblies, provided that loading is restricted to the four corner fuel tube positions in the basket for:

- All 14 x 14 fuel assemblies with less than 176 fuel rods or solid filler rods
- All 14 x 14 fuel assemblies with hollow rods
- All 17 x 17 consolidated fuel lattices

Table 6.6.1.1-9 Fuel Can Infinite Height Model Results of Fuel - Water Mixture Between Rods

Volume Fraction of UO_2 in Water	k_{eff}	Δk_{eff} to 24 (Four Corners)[1]
0.000	0.91090	-0.00063
0.001	0.91138	-0.00015
0.002	0.91120	-0.00033
0.003	0.91177	0.00024
0.004	0.91285	0.00132
0.005	0.90908	-0.00245
0.006	0.91001	-0.00152
0.007	0.90895	-0.00258
0.008	0.91005	-0.00148
0.009	0.90986	-0.00167
0.010	0.90864	-0.00289
0.020	0.91003	-0.00150
0.030	0.90963	-0.00190
0.040	0.91063	-0.00090
0.050	0.90931	-0.00222
0.060	0.90765	-0.00388
0.070	0.90753	-0.00400
0.080	0.91088	-0.00065
0.090	0.91122	-0.00031
0.100	0.90879	-0.00274
0.150	0.90968	-0.00185
0.200	0.90952	-0.00201
0.250	0.90815	-0.00338
0.300	0.90748	-0.00405
0.350	0.90581	-0.00572
0.400	0.90963	-0.00190
0.450	0.90547	-0.00606
0.500	0.90603	-0.00550
0.550	0.90753	-0.00400
0.600	0.90674	-0.00479
0.650	0.90589	-0.00564
0.700	0.90594	-0.00559
0.750	0.90568	-0.00585
0.800	0.90532	-0.00621
0.850	0.90693	-0.00460
0.900	0.90639	-0.00514
0.950	0.90684	-0.00469
1.000	0.90677	-0.00476

1. See Table 6.6.1.1-6.

Table 6.6.1.1-10 Fuel Can Finite Model Results of Fuel - Water Mixture Outside Neutron Absorber Coverage

Volume Fraction of UO_2 in Water	k_{eff}	Δk_{eff} to 0.00 UO_2 in Water	Δk_{eff} to 24 (Four Corners)[1]
0.00	0.91045[2]	NA	-0.00108
0.05	0.90781	-0.00264	-0.00372
0.10	0.90978	-0.00067	-0.00175
0.15	0.91048	0.00003	-0.00105
0.20	0.90916	-0.00129	-0.00237
0.25	0.90834	-0.00211	-0.00319
0.30	0.90935	-0.00110	-0.00218
0.35	0.90786	-0.00259	-0.00367
0.40	0.90892	-0.00153	-0.00261
0.45	0.91015	-0.00030	-0.00138
0.50	0.91011	-0.00034	-0.00142
0.55	0.91003	-0.00042	-0.00150
0.60	0.90874	-0.00171	-0.00279
0.65	0.91165	0.00120	0.00012
0.70	0.90977	-0.00068	-0.00176
0.75	0.90813	-0.00232	-0.00340
0.80	0.90909	-0.00136	-0.00244
0.85	0.91028	-0.00017	-0.00125
0.90	0.91061	0.00016	-0.00092
0.95	0.91129	0.00084	-0.00024
1.00	0.91076	0.00031	-0.00077

1. See Table 6.6.1.1-6.
2. $\sigma = 0.00084$.

Chapter 7

2. Detorque and remove the vent coverplate bolts.
3. Remove the vent port coverplate from the lid.

   Note: The drain port coverplate need not be removed for dry loading or unloading.
4. Visually inspect the port coverplate o-rings for damage or defects and replace if necessary. Store the coverplate so that the o-rings and o-ring grooves are protected from incidental damage.
5. Detorque the cask lid bolts using the reverse torquing sequence.
6. Remove the bolts and store them in a temporary storage area.
7. Clean and visually inspect bolts for damage. Replace any damaged bolts.
8. Install the two cask lid alignment pins.
9. Install lifting hoist rings in the lid-lifting holes.
10. Attach the lid-lifting device to the lid and an overhead crane.

    Caution: Ensure that the o-rings and o-ring grooves in the lid are protected from any incidental damage to the seal area in its temporary storage position.
11. Remove the lid and store in a temporary storage area.
12. Decontaminate the lid and visually inspect the lid o-rings for damage and wear and replace as necessary.

    Note: Visually Inspecting and cleaning of bolts can be performed in parallel to other operations performed in this procedure.
13. Clean and visually inspect the threaded connections in the top forging.
14. Remove the two cask lid alignment pins.
15. Visually examine the internal cavity to ensure that no damage has occurred during transit and that no foreign materials are present.
16. Record all inspection results.
17. Install the cask adapter ring to protect the cask sealing surfaces.
18. If a canister spacer is to be installed:
    a) Attach the spacer lift fixture to the spacer.
    b) Using an appropriate crane, lower the spacer into the cask cavity and remove the lift fixture.
19. Install the transfer cask adapter plate guide pins.
20. Install the adapter plate on top of the cask.
21. Remove the adapter plate guide pins.
22. Install the transfer cask on the adapter plate.

7.1.3 Loading the Transportable Storage Canister

1. Visually inspect the Transportable Storage Canister (canister) to ensure that it is clean and free of debris.
2. Place the canister in the Transfer Cask.
3. Place the transfer cask and canister into the fuel loading pool.
4. Load the previously designated fuel assemblies into the canister.
5. Place the shield lid on top of the loaded canister.
6. Remove the transfer cask with the loaded canister from the fuel loading pool.
7. Insert the drain tube assembly and remove approximately 70 gallons of water.
8. Weld the shield lid in place and verify the adequacy of welds with liquid penetrant examinations. Record results of examinations as required.
9. Pressurize the canister to 35 psia with air or nitrogen and hold the pressure.
10. Release the pressure.
11. Drain the remaining water from the canister.
12. Vacuum dry the canister.
13. Backfill the canister with helium.
14. Evacuate the canister to a vacuum of 3 mm mercury.
15. Backfill the canister with helium.
16. Evacuate the canister to a vacuum of 3 mm of mercury.
17. Backfill the canister with helium.
18. Close vent and drain ports and weld port covers in place and verify the adequacy of welds with liquid penetrant examinations. Record results of examinations as required.
19. Attach the leak detector system to the canister and verify the leaktightness of the canister.
20. Install the structural lid in place.

    Note: If necessary, install one or more shims to ensure that the structural lid is flush with, or protrudes slightly above, the canister shell.
21. Weld the structural lid in place and verify the adequacy of welds with liquid penetrant examinations. Record results of examinations as required.
22. Perform a smear survey of the accessible areas of the canister to ensure that the surface contamination is within limits.
23. Install the transfer cask retaining ring.
24. Decontaminate the external surface of the transfer cask to the limits established for the site.

7.1.4 Loading Transportable Storage Canister into Universal Transport Cask

1. Verify that the retaining ring is installed on the transfer cask.
2. Lift the transfer cask and lower it on top of the adapter plate on the transport cask and engage the hydraulic cylinders with the doors.
3. Engage the transportable storage canister lifting sling's master ring with the crane hook and engage the individual sling hooks with their respective hoist rings located on the structural lid of the transportable storage canister.
4. Raise the canister enough to remove the load on the Transfer Cask doors and then open the doors.

   CAUTION: While lowering the canister in Step 5, be careful to avoid contact with the interior cavity wall of the Universal Transport Cask.
5. Lower the canister into the Universal Transport Cask.
6. Disengage the lift sling hooks from the hoist rings and close the Transfer Cask doors.
7. Remove the Transfer Cask and store it in the designated location.
8. Remove the hoist rings from the top of the canister structural lid.
9. Attach the adapter plate lifting sling to the adapter plate.
10. Remove the four bolts attaching the adapter plate to the Universal Transport Cask.
11. Remove the adapter plate and store it in the designated location.
12. Remove the cask adapter ring and clean the sealing surface.
13. Install the cask lid alignment pins.
14. Attach the lid-lifting device to the lid and to the overhead crane.
15. Install the lid, using the alignment pins to assist in proper seating.
16. Install 10 cask lid bolts equally spaced and torque hand-tight.
17. Remove the lid alignment pins.
18. Install the remaining cask lid bolts and torque all of the bolts to the value specified in Table 7-1.
19. If previously removed, re-install the drain port coverplate.

20. Connect a pressure test fixture to the drain port coverplate o-ring test port and pressurize to 15 (+2, -0) psig and hold for a minimum of 10 minutes. There must be no pressure drop in the test period.

    Note: If the test condition is not met, remove the drain port coverplate and inspect and clean the o-rings and o-ring sealing surfaces and re-perform the test. If the test condition is not met on the second attempt, replace the o-rings, cleaning the o-ring grooves and sealing surface. A small amount of vacuum grease may be used to lubricate new o-rings.

    Caution: If the drain port o-rings are replaced as a result of the inspection, then a helium leak test of the new o-rings must be performed at Step 28. Using a helium leak detector with a sensitivity of 3.25×10^{-6} cm^3/sec, establish a vacuum in the o-ring annulus and test for helium leakage. The leak rate must be less than 6.5×10^{-6} cm^3/sec (helium) in accordance with Table 7-2.
21. Connect the Vacuum Drying System vacuum pump to the cask vent port and evacuate the cask cavity to a stable vacuum pressure of 3 mm Hg for 10 minutes.
22. Backfill the cask with high purity helium (99.9% minimum) to 1 atm (absolute) pressure.
23. Operate the vacuum system to obtain a vacuum pressure of 3 mm Hg. When the vacuum pressure is obtained, backfill the cask with high purity helium (99.9% minimum) to 1 atm (absolute) pressure.
24. Disconnect the vacuum system and helium supply.
25. Install the vent port coverplate and torque the bolts as specified in Table 7-1.
26. Connect a pressure test fixture to the lid o-ring test port (marked "Seal Test" on cask lid) and pressurize to 15 (+2, -0) psig and hold for a minimum of 15 minutes. There must be no pressure drop in the test period.

    Note: If the test condition is not met, replace the o-rings, cleaning the o-ring grooves and sealing surface. A small amount of vacuum grease may be used to lubricate new o-rings.

    Caution: If the lid o-rings are replaced as a result of the inspection in Step 12 of Section 7.1.2, then a helium leak test of the new o-rings must be performed. Using a helium leak detector with a sensitivity of 3.25×10^{-6} cm^3/sec, establish a vacuum in the o-ring annulus and test for helium leakage. The leak rate must be less than 6.5×10^{-6} cm^3/sec in accordance with Table 7-2.
27. Install the plug in the lid Seal Test port, verifying that the test plug o-ring is in place, and torque the plug to the value specified in Table 7-1.
28. Connect a pressure test fixture to the vent coverplate o-ring test port and pressurize to 15 (+2, -0) psig and hold for a minimum of 10 minutes. There must be no pressure drop in the test period.

    Note: If the test condition is not met, remove the vent port coverplate and inspect and clean the o-rings and o-ring sealing surfaces and re-perform the test. If the test condition

8. Attach the lifting eyes in the cask lid.
9. Attach the lid-lifting device to the cask lid and to the overhead crane.
10. Remove the cask lid and place the lid in a designated area.
11. Ensure that the O-ring grooves in the lid are protected so that they will not be damaged during handling.
12. Decontaminate the lid as necessary.
13. Remove the two alignment pins.
14. Install the cask adapter ring to protect the sealing surfaces of the cask.
15. Install the adapter plate guide pins.
16. Install the transfer cask adapter plate to protect the sealing surfaces of the transport cask and to provide a seating surface for the Transfer Cask.
17. Install the four adapter plate bolts.
18. Install the transfer cask alignment pins in the adapter plate.

7.3.3 Unloading Transportable Storage Canister from Universal Transport Cask

A transfer cask is used to unload the Transportable Storage Canister. The transfer cask could be used to transfer the loaded canister to the spent fuel building for subsequent storage in the spent fuel pool or to transfer it to another storage or disposal overpack. Prior to beginning operation of the transfer cask doors and the hydraulic system should be checked. The transfer cask retaining ring should be installed.

1. Install the swivel hoist rings in the canister structural lid.
   CAUTION: The structural lid may be thermally hot.
2. Install the transport cask adapter ring to protect the sealing surfaces of the transport cask.
3. Install the transfer cask adapter plate on the transport cask.
4. Attach the canister lifting sling to the hoist rings in the structural lid. Position the sling so that the free end of the sling can be engaged by the cask-handling crane hook.
5. Attach the transfer cask lifting yoke to the cask-handling crane hook.
6. Engage the yoke to the lifting trunnions of the transfer cask.
7. Lift the transfer cask and move it above the Universal Transport Cask.
8. Lower the transfer cask to engage the alignment pins of the transfer cask adapter plate.
9. Once the transfer cask is fully seated, remove the transfer cask lifting yoke and store it in the designated location.

10. Install the transfer cask bottom door hydraulic operating system.
11. Open the transfer cask bottom doors.
12. Lower the cask-handling crane hook through the transfer cask and engage the canister lifting sling.

    CAUTION: When raising the canister in Step 14, be careful to minimize any contact between the canister and the cavity wall of the Universal Transport Cask and between the canister and the cavity wall of the transfer cask.
13. Raise the canister into the transfer cask just far enough to allow the transfer cask bottom doors to close.
14. Close the transfer cask bottom doors and install the door locking pins.
15. Carefully lower the canister until it rests on the transfer cask bottom doors.
16. Disengage the canister lifting sling from the crane hook.
17. Retrieve the transfer cask lifting yoke and engage it with the transfer cask trunnions.
18. Lift the transfer cask from the transport cask and move it to the designated location.
19. Attach the adapter plate lifting fixture.
20. Remove the four bolts securing the adapter plate to the Universal Transport Cask.
21. Using the auxiliary crane, lift the adapter plate from the top of the cask and move the adapter plate to the designated storage location.
22. Remove cask adapter ring.
23. Install the vent port coverplate over the vent port in the cask lid.
24. Install/torque the coverplate bolts to the values specified in Table 7-1.
25. Install the cask lid alignment pins.
26. With the lid-lifting device, install the cask lid by using the alignment pins to assist in proper seating.
27. Remove the lid-lifting device, lid lift hoist rings, and the lid alignment pins.
28. Install the lid bolts and torque them to the value specified in Table 7-1.
29. Using a pressure test fixture, pressurize the o-ring annulus of the cask lid to 15 psig and hold for 15 minutes. There should be no loss of pressure during the test period.
30. Install the plug in the Seal Test port, verifying that the test plug o-ring is in place, and torque the plug to the value specified in Table 7-1.
31. Using a pressure test fixture, pressurize the vent coverplate o-ring annulus to 15 psig and hold for 10 minutes. There should be no loss of pressure during the test period.
32. Install the plug in the seal test port, verifying that the test plug o-ring is in place, and torque the plug to the value specified in Table 7-1.
33. Repeat Steps 32 and 33 for the drain port, if the drain port was used.