Enclosure 1

List of Changes

NAC-LWT SAR, Revision LWT-14A

OPAL Amendment

List of Changes, NAC-LWT SAR, Revision LWT-14A

Note: The List of Effective Pages and the Chapter Tables of Contents, including the List of Figures and the List of Tables, were revised as needed to incorporate the following changes.

Chapter 1

- Page 1.2-4, deleted text near the end of the last paragraph of the page, causing text flow on pages 1.2-5 and 1.2-6.
- Page 1.2-10, modified numbers in the last paragraph of the page.
- Page 1.2-41, added note "10" callout to Table 1.2-4, for the Parameter, "Maximum Unit Decay Heat, kW" under the column heading "MTR LEU"; modified the numbers in note 2; modified the cool time in note 8; removed 2.474 kg U as Maximum Uranium limit in MTR LEU column, and added new note 10.

Chapter 2

- No changes.

Chapter 3

- Page 3.4-4, added new text as item (3), MTR Fuel with Alternative variable decay heat, in the middle of the page and a new bullet at the end of the page.
- Pages 3.4-5 thru 3.4-36, text flow changes.
- Page 3.4-81, modified footnote number 2 at the bottom of the page.
- Page 3.5-7, modified the second full sentence at the top of the page.
- Page 3.5-34, modified the second note (with 2 ** marks) following Table 3.5-2.

Chapter 4

- No changes.

Chapter 5

- Page 5-ii, updated the List of Figures to reflect new figures and page number changes from text flow.
- Pages 5-iii thru 5-v, text flow changes.
- Page 5-vi, updated the List of Tables to reflect new tables and page number changes from text flow.
- Pages 5-vii thru 5-xii, text flow changes.
- Page 5.1.1-8, modified bullet under "Fuel Type" near the top of the page.
- Page 5.3.4-1, modified the second paragraph of Section 5.3.4, MTR Fuel Configuration.

List of Changes, NAC-LWT SAR, Revision LWT-14A (cont'd)

- Page 5.3.4-2, modified the cooling time in the last paragraph of the page.
- Page 5.3.4-3, added new text after the first partial paragraph on the page.
- Pages 5.3.4-4 thru 5.3.4-7, text flow changes.
- Page 5.3.4-8, added the Note at the end of Figure 5.3.4-3.
- Pages 5.3.4-9 thru 5.3.4-11, added new Figures 5.3.4-4 thru 5.3.4-8.
- Page 5.3.4-12, modified the Footnote number 2.
- Pages 5.3.4-13 thru 5.3.4-23, text flow changes.
- Pages 5.3.4-24 thru 5.3.4-25, added new Tables 5.3.4-16 and 5.3.4-17.

Chapter 6

- Page 6-ix, added new Table 6.4.3-30 to the List of Tables.
- Page 6.4.3-14, added new paragraph near the top of the page and modified subheading following the new paragraph.
- Page 6.4.3-15, text flow changes.
- Pages 6.4.3-31 thru 6.4.3-32, modified Table 6.4.3-26 by adding a row for "25% - K[1] and reformatting the footnotes and adding a general Note following Table 6.4.3-27.
- Page 6.4.3-35, added new Table 6.4.3-30.

Chapter 6 Appendices

- No changes.

Chapter 7

- Pages 7-i thru 7-ii, updated the Table of Contents to reflect text flow changes to page numbers and the List of Figures to revise Figure 7.1-2, "LEU MTR Fuel Basket Loading Guidelines for 30 W Uniform Loading – Maximum 470 grams ^{235}U" and include new Figure 7.1-12, "LEU MTR Fuel Basket Loading Guidelines for 30 W Uniform Loading – Maximum 640 grams ^{235}U" new Figure 7.1-13, "LEU MTR Fuel Basket Loading Guidelines for 40 W Preferential Loading – Maximum 490 grams ^{235}U."
- Page 7.1-2, modified text near the end of the second paragraph in section 7.1, "Procedures for Loading Packages."
- Pages 7.1-19 thru 7.1-22, modified text throughout section 7.1.5, including text flow changes.
- Page 7.1-24, revised Figure 7.1-2, and the title, "LEU MTR Fuel Basket Loading Guidelines for 30 W Uniform Loading – Maximum 470 grams ^{235}U."
- Pages 7.1-25 thru 7.1-29, revised Figures 7.1-3 thru 7.1-7.

List of Changes, NAC-LWT SAR, Revision LWT-14A (cont'd)

- Page 7.1-33, added new Figure 7.1-12, "LEU MTR Fuel Basket Loading Guidelines for 30 W Uniform Loading – 640 grams ^{235}U."
- Page 7.1-34, added new Figure 7.1-13, "LEU MTR Fuel Basket Loading Guidelines for 40 W Preferential Loading – Maximum 490 grams ^{235}U."
- Pages 7.1-35 thru 7.1-48, text flow changes.

Chapter 8

- No changes.

Chapter 9

- No changes.

Enclosure 2

Supporting Calculations:

Calculation 14100.005.4.1.2.2, Appendix H, Rev. 6

Calculation 14100.005.4.1.3.2, Appendix H, Rev. 7

NAC-LWT SAR, Revision LWT-14A

OPAL Amendment

NAC PROPRIETARY CALCULATIONS WITHHELD
PER 10 CFR 2.390

Enclosure 3

Proposed Changes for Revision 59 of Certificate of Compliance

No. 9225 for NAC-LWT Cask

NAC-LWT SAR, Revision LWT-14A

OPAL Amendment

CoC Sections (revised)

CoC Page 8 of 31:

5.(b)(1) Type and form of material (continued)

(iv) (c) Expanded LEU MTR Fuel Content Description

Parameter	Base	≤7.0 cm Active Fuel Width				≤7.1 cm Active Fuel Width		≤7.15 cm Active Fuel Width		
Enrichment, wt. % ^{235}U	≤25	≤25				≤25		≤25		
Number of fuel plates	≤23	≤23				≤17	≤23	≤22	≤23	≤23
^{235}U content per plate	≤22	≤22	≤22	≤21.5	≤23.5	≤22		≤22	≤21.5	≤22
Plate thickness (cm)	≥0.115	≥0.119	≥0.115	≥0.115	≥0.130	≥0.115	≥0.200	≥0.119		
Clad Thickness (cm)	≥0.02									
Active fuel width (cm)	≤6.6	≤7.0				≤7.1		≤7.15		
Active fuel height (cm)	≥56	≥56	≥63	≥56		≥56		≥56	≥56	≥61
^{235}U content per element (g)	≤490	≤490				≤490		≤490		

CoC Page 20 of 31:

5.(b)(2) Maximum quantity of material per package (continued)

(iii) Deleted.

(iv) For MTR fuel elements as described in Item 5.(b)(1)(iv):

Up to 42 fuel elements positioned within the MTR fuel assembly basket (7 fuel elements per basket module). Each of the MTR basket cell openings may contain a loose plate canister. The contents of each loose plate canister are limited to the number of fuel plates, dimensions, and masses that are equivalent to an intact MTR fuel element, as specified in Item 5.(b)(1)(iv).

(a) The maximum decay heat is not to exceed 1.26 kilowatts per package, with each MTR fuel assembly basket module not to exceed 210 watts.

(b) HEU, MEU, and LEU MTR fuel elements with decay heat not exceeding 40 watts per element may be loaded in any basket position.

(c) Mixed HEU, MEU, and LEU MTR contents, with decay heat limits as specified above, are authorized.

(d) MTR fuel elements with degraded or mechanically damaged cladding are authorized, provided the total surface area of through-clad corrosion and/or mechanical damage does not exceed 5% of the total surface area of the damaged element.

(e) For HEU-MTR fuel elements only, the center fuel element in any basket module is not to exceed 120 watts. The two exterior fuel elements vertically in-line with the center assembly for transport are not to exceed 70 watts.

(f) MTR fuel elements containing more than 23.5 g ^{235}U per plate are limited to up to four elements loaded in basket positions 4, 5, 6, and 7 of a seven-element basket per Figure 7.1-1 of the application. Basket positions 1, 2, and 3 are to be blocked by spacer hardware.

<u>CoC Page 31 of 31</u>

19. Revision 59 of this certificate may be used until October 31, 2015.

REFERENCES

NAC International, Inc., application dated June 18, 2010.

NAC International, Inc., supplements dated February 3, March 2, and May 24, October 26, and December 5, 2012; January 14, February 14, July 19 (two supplements), October 18, and December 31, 2013.

January 2014

Revision LWT-14A

NAC-LWT

Legal Weight Truck Cask System

SAFETY ANALYSIS REPORT

Volume 1 of 2

Docket No. 71-9225

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LIST OF EFFECTIVE PAGES

LIST OF EFFECTIVE PAGES (Continued)

LIST OF EFFECTIVE PAGES (Continued)

Appendix 6.6

Chapter 7

LIST OF EFFECTIVE PAGES (Continued)

1.2.1.2.2 Closure Lid

The cask closure lid is a Type 304 stainless steel forging 11.3 inches thick. The lid is machined to recess into the upper ring forging when it is installed on the cask. The closure lid and upper end forging are machined to provide a series of steps to prevent radiation streaming through the gap between the components. The closure lid attaches to the cask using 12 bolts with a 1-inch diameter. The containment boundary seal is achieved by a metallic O-ring captured in a groove machined on the underside of the closure lid (a second O-ring is provided to allow seal testing of the containment boundary O-ring). The O-rings mate against a machined sealing surface of the cask upper ring forging.

1.2.1.2.3 Impact Limiters

The impact limiters are fabricated from aluminum. The aluminum "honeycomb" has a crush strength of 3,500 psi. The honeycomb is a multidirectional crushable material that does not actually resemble a hexagonal honeycomb structure. The impact limiter is attached to the cask body at four locations. The outside diameter of the top end impact limiter is 65.25 inches and the bottom end impact limiter has a 60.25-inch diameter. The top and bottom impact limiters are 27.8 and 28.3 inches long, respectively, and both overlap the ends of the cask body by 12.0 inches.

1.2.1.3 Valves and Testing

The closure lid and the alternate and Alternate B drain and vent port covers each have a seal test port. The seal test port accesses the volume between the two O-ring seals on the cover or lid permitting leakage testing to verify proper sealing. The vent and drain valves are not considered part of the containment boundary and are used during in-plant loading operations to access the cask cavity for water filling and draining, vacuum drying, helium backfilling, etc.

1.2.1.4 Heat Dissipation

There are no special devices utilized on the NAC-LWT cask for the transfer or dissipation of heat. The package is passively cooled, which is possible because of its relatively low maximum heat load of 2.5 kW. A more detailed discussion of the package thermal characteristics is provided in Chapter 3.

1.2.1.5 Coolants

There are no coolants utilized within the package other than the normal transportation atmosphere of air or helium, depending on content conditions.

1.2.1.6 Protrusions

There are no outer protrusions on the package other than the four external lifting trunnions, the longitudinal shear ring at the upper end of the cask, and the eight impact limiter attachment lugs, four near each end of the package. All of these protrusions are located within the envelope protected by the impact limiters. The closure lid and valve port covers are recessed into the cask body and do not protrude from the cask surface. Refer to the drawings in Section 1.4 for more detail.

1.2.1.7 Lifting and Tiedown Devices

Of the four trunnions located on the exterior of the package at the upper end forging, two are intended for lifting with a nonredundant lifting yoke and the other two are used with a redundant lifting yoke. The package lifting and tiedown features are described in more detail in Section 2.5.

1.2.1.8 Shielding

A 5.75-inch annulus of lead and 2.19 inches of steel are maintained between the cask contents and the exterior radial surface of the package for the attenuation of radiation. Five inches of borated water are also provided for neutron shielding. The bottom end of the cask provides 7.5 inches of steel and 3.0 inches of lead shielding, and the closure lid provides 11.3 inches of steel shielding. Further detail is provided in Chapter 5.

1.2.2 Operational Features

The NAC-LWT cask is intended to be simple to operate. The cask is designed to be easily loaded and handled at any nuclear facility. The outer surface of the cask is electropolished and the configuration of the exposed surfaces aids in decontamination. An optional sleeving arrangement is available to limit contact between the cask and the contaminated pool water during wet loading and unloading.

The closure lid of the cask and the two valve port covers (alternate and Alternate B designs) are one-piece fixtures designed for ease of handling and to maintain personnel dose rates as low as reasonably achievable (ALARA). The closure lid has built-in alignment grooves (i.e. key ways) to facilitate installation. The alternate and Alternate B port cover designs provide clearance for valves underneath the port cover. The inner O-rings on the closure lid and the vent and drain valve port covers are components of the cask containment boundary. For the transport of TPBAR contents and other contents requiring both leaktight and high-pressure containment capabilities, the cask is required to be configured with Alternate B drain and vent port covers incorporating metallic seals. For all other contents, the leaktight capable (i.e., no credible

leakage) alternate port covers incorporating Viton O-ring seals can be used. The transport arrangement drawings for approved contents are presented in Section 1.4.

An alternative drain tube, including a drain tube alignment ring, is required to be installed and utilized when loading and transporting modular fuel baskets (i.e., not full length) and canisters.

The impact limiters and the personnel barrier are designed to be removed and installed without the aid of supplemental lifting gear or fixtures. All approved content may be transported in an International Shipping Organization (ISO) container, except for PWR and BWR fuel assemblies. All operational features are readily apparent from the drawings provided in Section 1.4. Operational procedures are delineated in Chapter 7.

1.2.3 Contents of Packaging

The NAC-LWT cask is analyzed, as presented in this SAR, for the transport of the contents listed in Table 1.1-1 and Section 1.1.

Shipments in the NAC-LWT package shall not exceed the following limits:

1. The maximum contents weight shall not exceed 4,000 pounds.
2. The limits specified in Table 1.2-1 through Table 1.2-13 for the fuel and other radioactive contents shall not be exceeded.
3. Any number of casks may be shipped at one time, one cask per tractor/trailer vehicle.
4. The maximum decay heat shall not exceed the following: 2.5 kW for PWR fuel assemblies; 2.2 kW for BWR fuel assemblies; 2.3 kW for 25 high burnup PWR fuel rods; 2.1 kW for 25 high burnup BWR fuel rods; 2.3 kW for 16 PWR MOX/UO_2 fuel rods; 1.26 kW for MTR fuel; 1.05 kW for DIDO fuel assemblies with top spacer and 0.756 kW without top spacer; 1.05 kW for TRIGA fuel elements or fuel cluster rods; 13.05 W for GA IFM packages; 0.693 kW for 300 TPBARs; 0.127 kW for TPBAR segments; 0.058 kW for 25 TPBARs; 0.84 kW for the PULSTAR fuel contents; 0.659 kW for spiral fuel assemblies (0.109 kW per basket); 0.126 kW for MOATA plate bundles (21 W per basket); and 1.26 kW for solid, nonfissile, irradiated hardware.
5. Radiation levels shall meet the requirements delineated in 10 CFR 71.47 or 49 CFR 173.441. The neutron shield tank may be drained for shipment of metallic fuel rods.
6. Surface contamination levels shall meet the requirements of 10 CFR 71.87(i) or 49 CFR 173.443.
7. Damaged TRIGA fuel elements and fuel debris (up to two equivalent elements) will be shipped in a sealed damaged fuel canister.
8. Damaged TRIGA cluster rod and fuel debris will be transported in a sealed damaged fuel canister (maximum of up to six equivalent fuel cluster rods).
9. MTR fuel elements may consist of any combination of intact or damaged highly enriched uranium (HEU), medium enriched uranium (MEU) or low enriched uranium (LEU) fuel elements that are enveloped by the parameters listed in Table 1.2-4 as supported by information presented in Table 5.1.1-2, Table 6.4.3-21, Table 6.4.3-22, Table 6.4.3-25

and Table 6.4.3-28. MTR fuel elements will be transported in a leaktight configuration NAC-LWT cask.

10. High burnup PWR fuel rods will be shipped in either a sealed, free flow or screened can.
11. High burnup BWR fuel rods will be shipped in either a sealed, free flow or screened can.
12. Up to 25 high burnup PWR or BWR fuel rods in a fuel assembly lattice or rod holder. Up to 14 of the fuel rods in a rod holder may be classified as damaged. Damaged fuel rods or rod sections may be placed into fuel rod capsules prior to placing them in the fuel rod holder. Typical failed fuel rod capsule configuration is shown in Figure 1.2-11.
13. Production TPBARs will either be shipped in an open top consolidation canister as shown in Figure 1.2.3-10 and assembled in the cask as shown in Figure 1.2.3-12, or shipped in a PWR/BWR Rod Transport Canister in accordance with License Drawing No. 315-40-104.
14. Intact PULSTAR fuel elements may be loaded into a fuel rod insert or the PULSTAR screened or failed fuel can.
15. Damaged PULSTAR fuel elements and nonfuel components of PULSTAR fuel assemblies shall be loaded into either a PULSTAR failed fuel or screened fuel can, and placed into the top or base module of the 28 MTR fuel basket. Damaged fuel, including fuel debris, may be placed in an encapsulating rod prior to loading in a PULSTAR can.
16. Any combination of spiral fuel assemblies or MOATA plate bundles, each loaded into separate ANSTO basket modules containing up to a total of 42 assemblies/bundles.
17. Segmented TPBARs will be shipped in a sealed, dry Waste Container as shown in Figure 1.2.3-16 and assembled in the cask as shown in Figure 1.2.3-17.
18. Solid, irradiated and contaminated hardware containing less than a Type A quantity of fissile material and meeting the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c), loaded directly into the cask or contained in a secondary container or basket. The irradiated hardware spacer will be installed to limit the axial movement of the hardware above the lead shielded region of the cask body. As needed, additional secondary containers, dunnage and shoring may be used to limit the movement of the contents during normal and accident conditions of transport.
19. PWR MOX fuel rods (or a combination of PWR MOX and UO_2 PWR fuel rods) are required to be loaded in a screened or free flow PWR/BWR Rod Transport Canister provided with a 5 × 5 insert.
20. Any combination of up to 7 degraded clad DIDO, spiral or MOATA plate elements/ bundles loaded into an aluminum screened DFC as shown Figure 1.2.3-18 placed in an ANSTO top basket module, with remainder of either ANSTO basket modules containing MOATA plate bundles or spiral fuel elements or ANSTO-DIDO combination basket containing DIDO elements. Degraded aluminum-clad DIDO, spiral or MOATA plate elements/bundles will be transported in a leaktight configuration NAC-LWT cask.

3. Damaged TRIGA cluster rods and cluster rod fuel debris (up to the equivalent of six cluster rods) shall be loaded into a sealed DFC and then loaded into a top or base basket module.

1.2.3.1.2 TRIGA Fuel Baskets and Damaged Fuel Cans

The TRIGA fuel basket assembly configurations consist of five modules – a base module, three intermediate modules, and a top module. The three intermediate modules are interchangeable, but the base and top modules are required to be in their proper positions. Two basket configurations are available, "nonpoisoned" and "poisoned," where the poisoned basket configuration utilizes borated steel plates for additional criticality control. Each module has up to seven cells (fuel positions) for loading TRIGA fuel elements or cluster rods. The center cell of each module of the nonpoisoned basket configuration is blocked by a welded stainless steel baffle that prevents loading of that cell. The nonpoisoned configuration is also referred to as the 24-element basket or the 120-element loading, based on the maximum of 120 intact TRIGA fuel elements that may be loaded into the baskets in this configuration. The nonpoisoned configuration may also be loaded with a mixed loading of TRIGA fuel elements and TRIGA fuel cluster rods in separate cells of the basket module. The poisoned configuration is also referred to as the 28-element basket or the 140-element loading, based on the maximum of 140 intact TRIGA fuel elements that may be loaded into the baskets in this configuration. Additionally, the nonpoisoned configuration can accommodate up to 480 intact TRIGA fuel cluster rods, while the poisoned basket can hold up to 560 intact TRIGA fuel cluster rods.

Each basket module is a Type 304 stainless steel weldment consisting of longitudinal divider plates with circular support plates near each end; the top module also has a support plate at its midpoint due to its longer length. The poisoned basket modules contain four borated stainless steel plates that are seal welded to surfaces of the divider plates in the central region of the basket cross-section. The nonpoisoned basket modules are shown in Drawings 315-40-070, -071, and -072 and the poisoned basket modules are shown in Drawings 315-40-080, -081, and -082.

The nonpoisoned TRIGA fuel basket assembly in the NAC-LWT cask is shown in Drawing 315-40-079. The poisoned basket assembly in the NAC-LWT cask is shown in Drawing 315-40-084. In the poisoned basket configuration, an alternate assembly is presented that utilizes one base module and four intermediate modules, along with a spacer (Drawing 315-40-083). The spacer is utilized to fill the space differential in the cask cavity resulting from the use of an additional intermediate module, rather than a top module. This additional assembly configuration is provided for flexibility in situations where the extra length provided by the top module is not needed. The fuel basket modules are described in further detail in Section 2.6.12.8. Damaged TRIGA fuel and fuel debris shall be loaded into sealed DFCs.

The sealed DFC is a 3.25-inch outside diameter tube with a 0.065-inch thick wall. The bottom of the sealed fuel can includes a check valve and drain plug to facilitate draining of the can. The top of the sealed DFC is closed by a bolted lid that is sealed with a metallic O-ring and includes a diaphragm valve to facilitate draining, drying, and helium backfilling of the can. The sealed DFC is constructed of austenitic stainless steels as shown on Drawings 315-40-086, -087, and-088.

1.2.3.2 MTR and DIDO Fuel and Basket Description

The MTR fuel elements to be shipped are 33 to 57 inches long, including the upper and lower nonfuel-bearing hardware, which may be removed from the element prior to transport. The MTR element fuel plates consist of a U-Al, U_3O_8-Al, or U_3Si_2-Al fuel meat clad with aluminum. The fuel plates are held in a parallel arrangement with two thick aluminum slotted pieces to form a fuel element. The active fuel region is typically 22.75 inches in height, and the fuel meat is typically 0.023-inch thick. MTR elements/plates may contain cadmium wires. A maximum 100-gram cadmium source is addressed in the shielding evaluations documented in Chapter 5. Axial fuel spacers and plates may be used in the cells of the basket modules to position MTR elements to facilitate fuel unloading and handling. The axial fuel spacers do not perform a safety function and are considered dunnage. The axial fuel spacers and plates are shown on Drawing 315-40-085.

A maximum of 42 MTR fuel elements has been analyzed for transport in the NAC-LWT cask. This configuration consists of up to seven fuel elements placed radially in each of the six axial fuel basket modules. Two alternate configurations of MTR fuel element loading provide for loads of 35 elements in five basket modules or 28 elements in four basket modules. HEU MTR fuel elements having > 380 g ^{235}U, but less than 460 g ^{235}U, shall have a minimum of 2.0 cm (0.8 inch) of nonfuel hardware and/or spacers/plates at both ends of the fuel element. The minimum 2.0 cm nonfuel hardware and/or spacer/plate dimension assures criticality control. The axial fuel spacer and plate design is shown on Drawing 315-40-085. For the shipment of MTR fuel elements (or an equivalent number of plates in a plate canister) having ^{235}U greater than 490 g per element, or greater than 23.5 g per plate (up to a maximum of 640 g per element or 32 g per plate), the maximum quantity of elements per basket module is limited to four, which are to be loaded in basket positions 4, 5, 6 and 7. Cell block spacers shall be installed in basket openings 1, 2 and 3 to block these cells from being inadvertently loaded with fuel elements. The cell block spacer design is shown on Drawing 315-40-085. Therefore, for the transport of elements of greater than 490 g ^{235}U , if only one element exceeds the 490 g (23.5 g per plate) limit, a maximum of four elements shall be loaded into the seven-element basket module and cell block spacers shall be placed in basket opening positions 1, 2 and 3.

Table 1.2-4 Fuel Characteristics (Continued)

Parameter	Metallic Fuel	Metallic Fuel	Metallic Fuel	MTR HEU	MTR MEU	MTR LEU	TRIGA LEU Element	TRIGA HEU Element	TRIGA Cluster Rod
Maximum Number of Assemblies, Elements or Rods	15 rods (sound)	9 rods (failed)	3 rods (severely failed in filters)	42[1]	42	42[2]	140	140	560
Maximum Overall Weight, lbs	1805	1805	1805	30 (max)[3]	30 (max)[3]	30 (max)[3]	13.2 (max)[3]	8.82 (nom.) 13.2 (max)[3]	1.5[3]
Maximum Overall Length, in	120.5	120.5	120.5	25.4[4]	26.1[4]	26.1[4]	47.74[5]	47.74[5]	31.0
Maximum Active Fuel Length, in	120.0	120.0	120.0	24.8	25.6	25.6	15	15	22.5
Fuel Rod Cladding	Al	Al	Al	Al	Al	Al	Al or SS	Al or SS	Incoloy 800
Maximum Uranium, kg U	54.5	54.5	54.5	0.422 0.511	0.950	3.368[2]	0.824	0.196	0.0505 (HEU) 0.2894 (LEU)
Maximum Initial ^{235}U, wt %	Natural	Natural	Natural	94	94[6]	25	20	70	95 (HEU)/20 (LEU)
Maximum Burnup, MWd/MTU	1,600	1,600	1,600	Variable up to 660,000[7]	Variable up to 293,300	Variable up to 139,300	151,100 (80% ^{235}U)	460,000 (80% ^{235}U)	600,000 (HEU)/ 140,000 (LEU) (80% ^{235}U)
Maximum Unit Decay Heat, kW	0.036	0.036	0.036	Variable[8]	0.030[8]	0.030[8, 10]	0.0075	0.0075	0.001875
Maximum Cask Decay Heat, kW	0.54	0.54	0.54	1.26	1.26	1.26	1.05	1.05	1.05
Minimum Cool Time, yr	1	1	1	Variable[8]	Variable[8]	Variable[8]	Variable[9]	Variable[9]	Variable[9]

1 For NISTR fuel. 42 assemblies may be cut in half, producing 84 fuel-bearing pieces. Each fuel-bearing piece may contain up to 0.211 kgU.

2 MTR fuel elements having ^{235}U content >490 g (>23.5 g per plate) are limited to a total of 4 elements in a 7-element basket. Basket openings 1, 2 and 3 shall be blocked by cell block spacers to ensure that MTR elements are not loaded in these openings. Therefore, depending on the number of such 4-element baskets, the maximum number of elements per cask will be reduced accordingly.

3 Maximum weight of fuel element(s), spacer(s) and fuel can, as applicable, per basket module cell shall be 80 pounds.

4 For MTR fuel elements, which are cut to remove nonfuel-bearing hardware prior to transport, a nominal 0.28 inch of nonfuel or spacer hardware will remain above and below the active fuel region to allow for fuel handling operations. The HFBR element, with an element length of 57.24 inches, must be cut prior to shipment. For HEU MTR elements having >380 g ^{235}U but less than 460 g ^{235}U, a minimum of 2.0 cm (0.8 inch) of nonfuel hardware and/or spacers/plates shall be provided at the ends of the element.

5 Permissible fuel element length is limited to basket cavity length, which is a minimum 47.74 inches for the basket top module, 30.94 inches for the intermediate modules, and 32.64 inches for the bottom module.

6 Typical MEU enrichment is 45 wt% ^{235}U. Criticality analysis supports up to 94 wt% under the MEU fuel definition.

7 Maximum burnup is 660,000 MWd/MTU for 380g ^{235}U and 577,500 MWd/MTU for 460g ^{235}U.

8 Minimum cool times for MTR fuel, down to 90 days, shall be determined using the procedure presented in Section 7.1.5.

9 Minimum cool times for TRIGA fuel elements and fuel cluster rods, down to 90 days, are determined so that the maximum decay heat of any element to be shipped is ≤ 7.5 watts and any fuel cluster rod is ≤ 1.875 watts.

10 Up to five LEU MTR fuel assemblies with ≤ 40 W may be loaded per basket module with total heat load for the basket module ≤ 210 W. Fuel assembly selection shall be determined using the procedure presented in Section 7.1.5.

Table 1.2-4 Fuel Characteristics (Continued)

Parameter	DIDO HEU	DIDO MEU	DIDO LEU
Number of Fuel Cylinders per Assembly	4	4	4
Maximum Overall Weight (lb)[1]	15	15	15
Minimum Plate Thickness, in	0.051	0.051	0.051
Minimum Clad Thickness (Al), in	0.00984	0.00984	0.00984
Maximum ^{235}U per Element, g	190	190	190
Maximum Initial ^{235}U, wt %	94	94	94
Minimum Initial ^{235}U, wt %	90	40	19
Maximum Uranium, kg U	0.2111	0.4750	1.0000
Minimum Active Fuel Height, in	23.13	23.13	23.13
Minimum Element Height[2], in	24.21	24.21	24.21
Maximum Burnup, MWd/MTU	577,460	256,650	121,910
Maximum Unit Decay Heat[3], kW	0.025	0.025	0.025
Maximum Cask Decay Heat, kW	1.05	1.05	1.05
Minimum Cool Time[4], yr	Variable	Variable	Variable

1 Maximum weight of fuel element(s), spacer(s) and fuel can, as applicable, per basket module cell shall be 80 pounds.

2 Element height provides for spacing of fissile material. An optional spacer may be used to maintain spacing if the element is cut shorter than 24.21 inches.

3 Maximum unit decay heat of 0.025 kW allowed only in conjunction with spacers for top basket (see Section 7.1.4). The per element heat load is limited to 0.018 kW with no top basket spacer. For DIDO fuel elements loaded into a top ANSTO basket module, the maximum decay heat load is limited to 0.010 kW per element (with or without DFC).

4 Minimum cool times for DIDO fuel assemblies, down to 180 days, shall be determined using the procedure presented in Section 7.1.4.

lower at all locations (except the neutron shield region) than the corresponding temperatures for the design basis PWR fuel presented in Table 3.4-2.

3.4.1.3 MTR Fuel Analytical Models

Heat transfer analysis of the NAC-LWT containing MTR fuel is performed using two separate two-dimensional planar finite element models and the general purpose ANSYS computer code. The first model represents the entire cask and uses a nominal, effective thermal conductivity to represent the fuel element in each basket location. This cask model is used to determine the maximum temperatures throughout the cask, including the temperature of the fuel element side plates. The second model represents the detailed construction of the fuel element itself. The detailed fuel model uses the results from the cask model to specify the boundary condition temperature of the fuel element side plate. This model is used to determine the maximum fuel temperature for each case. Note that the loose fuel plate configuration in the MTR canister is bounded by the assembled fuel element because the stacked loose plates have a much greater contact area for heat transfer to the basket walls. Therefore, the loose fuel plate configuration is not evaluated. Two transport conditions are evaluated:

Condition 1:

The NAC-LWT is supported in an ISO container with solar insolance applied on the surface of the ISO container, and the NAC-LWT is considered to be insulated from the environment (only for normal conditions of transport steady state conditions). The gas inside the ISO container is air. The cavity of the NAC-LWT is backfilled with helium as required by operational procedures.

Condition 2:

The NAC-LWT is not located in an ISO container and solar insolance is applied to the NAC-LWT cask surface. For the purpose of performing the thermal analyses, the cavity of the NAC-LWT is considered to be filled with air.

Of these two conditions, Condition 2 (air in cavity case) produces the higher temperatures as shown in Table 3.4-6. Therefore, the detailed fuel model is used to evaluate Condition 2 only. For each of the two conditions listed above, two different fuel configurations are considered for evaluation for steady-state normal transport conditions.

(1) Uniform design basis heat load of 30 watts per MTR fuel assembly:
This configuration consists of seven MTR fuel elements with design basis heat loads (30 watts per element) corresponding to a total MTR package contents heat load of 1.26 kilowatts (42 fuel elements).

(2) MTR fuel with variable decay heat:

As described in Section 5.3.4, MTR fuel may also be shipped in a variable decay heat configuration. In this case, a basket module may be loaded with only three elements, each having a maximum decay heat of 70 watts, or with three elements with maximum decay heats of 120 watts, 70 watts, and 20 watts. The total decay heat load for the basket must not exceed 210 watts. The same detailed heat transfer model described in Section 3.4.1.3.1 is also used for this analysis.

(3) MTR fuel with Alternative variable decay heat:

For the Alternative variable decay heat pattern, the maximum heat load for an MTR assembly is 40 Watts. A maximum of five 40-watt MTR assemblies can be transported in a single MTR basket with a total heat load per basket of 210 watts or less. For the condition in which five 40-watt MTR assemblies are being transported, the heat load in the remaining two slots in a single MTR basket is limited by the 210-watt total single MTR basket limit. Table 3.4-6 indicates that the increased single MTR assembly heat load of 120 watts results in the maximum MTR temperatures (when the total basket heat load remains to be 210 watts per basket). The preferential MTR loading using 120-watts at the basket center is the bounding gradient of heat generation from the basket periphery to the basket center as compared to the 40-watt maximum MTR heat load. This will result in the 120-watt preferential loading identifying the bounding MTR temperatures. Since the 120-watt loading is the bounding condition, further evaluation of the 40-watt maximum (with a total of 210 watts per MTR basket) is not required.

The fuel decay heat is modeled using uniform volumetric heat generation terms defined by administrative controls from Section 7.1.5. The administrative controls define bounding basket loading configurations that:

- Limit the combined basket heat load to 210 watts per basket module.
- Exclude MTR elements having decay heat loads in excess of 120 watts.
- Require MTR elements having decay heat loads between 120 watts and 70 watts to be loaded into the center basket module position.
- Require MTR elements with decay heat loads between 30 watts and 70 watts to be loaded in the center in-line row of the basket module.
- Limit decay heat loads of MTR elements placed in peripheral basket tubes, not on the center line, to a 30-watt decay heat load (per element).
- For the alternative preferential loading, the maximum heat load for any slot is 40 watts and the total heat load for each basket is limited to 210 watts.

These constraints result in two bounding loading configurations of MTR fuel elements. Assuming that individual elements have maximum decay heats of 70 watts and 120 watts, the two bounding configurations are:

1. Three 70-watt fuel elements
2. One 120-watt fuel element, one 70-watt fuel element, and one 20-watt fuel element

These combinations are depicted in Figure 3.5-7. Of these two configurations, the second configuration will produce the highest temperatures, as the center assembly contains a 120-watt MTR fuel element. This is the fuel configuration, which is analyzed for the variable decay heat loading. The thermally limiting configuration is also depicted in Figure 3.4-4, which conservatively bounds any fuel loading configuration permitted by the operating procedure presented in Section 7.1.5.

3.4.1.3.1 MTR Fuel Thermal Model of the NAC-LWT (Transported in an ISO Container)

For Condition 1, the detailed fuel model is not used because this condition is bounded by Condition 2, as shown in Section 3.4.1.3.2. Thermal analyses of the NAC-LWT cask for Condition 1 are performed using a half-symmetry, cross-sectional model of the cask in an ISO container positioned along the container centerline. Heat transfer to the environment is limited to surface convection and radiation on both horizontal and vertical surfaces of the ISO container with an emissivity of 0.36. Solar insolance is applied to the vertical surfaces and the top horizontal surface of the ISO container. Heat transfer from the cask to the ISO container is modeled as conduction, convection and radiation. Convective and conductive heat transfer are modeled in the liquid neutron shield, while heat transfer in the cask cavity is limited to conduction and radiation. Axial heat transfer is conservatively ignored in the model. The MTR fuel elements are represented in the model with homogenized fuel elements. The conductive heat flow path from the cask through the saddle support to the bottom surface of the ISO container is conservatively ignored.

Thermal conductivity for 6061-T6 aluminum alloy is based on ASME Code, Section II, Part D, Table TCD. The finite element model for the uniform 30 watts per MTR fuel element is shown in Figure 3.4-3, while the finite element model for the variable decay heat of 120 watts, 70 watts and 20 watts is shown in Figure 3.4-4. For the basket slots, which are empty for the variable decay heat, only conduction through the cavity gas is modeled. In each of these fuel models, the fuel is considered to rest on the surface of each basket slot. The details of this modeling are shown in Figure 3.4-6. While the MTR fuel assemblies are considered to rest on the surface of the basket, the basket is conservatively modeled as being in the center of the cask cavity. Conduction (through helium) and radiation (using emissivity of stainless steel for both surfaces) are modeled from the inner shell of the cask to the basket.

The heat transfer analysis model represents the cask cavity free space using the conductivity of helium. (see Table 3.2-7). The properties for the remaining materials are contained in Table 3.2-1 through Table 3.2-6.

The air space between the NAC-LWT cask and the ISO container is modeled using air with an effective conductivity. This effective conductivity (Incropera) is:

$$\frac{k_{eff}}{k} = 0.386\left(\frac{Pr}{0.861+Pr}\right)^{1/4}\left(Ra_c^*\right)^{1/4}$$

$$Ra_c^* = \frac{\left[\ln(D_0/D_i)\right]^4}{L^3\,(D_i^{-3/5}+D_0^{-3/5})^5}\,Ra_L$$

$$Ra_L = \frac{g\beta(T_i - T_o)L^3}{\alpha\nu}$$

where:

Pr = Prandtl number (Krieth)

ν = kinematic viscosity (Krieth)

α = thermal diffusivity (Krieth)

β = $1/T_f$

T_f = $(T_i+T_o)/2$

T_i = inner surface temperature

T_o = outer surface temperature

D_i = inner diameter (cask surface)

D_o = outer diameter (height of the ISO container)

L = $(D_o - D_i)/2$

The effective conductivity for the neutron shield and expansion tank as well as the convection from the surface of the ISO container to an ambient temperature of 100°F are presented in Section 3.2.3.

Decay heat for the different MTR package configurations is conservatively enveloped for the heat transfer analysis. Each fuel element of the maximum capacity MTR package configuration, 42 elements, is modeled with a heat generation of 30 watts. Total MTR package contents heat

load is 1.26 kilowatts, approximately half of the NAC-LWT cask maximum decay heat load of 2.5 kilowatts. The decay heat is modeled as uniformly generated within the homogenized fuel regions.

The Condition 1 models of the NAC-LWT cask with uniform and variable decay heat MTR fuel element loadings are shown in Figure 3.4-3 and Figure 3.4-4, respectively.

3.4.1.3.2 MTR Fuel Thermal Model of the NAC-LWT (Transported via Truck Trailer)

Thermal analyses of the NAC-LWT cask for Condition 2 are performed using two separate models. The first is a half-symmetry cross-sectional model of the cask in which the outer surface of the expansion tank is the boundary of the model. This model is used to determine the temperatures throughout the cask up to and including the maximum fuel element side plate temperatures. The second is a half-symmetry cross-sectional model of the fuel element. This model is used to determine the maximum fuel temperature within the element for the worst-case fuel plate dimensions. The worst case dimensions are based on the limiting design dimensions combined with the limiting manufacturing tolerances that result in the maximum resistance to heat transfer from the fuel to the side plates.

Cask Model

The modeling of the normal steady state condition of the NAC-LWT from the center of the cask to the outer surface of the expansion tank is identical to the model described in Section 3.4.1.3.1 with the following exceptions:

1. The gas in the NAC-LWT cask cavity is considered to be air.
2. The MTR basket is shifted downward towards the inner shell leaving a minimum gap of 0.07 inch between the outer diameter of the basket end plate and the cask inner shell surface. This is an effective representation of the normal condition of transport (i.e. cask horizontal).
3. The solar insolance and convection to the ambient temperature of 100°F is applied to the outer shell of the expansion tank.

The Condition 2 models of the NAC-LWT cask with uniform and with variable decay heat MTR fuel element loadings are shown in Figure 3.5-6 and Figure 3.5-7, respectively. These same models are used to calculate both normal and accident condition temperatures for the cask.

Fuel Element Model

The fuel element model includes the side plate, the fuel, cladding, and the air between the plates and surrounding the side plate. The total element heat load is uniformly distributed throughout the fuel. Based on symmetry, only one-half of the fuel element assembly is modeled. Figure 3.4-13 shows the model for both the minimum 10-plate and maximum 23-plate cases. These two

configurations bound fuel elements with any intermediate number of plates. The boundary condition for this model is the applied side plate temperature at the lower right corner of the model. This assumes that the basket is oriented such that only the ends of the element side plates are in contact with the basket. The lateral surfaces of the side plates are assumed to be adiabatic, which results in a conservative calculation of the maximum temperature of the fuel.

	K, BTU/hr-in-°F		
Temperature, °F	Aluminum	UO_2	Fuel Matrix 75% UO_2
100	8.08	0.42	2.33
200	8.25	0.37	2.34
300	8.38	0.33	2.35
400	8.49	0.30	2.35

The worst-case fuel effective thermal conductivity occurs for the maximum UO_2 percentage of 75% and corresponds to the LEU fuel plates.

The fuel in the center of each fuel plate is a matrix of aluminum and uranium or aluminum and uranium oxide (UO_2) combined in various ratios. The effective thermal conductivity is calculated using a mass-weighted average of the conductivity of the individual materials. The fuel plates are modeled using worst-case dimensions as shown:

1. Fuel plate thickness = 0.045 inch (< 0.05 inch)
2. Cladding thickness = 0.008 inch (< 0.015 inch)

A sensitivity analysis shows that variation of the active fuel width within the fuel plate has a negligible effect. A constant value of 6.6 cm is used in the analysis. This corresponds to the worst case for reactivity considerations. Note that the case of the loose fuel plates in the MTR canister is bounded by that of the assembled fuel element and, therefore, is not evaluated.

3.4.1.3.3 MTR Fuel Heat Transfer Analyses Results

The thermal analysis is performed to demonstrate that the temperature of the MTR fuel is maintained within acceptable limits. A conservative temperature of 400°F is established as the maximum allowable MTR fuel cladding temperature for normal conditions of transport. The aluminum retains its capability to function as a mechanical component in this temperature range, and it is not close to the 1,220°F melting temperature of aluminum (Table 6.4.1, pg. 6-60, Marks' Standard Handbook for Mechanical Engineers). The material properties presented in MIL-HDBK-5F indicate that 6061-T6 aluminum alloy retains over 40% of its room temperature yield and ultimate strengths at a long-term temperature of 400°F.

Maximum temperatures for package components with the NAC-LWT configured for MTR fuel are summarized in Table 3.4-6. The reported temperatures are lower at all locations than the corresponding temperatures for the design basis PWR fuel presented in Table 3.4-2. Temperatures of the MTR fuel element cladding are maintained below 400°F for both the design basis uniform decay heat loading and the variable heat loading.

3.4.1.4 PWR Rod

Heat transfer of the NAC-LWT containing 25 PWR rods with a total heat load of 1.41 kW configured in the PWR/BWR aluminum basket in the NAC-LWT cask enclosed in an International Shipping Organization (ISO) container was evaluated using ANSYS. The model presented in Figure 3.4-3 was revised to include the PWR/BWR aluminum basket and 25 PWR rods. Results from this evaluation are summarized in Table 3.4-7.

These results show that the temperatures are lower at all locations (except the neutron shield region) than the corresponding temperatures for the design basis PWR fuel presented in Table 3.4-2. Similar to the discussion presented in Section 3.4.1.3.3 for the MTR heat transfer analysis, temperature results from the two dimensional heat transfer analysis are conservative based on the imposed limitations of the model and can be used to evaluate acceptability of component temperatures outside the modeled section. Temperature of components in the lid closure region is less than the hottest basket temperature which is directly influenced by the decay heat of the fuel. It is concluded that the temperature of the safety related O-ring seals is within the allowable range of temperature of -40°F to +735°F. The maximum temperature of the lead gamma shield in the base of the LWT cask is less than the cask inner shell and much lower than the maximum of +600°F.

3.4.1.5 Thermal Evaluation for TRIGA Fuel

The thermal evaluation for TRIGA fuel is performed using classical analysis employing a thermal resistance model. The TRIGA fuel is transported in a basket assembly consisting of five modules - a base module, a top module, and three intermediate modules. During transport all 5 modules must be installed in the cask. The three intermediate modules are interchangeable, but the top and base modules are not. Each module contains 7 cells, and each open cell holds up to 4 TRIGA fuel elements. The top module is sized to accept fuel follower control elements, which are longer than the typical element. The center cell of each module is blocked with an 11-gage stainless steel plate so that fuel cannot be loaded in the center cell. The thermal evaluation conservatively assumes that the center cell also contains 4 fuel elements, so although only 120 fuel elements may be loaded into the cask, the thermal evaluation assumes 140 elements.

Consequently, the total heat load in the thermal evaluation is conservatively considered to be 1.05 kW (7.5 watt/fuel element × 140 = 1.05 kW).

TRIGA fuel elements may be transported directly in a basket module cell, in a screened failed fuel can, or in a sealed failed fuel can. The fuel cans fit in either a top or base module cell. The screened failed fuel cans hold up to four (4) TRIGA fuel elements, while the sealed failed fuel can holds up to two (2) damaged elements or equivalent fuel debris.

As described in Section 1.2.3.1, TRIGA fuel elements with minor cladding defects are loaded into screened failed fuel cans (screened cans). The screened can precludes gross particulate material from escaping the cell. The screened failed fuel cans are provided in two lengths. The screened failed fuel can is a square tube of 14-gage, Type 304 stainless steel, that holds four fuel elements. It is provided with a closure lid and an end plate that is screened to allow water draining.

TRIGA fuel debris and damaged fuel elements, which do not have structural integrity, are loaded into sealed failed fuel cans (sealed cans). The sealed cans are used to containerize the TRIGA fuel debris. The cans are provided in two lengths. The shorter can may be used in the base or top basket modules. The longer can may only be used in the top module. The cans are vacuum dried and leak tested prior to loading into a TRIGA fuel basket.

The TRIGA fuel thermal evaluation determines the maximum fuel cladding temperatures based on the maximum basket temperatures determined for the design basis heat load MTR thermal analysis presented in Section 3.4.1.3.1. An intermediate basket module with the shortest TRIGA fuel, which provides the highest heat load density, is used to obtain a bounding evaluation. Based on the maximum basket temperature and heat load density, the maximum fuel cladding temperatures are determined using a thermal resistance model.

The cross-section of the TRIGA and MTR fuel baskets are identical. As shown in Section 1.2.3 and Table 1.2-4, the maximum decay heat load for MTR fuel is 1.26 kW per cask. The maximum decay heat load for TRIGA fuel is 1.05 kW per cask. Therefore, it is conservative to use the maximum basket temperature for MTR fuel as a boundary condition for the thermal resistance model for TRIGA fuel.

Since the total decay heat load for MTR fuel bounds that for TRIGA fuel, the temperatures for cask components for the MTR fuel also bound those for the TRIGA fuel. The cask body temperatures for the MTR fuel are shown in Table 3.4-6.

3.4.1.5.1 TRIGA Model Description

The heat generated from the TRIGA fuel in the basket is transferred to the basket module by thermal conduction and radiation, and then transferred to the cask inner shell from the basket surface by the same heat transfer modes. The heat is finally transferred through the cask and

International Shipping Organization (ISO) container to ambient. The thermal resistance model and thermal analysis of TRIGA fuel considers the regions inside a single basket opening of the TRIGA fuel basket. This analysis bounds transport in the cask without an ISO container.

The thermal resistance model is shown in Figure 3.4-5. The maximum temperature of the basket (T_{basket}) is taken from the MTR design basis heat loading thermal analysis. The temperatures for the TRIGA fuel are determined by stepping through each of the resistors in the thermal circuit, from the basket to the fuel cladding. All temperatures calculated are maximums, based on the basket temperature. Each successive maximum temperature calculated is then applied uniformly over the next surface in the resistance model. Fuel may be shipped directly in a basket cell, in a screened failed fuel can, or in a sealed failed fuel can. Since the model assumes the presence of the can, the model is conservative for configurations in which a can is not used.

The gas in the cask cavity is considered to be air in the thermal resistance model. Thermal conductivities of air and stainless steel are obtained from "Fundamentals of Heat and Mass Transfer" (Incropera). Emissivities of stainless steel (basket) and aluminum (fuel clad) are obtained from the Nuclear Systems Material Handbook and from "Scoping Design Analyses for Optimized Shipping Casks Containing 1-, 2-, 3-, 5-, or 10-Year-Old PWR Spent Fuel" (Bucholz), respectively.

Assuming the maximum temperature of the basket (T_{basket}) occurs at all inside surfaces of the webs forming the central cell in the basket module, the temperature of the can (T_{can}) is then determined by considering heat conduction and radiation between the can surface and the inside surface of the basket central cell. Convection in the gap between these surfaces is conservatively ignored.

The heat transfer rate across the gap per unit length (q_{gap}) between the can surface and the inside surface of the basket central cell wall can be represented as follows:

$$q_{gap} = q_{cond} + q_{rad}$$

$$q_{gap} = \frac{A(k_{cond})(T1 - T2)}{L_{gap}} + \frac{A(\sigma)(T1^4 - T2^4)}{\left(\frac{1}{\varepsilon 1} + \frac{1}{\varepsilon 2} - 1\right)}$$

where:

q_{gap} = 7.5 watt × 4/14 = 2.14 watt = 7.302 Btu/hr

A = Can surface area = 3.33 × 4 = 13.32 inch^2

K_{cond} = Air conductivity @ 260°F (400°K) = 1.628 × 10^{-3} Btu/hr-in-°F

L_{gap} = Gap size between can and basket = (3.44-3.33)/2 = 0.055 inch

T1 = temperature at can surface (T_{can})

T2 = temperature at inside surface of the basket central cell (T_{basket}) = 267°F

σ = 1.19×10^{-11} Btu/hr-in^2-°R

ε1 = emissivity of web of basket central cell (stainless steel) = 0.36

ε2 = emissivity of can (stainless steel) = 0.36

The temperature at the can (T_{can}) is calculated to be 287°F.

The maximum temperature of the can (T_{can}) is then applied to all can surfaces for determining the cladding temperature of the fuel. It is assumed that there are four (4) fuel elements inside the can surrounded by air. In the equivalent resistor analogy, the fuel elements do not contact each other, neglecting heat conduction between fuel elements. For a specific fuel element, an assumed circular region equivalent to 1/4 of the area inside the can, is developed to contain a fuel element, which results in a uniform air gap. The fuel cladding temperature is determined using the formula representing a hollow cylinder. Note that convective heat transfer in the gap between the fuel clad and the can is conservatively ignored.

Heat transfer rate per unit length of the basket (Q_{leng}) can be represented as:

$$Q_{leng} = q_{cond} + q_{rad}$$

$$Q_{leng} = \frac{2\pi(k_{cond})(T1 - T2)}{\ln\left(\frac{r2}{r1}\right)} + \frac{\sigma(2\pi r1)(T1^4 - T2^4)}{\left(\frac{1}{\varepsilon 1}\right) + \left(\frac{1-\varepsilon 2}{\varepsilon 2}\right)\left(\frac{r1}{r2}\right)}$$

where:

r1 = fuel cladding outer radius = 0.675-inch

r2 = radius of equivalent circular region representing ¼ of the area inside a can

= 0.93 inch.

K_{cond} = Air conductivity @ 260°F (400°K) = 1.628×10^{-3} Btu/hr-in-°F

σ = 1.19×10^{-11} Btu/hr-in^2-°R

ε1 = emissivity of fuel cladding (aluminum) = 0.22

ε2 = emissivity of the can (stainless steel) = 0.36

T1 = fuel cladding temperature (T_{clad})

T2 = can temperature (T_{can}) = 287°F

The fuel cladding temperature (T_{clad}) is solved to be 326°F.

3.4.1.5.2 TRIGA Fuel Thermal Evaluation Results

Using the model described above, and the assumed boundary condition of 267°F for the maximum basket temperature (from Table 3.4-6), the maximum normal transport conditions temperature of the TRIGA fuel is determined as shown in Table 3.4-8.

A conservative temperature of 400°F is established as the maximum allowable temperature for aluminum-clad TRIGA fuel, as described in Section 3.4.1.3.3 for MTR fuel. Stainless steel clad TRIGA fuel is allowed a significantly higher cladding temperature, since the melting temperature of stainless steel is 2,600°F (Mark's) and stainless steel retains its capability to function as a mechanical component at temperatures up to the 800°F range. Therefore, the temperatures calculated for the TRIGA fuel cladding are acceptable.

3.4.1.6 TRIGA Fuel Cluster Rods

The TRIGA fuel cluster rods are 0.542 inches OD with 0.016-inch thick Incoloy 800 cladding. Each rod is inserted into a 6061-T6 aluminum tube (0.75 inch OD, 0.62 inch ID) that is part of the fuel rod insert. Up to sixteen rods and a fuel rod insert are placed into a single cell of the seven cell basket. This TRIGA basket has the same cross sectional dimensions and basket material as the MTR basket presented in Section 3.4.1.3. The thermal evaluation for the TRIGA fuel cluster rods is performed using two-dimensional planar finite element analyses and the general purpose ANSYS computer code. Two transport conditions are evaluated:

Condition 1:

The NAC-LWT is supported in an ISO container with solar insolance applied on the surface of the ISO container, and the NAC-LWT is considered to be insulated from the environment (only for the normal conditions of transport steady state conditions). The gas inside the ISO container is air. The cavity of the NAC-LWT is actually backfilled with helium as required by operational procedures.

Condition 2:

The NAC-LWT is not located in an ISO container and solar insolation is applied to the NAC-LWT cask surface.

For the purpose of performing these thermal analyses, the cavity of the NAC-LWT is considered to be filled with air.

For each of the two conditions listed above, only a single fuel configuration is evaluated: 16 rods in a fuel rod insert in each of the seven cells comprising a basket section. This corresponds

to a total heat load of 210 watts for each basket section (30 watts per cell of a basket section which corresponds to 30/16 or 1.875 watts per rod). Therefore, the heat load in the cask cavity corresponding to five basket sections is 5 times 210 watts or 1.05 kW.

Since the finite element model corresponds to a one inch axial length, the heat generation applied to each rod in the model was 1.875 watts divided by the length of the rod or 22 inches. Although the aluminum inserts will conduct heat in the axial direction, this was conservatively ignored.

3.4.1.6.1 Condition 1 Analysis of TRIGA Fuel Cluster Rods

Thermal analyses of the NAC-LWT cask for Condition 1 are performed using a half symmetry cross sectional model of the cask in an ISO container positioned along the container centerline. The model employed for the ISO container, cask body and the seven-celled basket is the same finite element model used in Section 3.4.1.3.1 for the MTR fuel thermal model (Condition 1). The similarity in modeling includes the finite element mesh and the material properties for conduction, convection and radiation. The 16 rods and fuel rod inserts are modeled in each of the seven cells, as shown in Figure 3.4-7. Figure 3.4-8 and Figure 3.4-9 show details of the fuel region model. The TRIGA fuel cluster rods were conservatively modeled in the center of the aluminum fuel tube, and the fuel rod inserts were modeled without any contact with the sides of the basket. The 0.13 inch aluminum shell, which surrounds the TRIGA fuel cluster, provides a heat transfer path from the rods to the basket surface. This aluminum shell was conservatively not considered in the analysis. The space between the aluminum tubes and the stainless steel basket surface was modeled with the cavity gas, and the modes of heat transfer from fuel rod insert to the basket surface included conduction through the gas and radiation from the surface of the insert to the basket surface.

3.4.1.6.2 Condition 2 Analysis of TRIGA Fuel Cluster Rods

Thermal analyses of the NAC-LWT cask for Condition 2 are performed using a half symmetry cross sectional model of the cask in which the outer surface of the expansion tank is the boundary of the model. The modeling of the normal steady state conditions of the NAC-LWT from the center of the cask to the outer surface of the expansion tank is identical to the model described in Section 3.4.1.3.1 with the following exceptions:

1. The gas in the NAC-LWT cask cavity is considered to be air.
2. The solar insolance and convection to the ambient temperature of 100°F is applied to the outer shell of the expansion tank.

3.4.1.6.3 TRIGA Fuel Cluster Rods Heat Transfer Results

The thermal analysis is performed to demonstrate that the temperature of the TRIGA fuel cluster rod is maintained within acceptable limits. A conservative temperature of 800°F is established

as the maximum allowable TRIGA fuel cladding temperature for normal conditions of transport. For aluminum 6061-T6 aluminum alloy, the allowable temperature is considered to be 400°F.

Temperatures for package components with the NAC-LWT configured for the TRIGA fuel are summarized in Table 3.4-9. In this table, the maximum fuel clad temperature is 295°F, which is significantly below the 800°F value. For the aluminum, the maximum reported temperature is 292°F, which is also well below the 400°F limit.

3.4.1.7 High Burnup PWR or BWR Rods in a PWR/BWR Rod Transport Canister

The high burnup rods may be either BWR rods or PWR rods. The decay heat for the PWR fuel rod contents is 2.3 kW with a corresponding peaking factor of 1.1. The decay heat for the BWR fuel rod contents is 2.1 kW with a peaking factor of 1.22. The thermal evaluation employs a two-dimensional planar model to ensure that the peaking factor is conservatively included and the heat load applied to the finite element model is the total heat load factored by the peaking factor. The bounding product of the heat load and the peaking factor corresponds to the BWR. The evaluation of the BWR rod is considered to bound the temperatures corresponding to the PWR rod configuration. All of the fuel rods are considered to be intact for this evaluation. The evaluation of damaged fuel rods is provided in Section 3.4.1.11. An additional configuration is also considered in which four tubes of the 5×5 insert are replaced by a single tube to accommodate a BWR water rod, which has negligible heat load. The single water rod occupies a position near the center of the matrix. However, the thermal response associated with the configuration with the water rod is bounded by the evaluation of the 5×5 matrix due to the reduced heat load and the removal of the heat generation at the center of the matrix.

The PWR/BWR Rod Transport Canister for the high burnup rod transport can accommodate three configurations: a 4 × 4 matrix of pin tubes containing up to 16 rods, a 5 × 5 matrix of pin tubes containing up to 25 rods, and an alternative 5×5 rod holder designed to contain an oversize nonfuel-bearing component (e.g., CE guide tube or BWR water rod) and up to 21 rods. Since the decay heat per rod is considered to be the same, the maximum heat load is bounded by the 25-rod configuration. For the 4 × 4 matrix of pin tubes, an additional 31-inch thick stainless steel insert is placed in the can weldment. This permits the can weldment to be employed for the 16-rod transport or the 25-rod transport configuration. For the can weldment, the aluminum basket and the remainder of the cask, the additional insert has a negligible affect on their temperatures. Therefore, the bounding configuration is the 25-rod configuration, since it produces 56% more heat load in the cask basket than the 16-rod configuration. The bounding configuration for the clad temperatures and the pin tubes supporting the fuel rods is also the 25-rod configuration due

to the 56% additional heat load. While the additional insert increases the thermal resistance, this is significantly offset by the additional 56% additional decay heat.

Heat transfer analysis of the NAC-LWT containing high burnup rods is performed using two-dimensional planar finite element analyses and the general purpose ANSYS computer code. Two transport conditions are evaluated:

Condition 1:

The NAC-LWT is supported in an ISO container with solar insolance applied on the surface of the ISO container, and the NAC-LWT is considered to be insulated from the environment (only for normal conditions of transport steady state conditions). The gas inside the ISO container is air.

The cavity of the NAC-LWT is backfilled with helium as required by operational procedures.

Condition 2:

The NAC-LWT is not located in an ISO container and solar insolance is applied to the NAC-LWT cask surface.

For the purpose of performing the thermal analyses, the cavity of the NAC-LWT is considered to be filled with air.

3.4.1.7.1 High Burnup PWR and BWR Fuel Rods Thermal Model of the NAC-LWT (Transported in an ISO Container)

Thermal analyses of the NAC-LWT cask for Condition 1 are performed using a half-symmetry, cross-sectional model of the cask in an ISO container. Heat transfer to the environment is limited to surface convection and radiation on both horizontal and vertical surfaces of the ISO container with an emissivity of 0.36. Solar insolance is applied to the vertical surfaces and the top horizontal surface. Heat transfer from the cask to the ISO container is modeled as conduction, convection and radiation. Convective and conductive heat transfer are modeled in the liquid neutron shield, while heat transfer in the cask cavity is limited to conduction and radiation. Axial heat transfer is conservatively ignored in the model.

Bounding configuration of BWR fuels used in analyses is based on U.S. Department of Energy, Office of Civilian Radioactive Waste Management, "Characteristics of Spent Fuel, High-Level Waste, and Other Radioactive Wastes Which May Require Long -Term Isolation," Appendix 2A, December 1987. Thermal properties of UO_2 and zirconium alloy cladding are from 1) Hagrman, D.L., Reymann, G.A., "Matpro-Version 11, A Handbook of Material Properties for Use in the Analysis of Light Water Reactor Rod Behavior," Idaho Falls, ID, EG&G Idaho, Inc., 1997; 2) Rust, J.H., "Nuclear Power Plant Engineering," Atlanta, GA, S.W., Holland Company,

1979. Thermal conductivity for 6061-T651 aluminum alloy is based on ASME Code, Section II, Part D, Table TCD.

The finite element model for the condition 1 is shown in Figure 3.4-10. The fuel cladding and the inner surface of the pin tube are considered to be in point-to-point contact. The outer surface of the fuel cladding only contacts the pin tube in one point in the model. The pin tubes are conservatively considered separated and a gap of 0.0005 inch between pin tubes is modeled. This condition neglects any pin tube contact due to dead weight loading of the contents. One of the can weldment sides is modeled in contact with the aluminum insert. For the other three sides, a gap 0.042/0.084/0.042 inch between the aluminum insert and the tube of the can weldment is modeled. The details of this modeling are shown in Figure 3.4-11. Likewise, only one surface between the PWR aluminum insert and the PWR basket is considered to be in contact.

Conduction (through helium) and radiation (using emissivity of stainless steel for both surfaces) are modeled from the inner shell of the cask to the basket.

The heat transfer analysis model uses conduction in the remaining volume of the cask cavity. The conductivity of this material corresponds to helium. (see Table 3.2-7). The properties for the remaining materials are contained in Table 3.2-1 through Table 3.2-8.

The air space between the NAC-LWT cask and the ISO container is modeled using air with an effective conductivity. This effective conductivity (Incropera) is:

$$\frac{k_{eff}}{k} = 0.386\left(\frac{Pr}{0.861+Pr}\right)^{1/4}\left(Ra_c^{\ast}\right)^{1/4}$$

$$Ra_c^{\ast} = \frac{\left[\ln(D_0/D_i)\right]^4}{L^3\,(D_i^{-3/5}+D_0^{-3/5})^5}\,Ra_L$$

$$Ra_L = \frac{g\beta(T_i - T_o)L^3}{\alpha\nu}$$

where:

Pr = Prandtl number (Krieth)

ν = kinematic viscosity (Krieth)

α = thermal diffusivity (Krieth)

β = $1/T_f$

T_f = $(T_i+T_o)/2$

T_i = inner surface temperature

T_o = outer surface temperature

D_i = inner diameter (cask surface)

D_o = outer diameter (height of the ISO container)

$L = (D_o - D_i)/2$

3.4.1.7.2 High Burnup PWR and BWR Fuel Rods Thermal Model of the NAC-LWT (Transported via Truck Trailer)

Thermal analyses of the NAC-LWT cask for Condition 2 are performed using a half-symmetry planar cross-sectional model of the cask in which the inner surface of the inner shell is the boundary of the model. The maximum temperature of 274°F (PWR design basis fuel with 2.5 kW heat load and a peaking factor of 1.2 under normal transport condition [Table 3.4-2]) is applied to the boundary of the model. The modeling of the normal steady state condition of the NAC-LWT from the center of the cask to the inner surface of the inner shell is identical to the model described in Section 3.4.1.7.1 with the following exceptions:

1. The gas in the NAC-LWT cask cavity is considered to be air.
2. The constant temperature of 274°F is applied to the outer surface of the model, which corresponds to the inner surface of the cask inner shell. This temperature corresponds to the condition, which imposes solar insolance and convection/radiation boundary at the outer shell of the expansion tank. This is also described in Section 3.4.1.1.

The Condition 2 model of the NAC-LWT cask with high burnup PWR and BWR fuel rods is shown in Figure 3.4-12. This model is also used to calculate both normal and accident condition temperatures for the cask.

3.4.1.7.3 High Burnup PWR and BWR Fuel Rods Heat Transfer Analyses Results

The thermal analysis is performed to demonstrate that the component temperature of NAC-LWT cask loaded with high burnup PWR and BWR rods is maintained within acceptable limits.

Maximum temperatures for package components with the NAC-LWT configured for high burnup PWR and BWR rods are summarized in Table 3.4-10. As shown in Table 3.4-10, component temperatures are all maintained within their allowable temperatures.

3.4.1.8 Thermal Evaluation for DIDO Fuel

3.4.1.8.1 Analytical Models for the DIDO Fuel Contents

Heat transfer analysis of the NAC-LWT containing DIDO fuel is performed using a two-dimensional planar finite element analysis and the general purpose ANSYS computer code. Two transport conditions are evaluated:

Condition 1:

The NAC-LWT is supported in an ISO container with solar insolance on the surface of the ISO container, and the NAC-LWT is considered to be insulated from the environment (only for the normal conditions of transport steady state conditions). The gas inside the ISO container is air. The cavity of the NAC-LWT is backfilled with helium as required by operational procedures.

Condition 2:

The NAC-LWT is not located in an ISO container and solar insolation is applied to the NAC-LWT cask surface. For the purpose of performing the thermal analysis, the cavity of the NAC-LWT is considered to be filled with air.

A single fuel configuration is considered for this evaluation. Each DIDO fuel assembly is limited to having a heat load of 25 W per assembly. The total contents of the NAC-LWT for the DIDO fuel are limited to having six basket modules and each module is limited to having seven DIDO fuel assemblies. This limits the heat load of a basket module to 175 W, and a total NAC-LWT heat load of 1.05 kW. The 1.05 kW total heat load is enveloped by the 1.26 kW total heat load for the NAC-LWT MTR fuel contents contained in Section 3.4.1.3. Since the NAC-LWT cask ambient conditions are the same for the DIDO fuel as for the MTR fuel, the maximum temperature of all cask body components for the DIDO contents are enveloped by the maximum temperatures for the MTR fuel contents. Therefore, the cask inner shell temperature for the MTR fuel contents bounds the maximum cask inner shell temperature for the DIDO fuel contents. The maximum cask inner shell temperature is used as the boundary condition for the finite element model for the DIDO thermal evaluation. For Condition 1 and Condition 2, the maximum inner shell temperatures are 214°F and 181°F, respectively. These values correspond to the design basis heat load values obtained from Table 3.4-6.

Two finite element models are used in the evaluation of the DIDO fuel basket and the DIDO fuel assemblies.

The evaluation of the maximum basket component temperatures for these conditions is performed using a finite element model, which is shown in Figure 3.4-14. This model is used to evaluate both conditions. This model corresponds to the 4.01-inch inside diameter stainless steel

tubes, the 1/2-inch thick plates, the 3/4-inch × 3/8-inch aluminum bars (thermal shunts) and the 0.19-inch thick aluminum sheet (heat transfer shell) on the outside of the tubes. The SOLID70, eight-noded brick element is used to represent stainless steel components, the heat transfer shell and the cavity gas between the surfaces of the circular plates and the heat transfer shell and the inner shell of the cask body. To account for the axial conductance of the thermal shunts, they are modeled as conduction elements using an area corresponding to the dimensions of the aluminum bars. Radiation is conservatively neglected from the outer surface of the heat transfer shell and the inner surface of the cask inner shell. The center tube is assumed not to be in contact with any of the six outer tubes. During transport, the NAC-LWT is in a horizontal position in which the basket modules are in contact with the inner shell of the cask. To represent the contact of the basket module with the cask inner shell, the inner shell temperature was applied to two nodes of the circular plates and the remaining nodes corresponding to the inner surface of the inner shell of the cask body. The 25 W per assembly heat load is represented by applying the heat flux along a concentrated area at the inner tube surface, which would correspond to the contact of the fuel assembly with the 4.01-inch inside diameter stainless steel tube.

For Condition 1, the elements representing the cavity gas between the basket and the inner shell correspond to helium, whereas for Condition 2, these elements use properties for air.

To determine the maximum temperature for the fuel, a separate detailed model of a DIDO fuel assembly is constructed. This model is shown in Figure 3.4-15, which consists of four circular cylinders in contact at a corresponding single point to be transported in the horizontal position. Each cylinder is comprised of a layer of fuel of 0.64 mm (0.025 in.) thickness between two aluminum shells, each being 0.46 mm (0.018 in.) thick. The boundary condition of this model is the maximum basket temperature determined from the detailed basket model and the volumetric heat generation corresponding to 25 W per assembly.

3.4.1.8.2 DIDO Fuel Heat Transfer Analyses Results

The thermal analysis is performed to demonstrate that the temperature of the DIDO fuel is maintained within acceptable limits. A conservative temperature of 400°F is established as the maximum allowable DIDO fuel cladding temperature for normal conditions of transport. The aluminum retains it capability to function as a mechanical component in this temperature range and it is not close to the 1,220°F melting temperature of aluminum (Table 6.4.1, p. 6-60, Marks' Mechanical Handbook for Mechanical Engineers). The material properties presented in MIL-HDBK-5F indicate that 2000 series aluminum retains over 40% of its room temperature yield and ultimate strengths at a long-term temperature of 300°F.

Maximum temperatures for package components with the NAC-LWT configured for DIDO fuel are summarized in Table 3.4-12. The reported temperatures are lower at all locations than the

corresponding temperatures for the design basis PWR fuel presented in Table 3.4-2. The DIDO fuel assembly cladding temperatures are maintained below 400°F.

3.4.1.9 Thermal Evaluation for General Atomics IFM

The heat generated from the General Atomics IFM in the Fuel Handling Unit (FHU) is transferred to the basket by thermal conduction and radiation, and is then transferred to the cask inner shell from the basket surface by the same heat transfer modes. The heat is finally transferred through the cask and International Shipping Organization (ISO) container to ambient. The thermal resistance model and thermal analysis of General Atomics IFM consider a single FHU of the fuel. The maximum temperature from the resistor model corresponds to the FHU's stainless steel shell, while the minimum temperature corresponds to the inner surface of the transport cask inner shell. The fuel is actually stored in two FHUs, but the evaluation conservatively considers the total heat load of 13 W to be placed into a container at the center of the cask cavity. The evaluation does not consider the reduction in thermal resistance due to the contact of the FHU with the basket or of the basket with the inner shell of the transport cask. Additional conservatism is included by ignoring heat transfer by radiation across any of the gaps in the system. To ensure that a bounding temperature for the basket is calculated, air properties are used in the analysis for the gas in the cavity. Also, conservatism is included by using the inner shell temperature corresponding to the 1.26 kW condition for the cask body as opposed to 13 W. This analysis, therefore, bounds transport in the cask with and without an ISO container.

A thermal evaluation of the top module is performed by considering a heat load of 13 W in the center of the basket with only one 6.0-inch diameter top module tube. This is conservative because it maximizes the gap between the tube and the cask inner shell. Air is used as the cavity gas as an additional conservatism. The maximum temperature is computed using the resistor analogy.

For concentric cylinders, the thermal resistance (R) for the heat flow through the cylinders is taken from Krieth as:

$$R = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi K\ L}$$

where:

r_2 = outer radius of cylinder (inch)

r_1 = inner radius of cylinder (inch)

K = thermal conductivity (BTU/hr/in/°F)

The effective resistance from the secondary enclosure can be expressed as to the cask inner shell:

$$R_T = R_1 + R_2 + R_3 + \frac{1}{\frac{1}{R_4} + \frac{1}{R_5}}$$

where:

R_1 = resistor of the outer canister

R_2 = resistor of the gap between outer canister and the basket shell

R_3 = resistor basket shell

R_4 = resistor of the air from the basket shell to inner shell surface (outside of the basket disks)

R_5 = resistor of stainless steel disks supporting the basket shell in series with the air gap between the basket disks and the inner shell

The maximum temperature of the secondary enclosure can be determined by the following equation:

$$T_i = R_t Q + T_{cask}$$

where:

Q = total heat load

T_{cask} = temperature of cask inner shell

The following parameters will be used for this evaluation:

Q = 13 Watts

L = 37.0 inches – length of shortest secondary fuel closure

r1 = 2.255 inches – minimum inner radius of secondary closure

r2 = 2.375 inches – minimum outer radius of secondary closure

r3 = 2.75 inches – inner radius of module fuel cell

r4 = 3.00 inches – outer radius of module fuel cell

r5 = 6.688 inches – inner radius of LWT

r6 = 6.6325 inches – outer radius of the basket disks

K_{ss} = 0.7143 Btu/hr/in/F at 70°F for stainless steel

$K_{air} = 0.00161$ Btu/hr/in/F at 300°F for air

From Table 3.4-6, the maximum temperature of the LWT inner shell for a 1.26 kW heat load is 214°F, with 100°F ambient temperature with solar insolance. This is used as a bounding temperature for the cask inner shell (T_{cask}) for this evaluation.

$$R_{eff} = \frac{1}{\frac{1}{R_4} + \frac{1}{R_5}} \qquad R_4 = \frac{\ln(6.688/3.0)}{2\pi(0.00161)(37.0-2)}$$

$$R_4 = 2.264$$

$$R_5 = \frac{\ln(6.8125/3.0)}{2\pi(0.7143)(2)} + \frac{\ln(6.688/6.6325)}{2\pi(0.00161)(2)}$$

(Stainless steel disk in series with the air between the basket disk and the inner shell)

$$R_5 = 0.503$$

$$R_{eff} = \frac{1}{\frac{1}{R_4} + \frac{1}{R_5}}$$

$$R_{eff} = 0.412$$

$$R_T = R_1 + R_2 + R_3 + R_{eff}$$

$$R_T = \frac{\ln(2.375/2.255)}{2\pi(0.7143)(37.0)} + \frac{\ln(2.75/2.375)}{2\pi(0.00161)(37.0)} + \frac{\ln(3.0/2.75)}{2\pi(0.7143)(37.0)} + 0.412$$

$$R_T = 0.0003 + 0.392 + 0.0005 + .412 = 0.805$$

The maximum temperature of the secondary enclosure (T_i) is:

$$T_i = 0.805(13 \times 3.415) + 214 = 250^\circ F$$

The maximum temperature of the basket is conservatively considered to be the same as the temperature of the secondary enclosure (250°F). Temperatures of individual components are summarized in Table 3.4-13.

The maximum content temperature for the GA IFM shipment is considered to be bounded by the TRIGA maximum fuel cladding temperature of 326°F contained in Table 3.4-8, which corresponds to a bounding heat load of 1.05 kW (as compared to the approximately 13 watts for the GA IFM).

A conservative temperature of 800°F is established as the maximum allowable temperature for the stainless steel basket and the contents, which is comprised of the steel-clad TRIGA fuel and the HTGR pellets. The steel cladding of the TRIGA fuel is actually an inconel alloy. Mil HDBK-5G (1 November 1994), Section 6.3.2, identifies that alloys of inconel are used for parts

requiring strength for temperatures exceeding 1,000°F, which significantly exceeds 800°F. The HTGR pellets were designed for operational exposure to reactor core temperatures exceeding 1,000°F, which also exceeds 800°F. Therefore, the maximum temperatures for the contents for the GA IFM are acceptable.

3.4.1.10 High Burnup PWR or BWR Fuel Rods in a Fuel Assembly Lattice

The NAC-LWT cask may transport up to 25 intact high burnup PWR or BWR fuel rods that are in a fuel assembly lattice. The decay heat for the PWR rods is 2.3 kW with a corresponding peaking factor of 1.1, and the decay heat for the BWR rods is 2.1 kW with a corresponding peaking factor of 1.22.

The thermal evaluation employs two-dimensional planar half-symmetry models of the fuel lattice with 25 fuel rods, fuel channel (for BWR fuel), PWR insert (for BWR fuel), fuel basket, and the gas inside the cask cavity. The model extends to the inner surface of the cask inner shell. The model for a 7 × 7 BWR fuel lattice with 25 fuel rods is shown in Figure 3.4-16. BWR arrays of 7 × 7, 8 × 8, 9 × 9, and 10 × 10 are analyzed. PWR arrays of 14 × 14, 15 × 15, 16 × 16, and 7 × 17 are analyzed. The BWR model includes a fuel channel and insert, which are absent from the PWR model.

To determine the worst-case fuel rod arrangement, the 25 fuel rods are analyzed in five different arrangements:

1. Centered (top and bottom) in the two-dimensional model (as shown in Figure 3.4-16).
2. Centered horizontally and concentrated at the bottom of the lattice cross-section.
3. Spread out horizontally and concentrated at the bottom of the lattice cross-section.
4. Centered horizontally and concentrated at the top of the lattice cross-section.
5. Spread out horizontally and concentrated at the top of the lattice cross-section.

For the even numbered fuel arrays (i.e., 8 × 8, 10 × 10, 14 × 14, and 16 × 16), only 24 fuel rods are modeled due to the use of the half-symmetry models. For these cases, a higher heat generation rate is applied at each fuel rod so that the total heat load of 2.3 kW for PWR and 2.1 kW for BWR is maintained. The empty fuel rod locations in the lattice are modeled as air. The maximum inner shell temperature (274°F) for the PWR design basis fuel with 2.5 kW heat load (Table 3.4-2) is applied to the boundary of the model.

For each fuel array and fuel rod location configuration, a steady-state thermal analysis is performed using the general purpose ANSYS computer code. The Condition 2 transport case, with the NAC-LWT not located in an ISO container is evaluated. As shown in Table 3.4-10, this results in higher maximum temperatures for the fuel cladding than transport Condition 1 where

the cask is assumed to be inside of the ISO container. Transport Conditions 1 and 2 are described in Section 3.4.1.3.

3.4.1.11 High Burnup PWR and BWR Fuel Rods in a Rod Holder with Damaged Fuel Rods

The NAC-LWT may transport up to 25 PWR or BWR high burnup fuel rods in a rod holder, with up to 14 of the fuel rods classified as damaged. The maximum decay heat for these configurations is 2.3 kW for PWR and 2.1 kW for BWR. The finite element model for the evaluation of the 25 intact fuel rods in a rod holder is described in Section 3.4.1.7. This section provides the thermal evaluation for the configuration containing damaged fuel rods. The analysis conservatively assumes 15 damaged fuel rods, with the remainder of the rod holder containing intact fuel. The model used for this analysis is based on the two-dimensional half-symmetry model described in Section 3.4.1.7 (Condition 2 configuration), as shown in Figure 3.4-12. Modifications were made to the fuel regions to simulate the damaged fuel rods.

The basket design for the high burnup fuel rod transport can accommodate three configurations: a 4 × 4 matrix of fuel tubes containing 16 rods, a 5 × 5 matrix of fuel tubes containing up to 25 rods, and an alternate 5 × 5 rod holder designed to contain an oversize nonfuel-bearing component (e.g., CE guide tube or BWR water rod) and up to 21 rods. Since the decay heat per rod is considered the same, the maximum heat load occurs with the 5 × 5 matrix and is the configuration evaluated. Thermal analysis is performed for three cases with different locations of the 15 damaged fuel rods. The fuel rod locations are shown in Figure 3.4-17, which shows the matrix region of the thermal model shown in Figure 3.4-12. The nine locations in the half-symmetry model correspond to 15 actual fuel rod locations. The three cases evaluated are:

Case 1: Damaged fuel rods in locations 4 through 12
Case 2: Damaged fuel rods in locations 7 through 15
Case 3: Damaged fuel rods in locations 1 through 9

The inner surface of the inner shell is the boundary of the model. From Table 3.4-2, the maximum inner shell temperature of 274°F for PWR design basis fuel with 2.5 kW heat load for normal transport conditions is applied to the boundary of the model. The maximum temperature of 274°F results from the condition of solar insolation and convection/radiation to surroundings.

To simulate the damaged fuel rods, a 50% compaction of the fuel material in the fuel tubes is considered. It is assumed that the interior region of the fuel rod tube consists of 50% fuel debris and 50% gas. One half of the heat generation rate for the intact fuel rod is conservatively applied to the entire interior region of the fuel rod tube. Since the volume of the interior of the fuel rod tube is four times that of the volume of an intact fuel rod, the applied heat load for the damaged

fuel is two times that of the heat load for an intact fuel rod. In addition, the heat generation rate is multiplied by a peaking factor of 1.22. The material properties in the entire interior of the fuel rod tubes for the damaged fuel are conservatively considered to be the thermal properties of the fuel (rather than 50% fuel and 50% gas), since this results in higher temperatures in the fuel rod tube walls and the surrounding components.

3.4.1.12 Thermal Evaluation for TPBARs

Heat transfer analysis of the NAC-LWT containing TPBARs is performed using a two-dimensional planar finite element analysis and the general purpose ANSYS computer code. The NAC-LWT is transported in an ISO container with solar insolance on the surface of the ISO container during normal conditions of transport. The gas inside the ISO container is air. The cavity of the NAC-LWT is backfilled with helium as required by operational procedures.

There are two TPBAR content conditions requested for certification: the first is for the transport of up to 300 production TPBARs (of which two can be prefailed) in an open consolidation canister; the second is for the transport of up to 55 segmented TPBARs in a welded closed waste container. The 55 segmented TPBARs and debris resulting from PIE are limited to a total heat load of 127 W, based on a minimum of 90 days of cooling (2.31 watts/rod). Therefore, the loaded TPBAR consolidation canister with 300 rods is considered the bounding content condition for this thermal evaluation with each TPBAR limited to a heat load of 2.31 W, which corresponds to a 90-day cooling period (see Appendix 1-C of Chapter 1). This limits the maximum heat load of the NAC-LWT with TPBAR contents to 0.693 kW. The 0.693 kW total heat load is enveloped by the 1.05 kW total heat load for the NAC-LWT TRIGA fuel contents as described in Section 3.4.1.6. Since the NAC-LWT cask ambient conditions are the same for the TPBAR contents as for the TRIGA fuel contents, the maximum temperature of all cask body components for the TPBAR contents are enveloped by the maximum temperatures for the TRIGA fuel contents. Therefore, the cask inner shell temperature of 222°F (Table 3.4-9) for the TRIGA fuel contents bounds the cask inner shell temperature for the TPBAR contents and is used as the bounding condition for the TPBAR thermal evaluation.

The evaluation of the maximum component temperatures for TPBARs is performed using a finite element model as shown in Figure 3.4-18. This model corresponds to the aluminum basket, the consolidation canister containing 300 TPBARs, and the helium inside the cask. The loaded TPBAR consolidation canister bounds the maximum decay heat of the TPBAR waste container containing 55 segmented TPBARs and, therefore, the thermal evaluation bounds all TPBAR content conditions.

Any axial conductance of the contents is conservatively neglected in this two dimensional planar model. The ANSYS PLANE55 and MATRIX50 elements are used. Radiation is considered

using radiation matrix elements while convection is conservatively ignored in the following regions.

- Between the outer surfaces of TPBARs.
- Between the inner surface of the consolidation canister and the adjacent TPBARs.
- Between the outer surface of the consolidation canister and the inner surface of the basket.
- Between the outer surface of the basket and the inner surface of the cask inner shell.

A constant temperature of 222°F (Table 3.4-9, Condition 1) was applied to the outer surface of the model, which corresponds to the inner surface of the cask inner shell. During transport, the NAC-LWT is in a horizontal position in which the TPBAR contents are in contact with the inner surface of the basket, while the basket plates are in contact with the inner shell of the cask.

The heat generated by the 300 TPBARs is applied via a heat generation rate to the stainless steel cladding of the TPBARs. A peaking factor of 1.15 is used in the heat generation rate calculation based on a heat load of 2.31 W for each TPBAR.

The thermal analysis demonstrates that the temperature of the TPBARs is maintained within a conservative limit of 300°F for normal conditions of transport. At 300°F, the aluminum retains its capability as a mechanical component.

Maximum component temperatures for the NAC-LWT containing TPBAR contents are summarized in Table 3.4-16. Maximum cask component temperatures for normal conditions are conservatively obtained from the analysis results corresponding to the TRIGA fuel contents, as shown in Table 3.4-9 (Condition 1).

3.4.1.13 PULSTAR Fuel Elements in 28 MTR Basket

Three loading patterns for PULSTAR fuel elements are postulated for the 28 MTR basket configuration.

- Intact fuel assemblies will be directly loaded into 28 MTR basket;
- Intact fuel elements (rods) will be loaded in the fuel rod insert or the PULSTAR cans;
- Damaged fuel elements (rods) or debris will be loaded in the PULSTAR cans.

The heat load in each basket cell is limited to 30 watts. This corresponds to a maximum heat load of 210 watts for each of the four basket modules. The cask cavity is back-filled with helium.

The thermal analysis for the PULSTAR fuel contents in the 28 MTR basket is bounded by the thermal analysis for the TRIGA fuel cluster rods as presented in Section 3.4.1.6. The MTR basket (Section 3.4.1.3) has the same cross-sectional dimensions and basket material as the basket for TRIGA fuel cluster rods. The maximum modular heat load for TRIGA fuel cluster

rods is identical to the maximum modular heat load of the PULSTAR fuel contents (210 watts). The bounding condition for the thermal evaluation for the TRIGA fuel cluster rods is "Condition 2" as described in Section 3.4.1.6.2. In the two-dimensional planar model for the TRIGA fuel cluster, the cask cavity is modeled as air. The model conservatively includes an air gap between the fuel cladding and the aluminum tube and between fuel tube assembly and the inner surface of the basket cell, as shown in Figure 3.4-8 and Figure 3.4-9. This is conservative since there is contact between these components, which provides a significant heat transfer path from the fuel to the basket. Note that the aluminum tubes have an insignificant effect on heat transfer, since the air gap controls the heat conduction in the in-plane direction and the model is a two-dimensional planar model, which neglects any heat transfer in axial direction. Since the PULSTAR fuel rod insert is identical to the TRIGA rod insert, the thermal analysis results for TRIGA fuel cluster rods, Condition 2, as presented in Table 3.4-9, are used as the temperature results for the PULSTAR fuel. These temperatures are summarized in Table 3.4-17 for the PULSTAR fuel. The cask body component maximum temperatures with the NAC-LWT configured for the PULSTAR fuel conservatively use the temperatures from Condition 1 and Condition 2 in Table 3.4-17. The maximum temperatures for the cask body and basket are 222°F and 278°F, respectively, which are significantly below the allowable for stainless steel. For the configuration with intact rods or failed rods loaded in a PULSTAR can, the maximum fuel cladding temperature from Table 3.4-17 is conservatively used as the maximum temperature of the fuel can. The maximum fuel cladding temperature is 295°F, which is significantly below the allowable temperature limit of 1,058°F during transport.

3.4.1.14 Thermal Evaluation for ANSTO Fuel

Two types of ANSTO fuel may be loaded in the ANSTO basket in the NAC-LWT cask:

- MOATA plate fuel elements
- Mark III spiral fuel elements

The ANSTO basket consists of six modules with seven fuel tubes in each module. Each fuel tube may be loaded with a MOATA plate bundle or a Mark III spiral fuel assembly. The maximum heat load for a MOATA plate bundle is 0.4 watt (3 watts per assembly is conservatively considered in the thermal evaluation in this section). The maximum heat load is 18 watts per assembly for the Mark III spiral fuel. The corresponding maximum heat load per cask is 0.126 kW for the MOATA plate bundles and 0.756 kW for the Mark III spiral fuel.

The NAC-LWT is supported in an ISO container with solar insolance applied on the surface of the ISO container. The gas inside the ISO container is air. The cavity of the NAC-LWT is actually backfilled with helium as required by operational procedures.

The thermal evaluation for the MOATA plate fuel elements and Mark III spiral fuel is performed using finite element analysis with the ANSYS program. The finite element models for the MOATA plate bundles and Mark III spiral fuel are shown in Figure 3.4-19 and Figure 3.4-20, respectively. Each model corresponds to a quarter-symmetry cross-section of the fuel, the basket and the helium inside the cask cavity. The models are constructed using ANSYS PLANE55 two-dimensional planar elements. The maximum cask inner shell temperature of 222°F for the LWT cask loaded with the TRIGA fuel cluster rods (see Table 3.4-9) is conservatively used as the boundary condition for both models. The heat load used in the evaluation of the TRIGA fuel cluster rods is 1.05 kW per cask (see Section 3.4.1.6), which is significantly higher than the heat load for the MOATA fuel and Mark III spiral fuel. The MOATA plate fuel elements are explicitly modeled with aluminum cladding on both sides of the fuel meat. A volumetric heat generation rate corresponding to 3 watts per assembly is applied to the elements for fuel meat for the MOATA plate fuel.

The MARK III spiral fuel assemblies are modeled as straight plates with effective orthotropic properties. The longitudinal (radial) properties are decreased to reflect the reduction of the length (from the actual curved plates to the straight plates in the model). The material properties for the fuel meat are conservatively used in the transverse (circumferential) direction of the fuel elements in the model (conductivity of the aluminum clad is higher than that for the fuel meat). A volumetric heat generation rate corresponding to 18 watts per assembly is applied to the fuel elements for the Mark III spiral fuel.

The thermal conductivities of the fuel matrix for MTR fuel from Section 3.4.1.3 are used as the conductivities for the fuel meat for the MOATA plate and MARK III spiral fuel elements in the thermal models. These thermal conductivities are conservative since the fuel meat for the MOATA plate fuel and Mark III spiral fuel is composed of uranium and aluminum alloy, which are significantly more conductive than the fuel matrix material for the MTR fuel. Radiation between the basket tube and the cask inner shell is conservatively not considered in the models. For the MOATA fuel, radiation is only considered between fuel plates. For the Mark III spiral fuel, radiation is modeled across the helium gap between the fuel outer tube and the basket tube.

Steady-state thermal analysis is performed to demonstrate that the temperature of the MOATA plate fuel and Mark III spiral fuel is maintained within acceptable limits. A conservative temperature of 400°F is established as the maximum allowable temperature for these aluminum-clad fuel elements, as discussed in Section 3.4.1.3.3 for the MTR fuel.

3.4.1.15 High Burnup PWR MOX Rods in a PWR/BWR Rod Transport Canister

A maximum of 16 PWR MOX fuel rods (or a combination of PWR MOX and standard PWR fuel rods) may be placed in the PWR/BWR Rod Transport Canister, including a 5 × 5 insert.

Along with the maximum 16 PWR MOX rod contents, the remaining tubes may be loaded with burnable poison rods or other zirconium alloy-based hardware components with negligible activation and heat load. The maximum decay heat for the PWR MOX rods is 2.3 kW (or 143 W/rod), with a corresponding peaking factor of 1.1.

The thermal evaluation described in Section 3.4.1.7 for the high burnup PWR and BWR rods is a two-dimensional planar model in which the heat load applied to the model is based on the BWR rod decay heat load factored by the peaking factor. The bounding product of the heat load and the peaking factor for the PWR MOX rods is (2.3)(1.1) or 2.53 kW, as compared to (2.1)(1.22) or 2.56 kW for the BWR high burnup rods. The evaluation performed in Section 3.4.1.7 using the BWR high burnup rods is considered to bound the heat load for the 16 PWR MOX rods.

As described in Section 3.4.1.7, the model for the 25-rod configuration (in a 5 × 5 insert) uses a heat load of (25/16) times the product of the BWR rod decay heat and associated peaking factor. With this bounding heat load, it is, therefore, not necessary to evaluate the 16-rod configuration in the Rod Transport Canister with a 5 × 5 insert.

The thermal conductivities of the UO_2 and MOX from MATPRO-Version 11 at 600°F are 0.26 Btu/hr-in-°F and 0.22 Btu/hr-in-°F, respectively. The thermal resistance to the heat rejection of the rod canister is due to the thin tube walls and the gaps modeled between the tubes and rods and the basket insert. The reduction in the conductivity of the rod material has an insignificant effect on the thermal resistance incorporated in the gaps and thin tube walls in the model. The thermal resistance internal to each rod does not affect the rejection of the heat from other rods in the basket. Since the maximum number of PWR MOX rods is limited to 16, there are nine or more other vacant positions in the basket without the heat generation of the PWR MOX rods. The evaluation of any arbitrary configuration of tubes, with and without the PWR MOX rods, is bounded by an evaluation of the model having all tubes containing the design basis heat load of 143 W for each PWR MOX rod.

The evaluation using BWR rods in Section 3.4.1.7 is considered to bound all configurations of PWR MOX rods.

Maximum temperatures for package components with the NAC-LWT cask configured for high burnup PWR and BWR fuel rods are summarized in Table 3.4-10. As the analyzed BWR fuel rod content condition is bounding, the temperatures presented in Table 3.4-10, Condition 1 (helium cavity gas backfill) provide bounding temperatures for the PWR MOX fuel rod content configuration. As shown in Table 3.4-10, maximum calculated component temperatures for all critical safety components including the fuel rod cladding, the lid metallic containment seal, the Alternate B port cover metallic containment seals, the lead gamma shield and the liquid neutron shield are maintained within their allowable temperature limits as further defined in Section 3.3. Note that for the transport of PWR MOX fuel rods, metallic containment seals will be installed

on the lid and Alternate B port cover in accordance with the NAC-LWT cask leaktight transport configuration specified for the PWR MOX fuel rod contents.

3.4.1.16 Thermal Evaluation for ANSTO-DIDO Combination Basket

The combination basket can be comprised of the following:

(1) ANSTO-DIDO basket configuration—i.e., five DIDO modules and an ANSTO basket for the top module containing up to seven damaged fuel cans (DFC) (for degraded fuel); or

(2) ANSTO basket with a possible use of a DFC—i.e., five standard ANSTO modules and an ANSTO basket top module containing up to seven DFCs (for degraded fuel).

Individual thermal evaluations for the DIDO fuel and ANSTO fuel are contained in Section 3.4.1.8 and Section 3.4.1.14, respectively. The two-dimensional analyses for the ANSTO fuels conservatively identified the maximum temperatures, since axial conduction is being neglected. With this basket configuration, degraded DIDO and degraded ANSTO fuels are also considered and are to be placed in a DFC prior to being placed in the cask. The temperature of any disassembled fuel is bounded by the assembled fuel elements, since the disassembled condition (in the horizontal position) will have significantly more contact to enhance heat rejection from the fuel elements to the basket.

For the ANSTO top module located on either an ANSTO-DIDO combination basket assembly or on an ANSTO basket, the fuel element heat loads are limited to: 10W for DIDO (Mark IV) with or without a DFC; 10W for spiral (Mark III) with a DFC and 15.7W without a DFC; and 1W for MOATA (Mark II) with a DFC and 3W without a DFC. In the lower five DIDO basket modules of the ANSTO-DIDO combination basket, the DIDO fuel elements are limited to a maximum heat load of 18W. In the lower five ANSTO basket modules of the ANSTO basket, the spiral (Mark III) fuel elements are limited to a maximum heat load of 15.7W and the MOATA (Mark II) plate elements are limited to a maximum heat load of 3W.

The following configurations of spiral, MOATA and DIDO fuels are considered.

1. Degraded DIDO fuel (complete element) in a DFC.

   In the ANSTO-DIDO basket configuration, the top ANSTO module may contain at least one degraded DIDO fuel element (10W) in a DFC. The remaining six tubes in the top module may contain Mark III spiral assemblies (15.7W) (or MOATA plate fuel elements, 3W). In the other five DIDO basket modules, only DIDO fuel (up to a maximum of 18W per element) may be contained.

   In the ANSTO basket configuration with a DFC, the top ANSTO module may contain at least one degraded DIDO fuel element (10W) in a DFC. The remaining six tubes in the

top module may contain Mark III spiral assemblies (up to a maximum of 10W per element) or MOATA plate fuel elements (up to a maximum of 3W per element). The other five standard ANSTO basket modules may contain Mark III or MOATA plate fuel elements.

The per element heat load for the ANSTO basket with Mark III spiral fuel in Section 3.4.1.14 was evaluated at 18W, which bounds the DIDO (10W) in the DFC by 80 percent. Therefore, the analysis results of the ANSTO basket with Mark III spiral fuel presented in Section 3.4.1.14 bound the analysis results of the DIDO in the DFC in the ANSTO top module of the ANSTO-DIDO combination basket or the ANSTO basket. Figure 3.4-15 shows that the DIDO fuel elements are modeled in contact with adjacent cylinders since the transport cask configuration is in the horizontal position. The addition of the DFC, which is constructed of aluminum, has a minimal affect on the addition of thermal resistance. Therefore, the temperature of the DIDO elements (in the ANSTO top module) is bounded (due to the 150% increase in the heat load in the design basis) by the evaluation of the DIDO basket and fuel in Section 3.4.1.8.1. The degraded condition of the fuel does not alter the contact of the individual DIDO cylinders and the ability of the fuel to reject heat. No further evaluation is required.

When any Mark III fuel is loaded at the top module of the ANSTO-DIDO combination basket, the heat load of 15.7W for Mark III fuel is lower than the heat load (18 W) analyzed in the thermal analysis in Section 3.4.1.14.

The DIDO fuel elements loaded in the bottom five DIDO modules have a maximum per element heat load of 18 W, which is bounded by the 25W heat load employed in the evaluation of the DIDO in Section 3.4.1.8.1.

The ANSTO-DIDO basket configuration heat load bounds the heat load of the six ANSTO basket modules, since the heat load of the five other ANSTO basket modules is limited to 15.7 W per fuel element (as compared to a 18W DIDO fuel element in the five other DIDO basket modules of the ANSTO-DIDO basket combination).

The maximum temperature for the degraded DIDO fuel (10W) in the DFC at the top module of the ANSTO-DIDO combination basket is bounded by the maximum temperature of the Mark III fuel for the standard loading condition as shown in Table 3.4-22. The maximum temperature for the Mark III fuels (15.7W in ANSTO top module or 15.7W in the bottom five standard ANSTO basket assembly) is also bounded by the maximum temperatures of the Mark III fuel for the standard loading condition, shown in Table 3.4-22. The maximum temperature for the MOATA fuels (3W in ANSTO top module or in the bottom five standard ANSTO basket modules) is also bounded by the maximum temperatures of the MOATA fuel shown in Table 3.4-22. The maximum temperature for the DIDO fuel (18W) in the bottom five modules of the ANSTO-DIDO

combination basket is bounded by the maximum temperature of the DIDO fuel with the heat load of 25W, shown in Table 3.4-12 (Condition 1). The maximum basket temperature for the standard ANSTO basket is bounded by the maximum basket temperature of the Mark III fuel for the standard loading condition, shown in Table 3.4-22. The maximum basket temperature for the ANSTO-DIDO basket combination is bounded by the maximum basket temperatures of the DIDO fuel with the heat load of 25W, shown in Table 3.4-12 (Condition 1). The maximum temperatures for the cask components (inner shell, lead, outer shell and the liquid neutron shield) are bounded by the maximum temperatures of the ANSTO fuel configuration as shown in Table 3.4-22.

2. DIDO fuel element loaded in an ANSTO top module (ANSTO-DIDO basket combination or standard ANSTO basket assembly).

   In the ANSTO-DIDO basket configuration, the top ANSTO module may contain at least one DIDO fuel element (10W). The remaining six tubes in the top module may contain Mark III spiral assemblies (15.7W) or MOATA plate fuel elements (3W). In the other five DIDO basket modules, only DIDO fuel (18W) may be contained.

   In the ANSTO basket configuration, the top ANSTO module may contain at least one DIDO fuel element (10W). The remaining six tubes in the top module may contain Mark III spiral assemblies (15.7W) or MOATA plate fuel elements (3W). The other five standard ANSTO basket modules may contain Mark III or MOATA plate fuel elements.

   The maximum possible heat load in this condition (Item 2, DIDO fuel of 10W) for the top ANSTO basket module cannot exceed the maximum possible heat load for the Item 1 configuration (with a degraded DIDO heat load of 10W). The only difference between the fuel in Item 1 and in Item 2 is the state of the DIDO fuel. Since the discussion in Item 1 confirmed that the existing analyses bound the condition defined in Item 1, the existing analyses referenced in Item 1 also bound the maximum temperatures for the condition of the fuel in Item 2.

3. Degraded Mark III spiral ANSTO fuel elements (disassembled)) (10W) in a DFC.

   In the ANSTO-DIDO basket configuration, the top ANSTO module may contain at least one degraded Mark III spiral fuel element (10W) in a DFC. The remaining six tubes in the top module may contain Mark III spiral assemblies (15.7W) or MOATA plate fuel elements (3W). In the other five DIDO basket modules, only DIDO fuel (18W) may be contained.

   In the ANSTO basket configuration with a DFC, the top ANSTO module may contain at least one degraded Mark III spiral fuel element (10W) in a DFC. The remaining six tubes in the top module may contain Mark III spiral assemblies (15.7W), MOATA plate fuel

elements (3W) or DIDO Mark IV fuel elements (10W). The other five standard ANSTO basket modules may contain Mark III spiral or MOATA plate fuel elements.

The maximum possible heat load in this condition (Item 3, degraded Mark III spiral fuel of 10W) for the top ANSTO basket module cannot exceed the maximum possible heat load for the Item 1 configuration (with a degraded DIDO heat load of 10W). The only difference between the fuel in Item 1 and in Item 3 is the configuration of the fuel in the top module. The disassembled fuel will increase the contact between the segments of the fuel and the DFC and, therefore, decrease the maximum temperature of the fuel. Since the discussion in Item 1 confirmed that the existing analyses bound the condition defined in Item 1, the existing analyses referenced in Item1 also bound the maximum temperatures for the condition of the fuel in Item 3.

4. Degraded MOATA plate element (disassembled) (1W) in a DFC.

   In the ANSTO-DIDO basket configuration, the top ANSTO module may contain at least one degraded MOATA plate fuel element (1W) in a DFC. The remaining six tubes in the top module may contain Mark III spiral assemblies (15.7W), DIDO Mark IV fuel elements (10W), or MOATA plate fuel elements (3W). In the other five DIDO basket modules, only DIDO fuel (18W) may be contained.

   In the ANSTO basket configuration with a DFC, the top ANSTO module may contain at least one degraded MOATA plate fuel element (1W) in a DFC. The remaining six tubes in the top module may contain Mark III spiral assemblies (15.7W), DIDO Mark IV fuel elements (10W), or MOATA plate fuel elements (3W). The other five standard ANSTO basket modules may contain Mark III or MOATA plate fuel elements.

   The maximum possible heat load in this condition (Item 4, degraded MOATA fuel of 1W) for the top ANSTO basket module cannot exceed the maximum possible heat load for Item 1 configuration (with a degraded DIDO heat load of 10W). The only difference between the fuel in Item 1 and in Item 4 is the configuration of the fuel in the top module tube. The disassembled fuel will increase the contact between the segments of the fuel and the DFC and, therefore, decrease the maximum temperature of the fuel. Since the discussion in Item 1 confirmed that the existing analyses bound the condition defined in Item 1, the existing analyses referenced in Item1 also bound the maximum temperatures for the condition of the fuel in Item 4.

3.4.1.17 Thermal Evaluation for TPBARs in the PWR/BWR Rod Transport Canister

The thermal evaluation of the NAC-LWT transport cask loaded with up to 25 TPBARs, the PWR/BWR Rod Transport Canister, the PWR insert and the TPBAR basket is conducted for the normal conditions of transport. The evaluation relies on the results of analyses for the shipment of 300 TPBARs in the TPBAR basket (see Section 3.4.1.12), and the shipment of high burnup PWR or BWR rods in a rod holder (see Section 3.4.1.7), in which bounding total heat loads and temperatures were considered. For this analysis, each TPBAR rod is limited to a heat load of 2.31 W, which corresponds to a 90-day cooling period.

The PWR/BWR Rod Transport Canisters can accommodate three configurations: a 4×4 matrix of pin tubes containing up to 16 rods, a 5×5 matrix of pin tubes containing up to 25 rods, and an alternate 5×5 rod holder designed to contain an oversize nonfuel-bearing component (e.g., CE guide tube or BWR water rod) and up to 21 rods. Since the maximum decay heat per TPBAR is 2.31 W, the maximum heat load of the NAC-LWT cask with TPBAR fuel rods and the PWR/BWR Rod Transport Canisters is 25 × 2.31 W or 58 W. A conservative maximum total heat load of 100 W is used for this evaluation.

The maximum contents temperature for the TPBARs in the PWR/BWR Rod Transport Canister is determined by first computing the temperature difference from the center of the basket, which is the location of the maximum contents temperature, to the inner surface of the cask's inner shell. This temperature difference is added to the inner shell temperature to determine the maximum contents temperature.

The computation of the center to inner shell temperature difference is divided into two separate calculations: first, the temperature difference from the basket center to the inner surface of the basket (ΔT_a); second, the temperature difference across the TPBAR basket (ΔT_b). The first segment of the temperature difference includes the PWR/BWR canister and PWR insert, which was analyzed for the evaluation of high burnup PWR or BWR rods in a Rod Transport Canister. The second segment of the temperature difference across the TPBAR basket was analyzed for the evaluation of TPBAR fuel in a TPBAR basket. Both the TPBAR and PWR analyses use a greater total heat load than what is associated with the 25 TPBARs in the PWR/BWR Rod Transport Canister configuration. The calculated temperature difference from each segment is

scaled by the ratio of the total heat load for the 25 TPBARs in the PWR/BWR Rod Transport Canister configuration to that of the corresponding analysis, or

$$\Delta T_a = \Delta T_{PWR} \frac{Q_{TPBAR/PWR} P_{TPBAR}}{Q_{PWR/BWR} P_{PWR/BWR}}$$

$$\Delta T_b = \Delta T_{TPBAR} \frac{Q_{TPBAR/PWR} P_{TPBAR}}{Q_{TPBAR} P_{TPBAR}} = \Delta T_{TPBAR} \frac{Q_{TPBAR/PWR}}{Q_{TPBAR}}$$

where:

$Q_{TPBAR/PWR}$ = the heat load for the shipment of 25 TPBARs in a PWR/BWR Rod Transport Canister.

Q_{TPBAR} = the heat load of the TPBAR analysis for the shipment of 300 TPBARs in the TPBAR basket (Section 3.4.1.12).

$Q_{PWR/BWR}$ = the heat load of the PWR/BWR analysis for the shipment of high burnup PWR (2.3 kW) or BWR (2.1 kW) rods in a PWR/BWR Rod Transport Canister (Section 3.4.1.7).

P_{TPBAR} = the TPBAR peaking factor = 1.15 (Section 3.4.1.12).

$P_{PWR/BWR}$ = the peaking factor used in the analysis of the high burnup PWR (1.1) or BWR (1.22) rods in a PWR/BWR Rod Transport Canister (Section 3.4.1.7).

The scaled temperature difference provides an appropriate value for the 25 TPBARs in the PWR/BWR Rod Transport Canister configuration. This scaling method is conservative since 100 W bounds the actual heat load of 58 W.

The analysis for the 300 TPBARs in the TPBAR basket, for normal conditions of transport, used a maximum inner shell temperature of 222°F and a design heat load of 690 W with a peaking factor of 1.15, which resulted in a maximum TPBAR basket temperature of 228°F and a maximum contents temperature of 290°F (Section 3.4.1.12). The analysis for the high burnup PWR/BWR fuel in a rod holder for normal conditions of transport used a maximum inner shell temperature of 385°F and a head load of 2.1 kW with a peaking factor of 1.22, which resulted in a maximum PWR basket temperature of 387°F and a maximum fuel temperature of 671°F (Section 3.4.1.7).

The segmented temperature differences and total temperature difference are calculated as follows.

Table 3.4-6 MTR Fuel Maximum Component Temperatures – Normal Transport Condition

Conditions: 100°F Ambient Temperature
Solar Insolation
1.26 Kilowatts Decay Heat Load

Condition 1: NAC-LWT (Transported in an ISO Container)
Cavity gas: Helium

Component	Temperature (°F)	
	Design Basis Decay Heat Load [1]	Variable Decay Heat Load [2]
Liquid Neutron Shield	198	198
Outer Shell	199	199
Lead Gamma Shield	212	214
Inner Shell	214	215
Basket (maximum)	256	292
Fuel (maximum)	< 363 [3]	< 363 [3]

Condition 2: NAC-LWT (Transported via Truck Trailer)
Cavity gas: Air

Component	Temperature (°F)	
	Design Basis Decay Heat Load [1]	Variable Decay Heat Load [2]
Liquid Neutron Shield	160	160
Outer Shell	161	160
Lead Gamma Shield	180	180
Inner Shell	181	180
Basket (maximum)	267	312
Fuel (maximum)	< 363 [3]	363

[1] Uniform 30-Watt/Element Configuration Heat Load.

[2] 120-Watt / 70-Watt / 20-Watt Configuration Heat Load. As discussed in Section 3.4.1.3 the loading configuration using the 120-Watt/70-Watt/20-Watt heat load bounds the perferential configuration of 40-Watt maximum heat load per basket slot with the same total heat load of 210-Watt per basket or 1.26 kW for the entire MTR contents.

[3] Fuel not modeled for this condition. Fuel temperature is bounded by the variable decay heat load in air case.

Table 3.4-7 PWR Rods (25 Total) Maximum Component Temperatures – Normal Transport Condition

Conditions: 100°F Ambient Temperature
Cask Inside ISO Container
Solar Insolation
1.41 Kilowatts Decay Heat Load

Component	Temperature (°F)
O-rings	< 249
Valves	< 249
Cask Radial Outer Surface	185
Lead Gamma Shield	248
Inner Shell	249
Outer Shell	235
Basket	252
Liquid Neutron Shield	235
Maximum Cladding Temperature	358

Shown in Figure 3.5-8. The temperature profile within the cask model at the time of the maximum fuel temperature is shown in Figure 3.5-9. The bounding case for the uniform and preferential loading (as discussed in Section 3.4.1.3) is an element with 10 fuel plates, a decay heat of 120W and with worst-case dimensions. The maximum temperatures of the components are presented in Table 3.5-2. These results demonstrate that the maximum MTR fuel plate temperature for the variable decay heat loading is 473°F. The MIL-HDBK-5F Specification for 6061-T6 aluminum alloy indicates that the material retains more than 35% of its room temperature yield and ultimate strengths during transient exposure to temperatures as high as 500°F. Therefore, the reduction in strength for the fuel cladding as a result of the fire transient is minor when compared to the values presented in Section 3.4.1.3.3 for aluminum at 400°F. Since the fuel cladding temperatures are maintained significantly below 500°F, it is concluded that the structural integrity of the fuel cladding is maintained. Furthermore, the aluminum cladding of the MTR fuel elements is heated to a temperature of approximately 900°F during the fabrication process and it is clear that the cladding integrity is maintained during that process.

3.5.3.3 Evaluation of TRIGA Fuel Contents

The accident condition temperatures are obtained by applying the temperature differential calculated for the MTR fuel configuration to the TRIGA fuel configuration. To determine the TRIGA accident condition maximum cladding temperature, the temperature difference between the maximum basket temperatures for the normal and accident component temperatures calculated for MTR fuel in Section 3.5.3.2, is added to the maximum cladding temperature calculated for TRIGA fuel in Section 3.4.1.5.

The maximum basket temperature for the MTR fuel design basis heat load fire accident analysis is 374°F, as reported in Table 3.5-2. This temperature is 107°F higher than the normal condition maximum temperature (267°F) reported in Table 3.4-6. The corresponding maximum TRIGA fuel cladding temperature for the fire accident condition is reported in Table 3.5-3 to be 433°F. The MIL-HDBK-5F Specification for 6061-T6 aluminum alloy indicates that the material retains more than 35% of its room temperature yield and ultimate strengths during transient exposure to temperatures as high as 500°F. Therefore, the reduction in strength for the aluminum-clad TRIGA fuel cladding as a result of the fire transient is minor when compared to the values presented in Section 3.4.1.3.3 for aluminum at 400°F. Since the fuel cladding temperatures are maintained significantly below 500°F, it is concluded that the structural integrity of the aluminum-clad TRIGA fuel is maintained. The allowable temperature for stainless steel-clad TRIGA fuel is significantly higher.

The TRIGA fuel generates small amounts of fission gases during reactor operations, but it contains no initial charge of helium gas. Consequently, the internal pressure developed in the accident condition is less for TRIGA fuel than for the design basis PWR fuel.

3.5.3.4 Evaluation of TRIGA Fuel Cluster Rod Contents

The temperatures in the TRIGA fuel cluster rod basket and cladding produced during the fire accident were determined using the ANSYS finite element model of the NAC-LWT for the TRIGA fuel discussed in Section 3.4.1.6 for Condition 2 (air in the cavity and without the ISO container). The gas in the NAC-LWT cask cavity is considered to be air. Other conditions applied to the model are the same as those described in Sections 3.5.1 and 3.5.2 for the axisymmetric fire transient model with respect to the liquid neutron shield and outer boundary conditions.

The temperatures in the basket are bounded by the maximum temperatures of the fuel region. The temperature time history for the fuel region is shown in Figure 3.5-10. The maximum temperature of the clad was determined to be 394°F. This value is below the 800°F limit for the clad or the 400°F limit for the aluminum specified in Section 3.4.1.6. Therefore, the components are determined to be acceptable for the fire accident condition.

3.5.3.5 Evaluation for PWR and BWR High Burnup Fuel Rod Contents in a Rod Holder

The maximum temperatures of the principal components are evaluated using the ANSYS model described in Section 3.5.1.2. The maximum cask component temperatures for the hypothetical accident are identical to those presented in Table 3.5-1 since the bounding temperature history from the analysis of NAC-LWT PWR contents is used as a boundary condition for the analysis for PWR and BWR high burnup fuel rod contents.

Maximum time dependent temperatures of different components, before, during and after the fire, are shown in Figure 3.5-11. For the maximum time dependent temperatures of cask components see Figure 3.5-4 and Figure 3.5-5.

As a result, the maximum average cavity gas temperature for fire accident is calculated as the average of the air contained inside the basket. This produces an average cavity gas temperature of 695°F.

Table 3.5-4 shows the can weldment and fuel rod cladding temperatures during the fire accident event.

3.5.3.6 Evaluation of DIDO Fuel Contents

The DIDO fuel maximum heat load is bounded by the maximum heat load of the MTR fuel. Therefore, in the accident condition, the maximum temperatures of the cask components for the MTR contents will bound the maximum temperatures for the cask components for the DIDO contents. It is conservative to use the results of the fire transient evaluated in Section 3.5.3.2 for

Table 3.5-1 Maximum Component Temperatures (°F) During the Fire Accident (Design Basis PWR Fuel, 2.5 kW Heat Load)

Component	Component Temperature (°F)	Temperature Limit (°F)
O-rings: TFE	558	735
Metallic	571[(3)]	800
Cask radial outer surface	1460	----[(1)]
Neutron shield region	1435	----[(1)]
Radial lead gamma shield	578	600
Bottom lead gamma shield	564	600
Inner stainless steel shell	505	800
Fuel basket outer wall	507	700[(2)]
Fuel rod cladding	703	1058
Alternate Port Cover	--	--
Bolt head	886	900
Bolt threads	807	900
Alternate Port Cover O-ring – bore	565[(4)]	550
Alternate Port Cover O-ring – face	547	550
Alternate B Port Cover metallic face seal	547	800

Notes:

(1) No upper limit established. The loss of the liquid neutron shield is assumed under HAC.

(2) The primary consideration in establishing the safe operating range of the aluminum is maintaining the integrity of the aluminum. According to MIL-HDBK-5F, it can be shown that aluminum at 700°F retains component performance.

(3) The maximum port cover seal temperature is conservatively used to bound the maximum temperature of the metallic seal.

(4) Should the bore seal fail post-fire accident, containment would not be breached.

Table 3.5-2 MTR Fuel Fire Accident Maximum Temperatures (°F), 10 Fuel Plate/120W Element Case (Bounding Configuration)

Condition 2: NAC-LWT (Transported via Truck Trailer)
Cavity Gas: Air

Component	Design Basis Heat Loading*	Variable Decay Heat Loading**
Cask Radial Outer Surface	***	***
Lead Shield	***	***
Inner Shell	334	337
Fuel Basket	374	420
Fuel Cladding	385	473

* Uniform 30-Watt/Element Configuration Heat Load.

** 120-Watt/70-Watt/20-Watt Configuration Heat Load. The 120-Watt/70-Watt/20-Watt Configuration bounds the configuration comprised of the 40-Watt maximum MTR heat load per slot, as discussed in Section 3.4.1.3.

*** The maximum temperatures for these components are bounded by the design basis reported.

Table 3.5-3 TRIGA Fuel Fire Accident Maximum Temperatures (°F)

Component	Temperature
Fuel Basket	374
Fuel Cladding	433

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Table 5.1.1-1 Type, Form, Quantity and Potential Sources of Design Basis Fuel

Fuel Type	-	PWR, Assembly
	-	3.7 wt % ^{235}U maximum initial enrichment
	-	35,000 MWd/MTU maximum burnup
	-	2.5 kW per assembly maximum decay heat
	-	2 years (or more) decay time after reactor discharge
Fuel Form	-	Intact assemblies
Quantity	-	1 design basis fuel assembly
Source of Fuel	-	Commercial PWR nuclear power reactors
Transport Index	-	35
Fuel Type	-	BWR, Assembly
	-	4.0 wt % ^{235}U maximum initial enrichment
	-	30,000 MWd/MTU maximum burnup
	-	1.1 kW per assembly maximum decay heat, 2.2 kW per cask for 2 assemblies
	-	2 years (or more) decay time after reactor discharge
Fuel Form	-	Intact assemblies
Quantity	-	2 design basis fuel assemblies
Source of Fuel	-	Commercial BWR nuclear power reactors
Transport Index	-	35
Fuel Type		High Burnup PWR or BWR rods
	-	5.0 wt % maximum ^{235}U initial enrichment
	-	80,000 MWd/MTU maximum average burnup
	-	2.3 kW /cask maximum decay heat
	-	Minimum cool time dependent on burnup (See Table 5.3.8-29)
Fuel Form	-	Intact rods in a fuel assembly lattice or rod holder and intact rods with up to 14 fuel rods classified as damaged in a rod holder
Quantity	-	Up to 25
Source of Fuel	-	Commercial PWR or BWR nuclear power reactor
Transport Index	-	36 (intact rods) 28 (intact rods in a fuel assembly lattice) 37 (intact rods with 14 rods classified as damaged)
Fuel Type	-	Uranium metal fuel rods
	-	Natural wt % ^{235}U
	-	1,600 MWd/MTU maximum burnup
	-	0.0357 kW per sound rod maximum decay heat, 0.54 kW per cask for 15 sound fuel rods
	-	1 year (or more) decay time after reactor discharge
Fuel Form	-	Intact or encapsulated failed fuel rods
Quantity	-	15 design basis fuel rods, or 6 design basis failed fuel rods
Source of Fuel	-	Research reactors
Transport Index	-	25

Table 5.1.1-1 Type, Form, Quantity and Potential Sources of Design Basis Fuel (cont'd)

Fuel Type	-	Material Test Reactor (MTR) Fuel Elements
	-	HEU: 90 wt % ^{235}U, Maximum burnup variable up to 660,000 MWd/MTU for 380 g ^{235}U and 577,500 MWd/MTU for 460 g ^{235}U
	-	MEU: 40 wt % ^{235}U, Maximum burnup variable up to 293,300 MWd/MTU for 380 g ^{235}U
	-	LEU: 19 wt % ^{235}U, Maximum burnup variable up to 139,300 MWd/MTU for 470 g ^{235}U, 490 g^{235}U and 640 g ^{235}U
	-	210 W per basket decay heat
	-	Variable cool time down to 90 days using the procedure in Section 7.1.5
Fuel Form	-	Intact aluminum clad parallel plates
Quantity	-	Up to 42 fuel elements
Source of Fuel	-	Research and Material Test Reactors
Transport Index	-	45
Fuel Type	-	TRIGA Fuel Element
	-	Nominal 20 to 93 wt % ^{235}U
	-	80% ^{235}U depletion (approximately 151 GWd/MTU for LEU fuel, and 460 GWd/MTU for 70 wt % ^{235}U HEU fuel, and 583 GWd/MTU for 93 wt % ^{235}U HEU fuel)
	-	7.5 watts per element decay heat
	-	Variable cool time down to 90 days
Fuel Form	-	Aluminum or stainless steel (304) clad rods, intact, failed or as debris
Quantity	-	Up to 140 fuel elements
Source of Fuel	-	Test, Research and Isotope Reactors
Transport Index	-	25
Fuel Type	-	HEU and LEU TRIGA Fuel Cluster Rods
	-	Minimum 92 wt % ^{235}U (HEU) and minimum 19 wt % ^{235}U (LEU)
	-	80% ^{235}U depletion (approximately 600 GWd/MTU for HEU and approximately 140 GWd/MTU for LEU)
	-	1.875 watts per rod decay heat
	-	Variable cool time down to 90 days
Fuel Form	-	Incoloy 800 clad damaged or undamaged rods
Quantity	-	Up to 560 fuel rods
Source of Fuel	-	Test, Research and Isotope Reactors
Transport Index	-	17.9
Fuel Type	-	DIDO Fuel Assemblies
	-	HEU: 90 wt % ^{235}U, Maximum burnup variable up to 577,460 MWd/MTU or 70% ^{235}U depletion
	-	MEU: 40 wt % ^{235}U, Maximum burnup variable up to 256,650 MWd/MTU or 70% ^{235}U depletion
	-	LEU: 19 wt % ^{235}U, Maximum burnup variable up to 121,910 MWd/MTU or 70% ^{235}U depletion
	-	175 or 126 W per basket decay heat
	-	Variable cool time down to 180 days using the procedure in Section 7.1.4

5.3.4 MTR Fuel Configuration

A maximum of 42 MTR fuel assemblies have been analyzed for transport in the LWT cask. This configuration consists of up to seven fuel assemblies placed radially in each of the six axial fuel basket modules. Two alternate configurations of MTR fuel assembly loading provide for loads of 35 assemblies in five basket modules or 28 assemblies in four basket modules.

LEU, MEU, and HEU fuel is evaluated for a base configuration that consists of a uniform loading of 30 W per fuel position, resulting in a basket module maximum of 210 W (or 1.26 kW per cask). To allow flexibility in loading either high burnup or short cooled HEU fuel, three possible fuel loading configurations are evaluated. The configurations are based on limiting the total heat load (and corresponding gamma/neutron source) in each basket module to a maximum of 210 W (1.26 kW per cask). Configuration 1 is the loading of three assemblies, having thermal outputs of 120, 70 and 20 watts, in close proximity, with the 120 W assembly occupying the center cell. Configuration 2 is the uniform loading of 7 MTR assemblies, each having a decay heat of 30 W. Configuration 3 has three assemblies in line across the center of the basket, as required by the loading procedure, with a maximum of 70 watts per assembly. These configurations are shown in Figure 5.3.4-1. To allow flexibility in loading shorter cooled LEU fuel, an optional configuration based on 40 W per fuel position is evaluated. Conservatively, 40 W elements are applied to all seven basket positions. This results in a modeled source of 280 W per basket. As described in Section 7.1.5, for cask operations, the basket module maximum of 210 W will be retained for this configuration, therefore, limiting the number of 40 W elements that may be loaded. Evaluations for the 40 W pattern are limited to the maximum 490 gram ^{235}U LEU element.

The shielding analysis evaluated all three MTR fuel types for variable burnup considering uniform basket loading for LEU and MEU fuel and the configurations above for HEU fuel. HEU fuel provides the limiting dose rates and, therefore, only the HEU results are discussed in detail. A comparison of dose rates at 2 meters from the transport vehicle is shown in Figure 5.3.4-3 for various LEU, MEU and HEU payloads. This figure demonstrates that HEU fuel bounds the LEU and MEU payloads. As discussed below, the HEU loading patterns produce significantly higher dose rates than those documented in Figure 5.3.4-3 for the uniform 30 W loading.

In order to present the limiting MTR dose rates, NAC performed a parametric study in which each of these configurations were examined using the SCALE 4.3 (ORNL,1995) SAS4 (Tang, 1995) computer code for shielding analysis and SAS2H (Herman, 1995) for source terms. The SAS4 sequence incorporates a FORTRAN coding modification that permits the determination of dose rate profiles along the axial and radial surfaces. This study established Configuration 1 as the bounding configuration, with respect to axial and radial dose rates. In the case of the radial

evaluation, Configuration 1 is clearly limiting based on the concentrated source term. The axial evaluation concluded that Configurations 1 and 3 are statistically similar and bound Configuration 2. Configuration 1 is selected as the limiting MTR preferential loading configuration and is the load bases for the shielding analysis.

The MTR fuel assembly consists of plates held in a parallel arrangement by thick aluminum slotted side plates. The number of fuel plates range from 17 to 23 per assembly, and the analysis assumed the maximum 23 plate value for each of the three MTR fuel types.

The design basis MTR fuel assemblies were constructed using typical MTR parameters. The physical characteristics of the analyzed LEU, MEU and HEU fuel assemblies are shown in Table 5.3.4-1. The fueled section of the assembly consists of 23 plates of 0.050-inch thickness and two side plates 0.187-inch thick, which do not contain fuel. The fuel core of each fuel plate is a cermet of aluminum and U-Al, which is 0.020-inch thick. The 6061 aluminum cladding has a minimum thickness of 0.015-inch. The HEU fresh fuel load analyzed consists of either 380 grams or 460 grams of ^{235}U per assembly 90% enriched. The initial enrichment is used to encompass other HEU MTR fuel types.

The SAS2H sequence was used to determine the gamma and neutron source terms and decay heat loads for the evaluated MTR fuel assembly loading configurations. The SAS2H sequence includes the ORIGEN-S code and a 1D XSDRNPM model of the fuel assembly. ORIGEN-S performs fuel assembly depletion at specified operating conditions and calculates heat generation, gamma and neutron spectra for a given discharge isotopic composition as a function of out of reactor time (cooling time). The 1D model of the fuel assembly is used to collapse the 27 group neutron cross-section library (27GROUPNDF4) into three broad energy groups for the depletion calculation. The 1D model is based on an equivalent area representation of the fuel/moderator cell and surrounding structural regions. Average power is based on reactor maximum power divided by the number of assemblies in the core.

For the HEU fuel, separate analyses were performed for ^{235}U loadings of 380 grams and 460 grams. For the 380 gram ^{235}U loading, the maximum allowable burnup was 660,000 MWd/MTU. For the 460 gram ^{235}U loading, dose rates exceeding 10 CFR 71 limits were calculated at 660,000 MWd/MTU, so the burnup was limited to 577,500 MWd/MTU. Calculated dose rates are higher for the 380 gram ^{235}U loading at 660,000 MWd/MTU.

For the bounding HEU fuel with 380 grams ^{235}U, a series of 10 cases was run in which burnup was varied from a minimum of 82,500 MWd/MTU to a maximum of 660,000 MWd/MTU. Cooling times were considered from 90 days to 6.0 years. Because the cask is loaded based on the decay heat limits, no single design basis fuel assembly or loading configuration exists. Design basis photon and neutron source terms for MTR assemblies with decay heats loads of 20, 30, 70 and 120 watts are determined for the 660,000 MWd/MTU burnup

case, which was bounding. The SAS2H results from these cases are used for the design basis photon and neutron source terms and are summarized in Table 5.3.4-2 and Table 5.3.4-3 for 380 grams ^{235}U and Table 5.3.4-4 and Table 5.3.4-5 for 460 grams ^{235}U. The material densities used in the analysis are summarized in Table 5.3.4-8. Minimum cool time curves for the various MTR fuel and loading configurations are shown in Section 7.1.5.

The 490-gram ^{235}U and 40 W per element configuration is evaluated identically to that applied to the lower and higher mass LEU element, MEU, and HEU elements. SAS2H cases are run between 1% and 80% with a minimum cool time of 90 days. At maximum depletion the element requires 424 days to decay to a heat load of 40 W per element. Dose rates are determined at the maximum depletion (equivalent burnup of 140,000 MWd/MTU) and a reduced cool time of 402 days for that statepoint (heat load marginally greater than 40 W). Gamma and neutron source terms at this statepoint are shown in Table 5.3.4-16 and Table 5.3.4-17. Radial cask and 2-meter from conveyance dose rates, which are the limiting locations for LWT transport of MTR fuel (as shown in Tables 5.4.3-9 through Table 5.4.3-15), are illustrated in Figures 5.3.4-4 and 5.3.4-5. Dose rates are below or statistically equivalent to those of the preferentially loaded HEU fuel shown in Tables 5.4.3-9 and 5.4.3-11. Note that this evaluation conservatively applies 40 W elements to all seven basket positions.

Minimum allowed cool time for MTR fuels is set to 90 days. Below 90 days the potential exists for high power core operations to produce significant amounts of short lived radionuclides (in particular ^{140}La with a 2-day half life and a 1.5 MeV gamma peak, parent nuclide is ^{140}Ba, a fission product with 13-day half life) with significant higher gamma penetration energies then those applied at the maximum depletion/burnup statepoint used in the evaluations discussed in the previous paragraphs. Restricting the minimum cool time to 90 days eliminates this concern. To verify acceptability, the following loading combinations were evaluated:

Fuel Type	^{235}U Mass (g)	Heat (W)
LEU	490	40
MEU	380	30
HEU	460	120

Each fuel type was evaluated at 90 days at maximum depletion to reach the desired heat load. Results of a comparison between minimum cool time and maximum depletion dose rates (fixed heat load) are shown in Figures 5.3-4-6 through 5.3.4-8. LEU and HEU data produces maximum dose rates at maximum depletion. MEU, while showing slightly higher dose at the low depletion point, is significantly bounded by the LEU and HEU cases and is, therefore, acceptable.

MTR elements may contain a small amount of cadmium (maximum 100 grams Cd) in the form of nonfuel hardware. Table 5.3.4-6 and Table 5.3.4-7 contain comparisons of the cadmium light element gamma source compared to the U-Al fuel material gamma source. The light element source is produced during the SAS2H depletion analysis and applies 100% of the element flux levels. Included for comparison are HEU (460 gram) and LEU (640 gram) fuel types at the maximum allowed burnup (i.e., maximum activation) and cool times required to meet 30 watts (uniform heat load limit per element). Also shown are conservative comparisons of the design basis 30-watt fuel source to a 90-day-cooled Cd source. As shown in the comparison tables, the cadmium source is not significant to NAC-LWT cask shielding evaluations. The hardware gamma source of the cadmium represents less than 0.1% of the fuel gamma source at the required minimum cool time and less than 2% at the conservative 90-day-cooled Cd source. As the majority of the Cd source is at energy lines less than 0.5 MeV and does not penetrate the NAC-LWT cask shields, the actual effect on dose rates is even smaller than that indicated by the difference in total source magnitude.

Based on the MTR source term calculation, the (alpha, n) reactions in ^{27}Al and ^{28}Si are included in the MTR neutron source term. The (alpha, n) reactions in ^{27}Al and ^{28}Si increase the neutron source term by a factor of ~2.9. Consequently, a factor of 2.9 is applied to the MTR neutron source terms.

The SAS4 (Tang) sequence is used to calculate the dose rates at all points of interest. In this sequence, a 1D adjoint XSDRNPM model generates biasing parameters for a 3D MORSE Monte Carlo model of the NAC-LWT cask with the MTR fuel. SAS4 requires model symmetry about the active fuel midplane (midplane of the six basket modules in this case). A 3D Monte Carlo model is developed for the upper half of the cask. This model bounds the results for a lower half model as the cask has more shielding in the axial direction at the bottom end. The upper half model is shown in Figure 5.3.4-2. The model assumes that the fuel is at the highest point in the basket module, that the fuel is loaded in the same way axially in all of the modules, and it ignores the presence of the impact limiters. Detectors are placed at three radial locations of interest. These locations are: 1) cask surface; 2) one meter from the cask surface; and 3) at two meters from the edge of the cask conveyance.

5.3.4.1 Shielding Evaluation for MTR Fuel

This section presents the shielding analyses for normal conditions of transport, illustrates compliance with 10 CFR Part 71. In normal transport, the dose rate limits are:

- The dose rate on the surface of the package is less than 200 mrem/hr, except that localized dose rates up to 1000 mrem/hr are allowed if it is shown that the dose rate on the surface of the ISO enclosure is less than 200 mrem/hr.
- At 2 meters from the edge of the transport vehicle the dose rate is limited to 10 mrem/hr.

- The truck cab (defined as a point 5 meters from the NAC-LWT lid) dose rate is limited to 2 mrem/hr.

The dose rates for the bounding loading configuration (Configuration 1) are shown in Table 5.3.4-9, Table 5.3.4-10 and Table 5.3.4-11 for the cask surface, plane of conveyance, and at 2 meters from the edge of the conveyance, respectively. These dose rates are well below the regulatory limits. The dose rates at 1 meter from the cask surface are presented in Table 5.3.4-12, where the maximum dose rate defines the Transport Index (TI) for the cask.

The axial surface and the 5 meter (back of tractor cab) dose rates are shown in Table 5.3.4-13 and Table 5.3.4-14. Shielding provided by the impact limiter is conservatively neglected. The axial dose rates at the bottom of the cask are conservatively assumed to be equal to the dose rates reported at the top.

This evaluation shows that the NAC-LWT cask, with up to 42 MTR fuel assemblies, meets the shielding requirements of 10 CFR 71, 49 CFR 173, and IAEA Transportation Safety Standards (TS-R-1).

5.3.4.2 Accident Conditions of Transport

This section presents the accident condition shielding analyses. Under accident conditions, the NRC limits the package dose rate to 1000 mrem/hr at 1 meter off the package surface. The only accident condition examined in this section is the loss of the LWT liquid neutron shield.

This analysis examines Configuration 1 consistent with the limiting configuration analysis for normal conditions of transport presented in Section 5.3.4. The accident condition source terms are identical to the normal condition source terms. The accident condition results are presented in Table 5.3.4-15.

Figure 5.3.4-1 MTR Fuel Evaluated Configurations

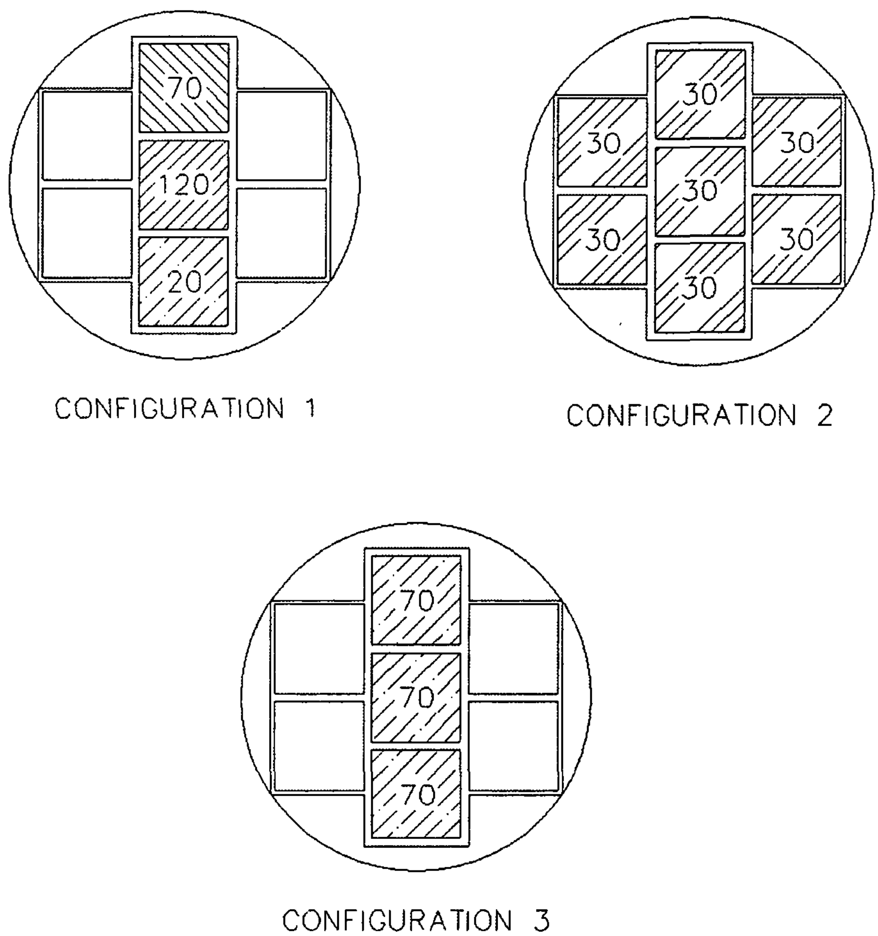


Figure 5.3.4-2 SAS4 Shielding Model for the MTR Fuel Basket in the NAC-LWT (Upper Half)

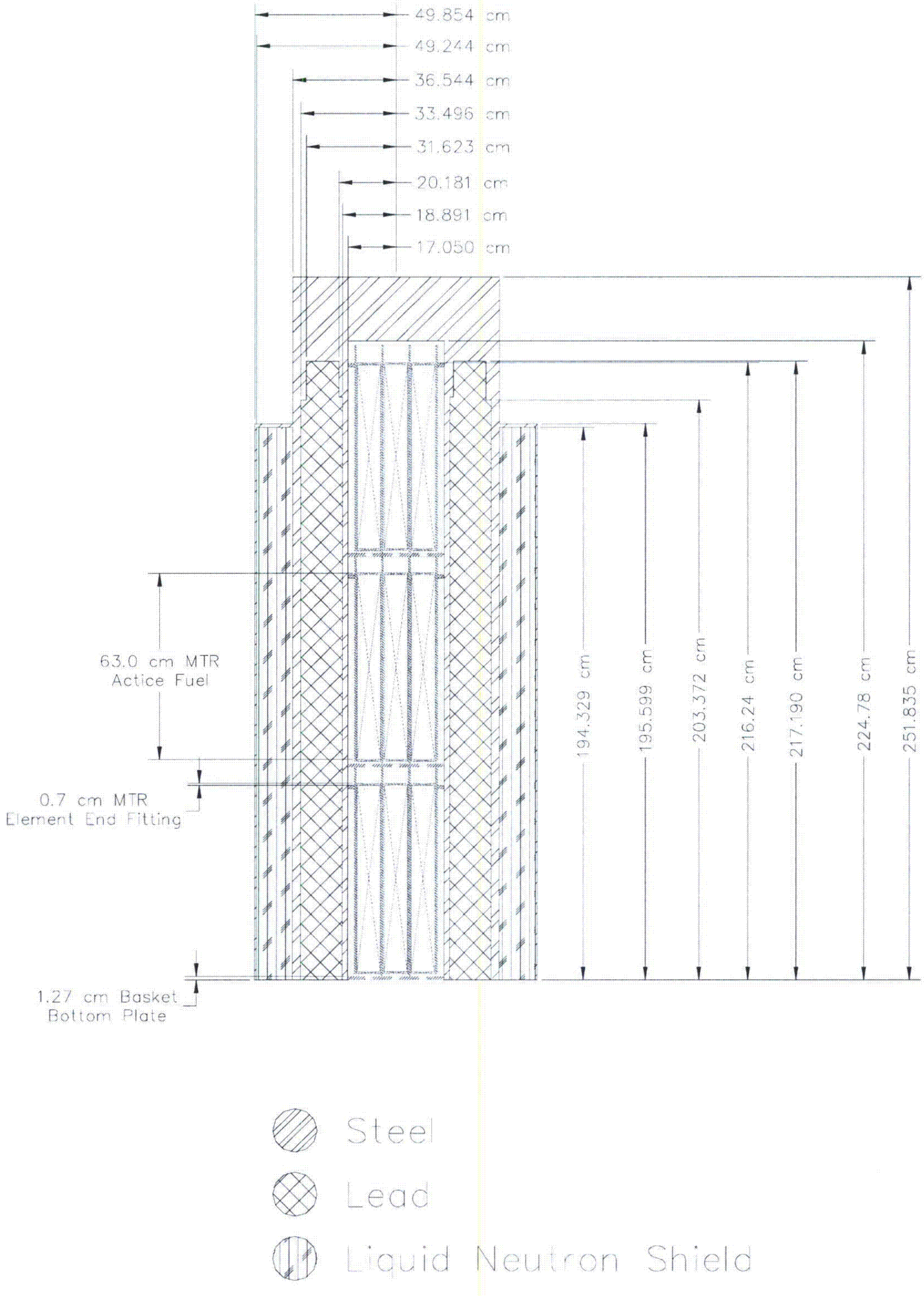
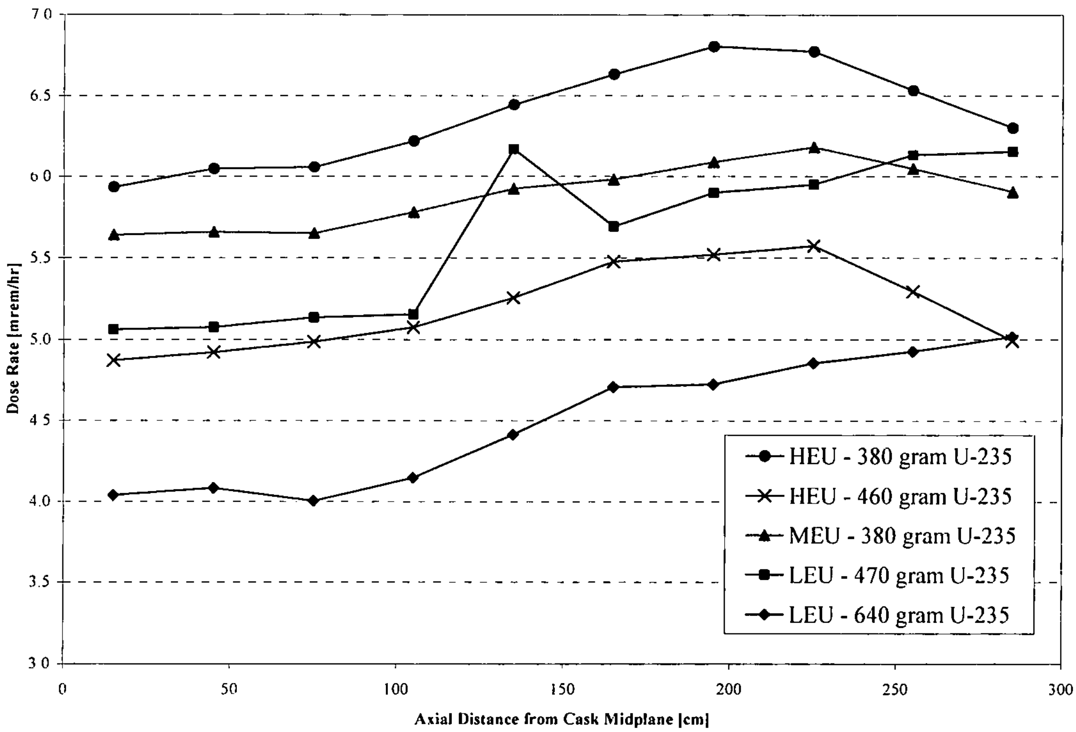


Figure 5.3.4-3 Dose Rates 2 Meters from Transport Vehicle (30 W Uniform Loading)



Note: The 40 W per element LEU and preferential loaded HEU patterns are not shown in this figure as the figure is designed to demonstrate fuel material enrichment and mass impact on dose rate at a fixed heat load.

Figure 5.3.4-4 Dose Rate Profile at Radial Surface of LWT Cask – Normal Conditions – LEU Fuel at 80% Burnup and 40W Uniform Loading

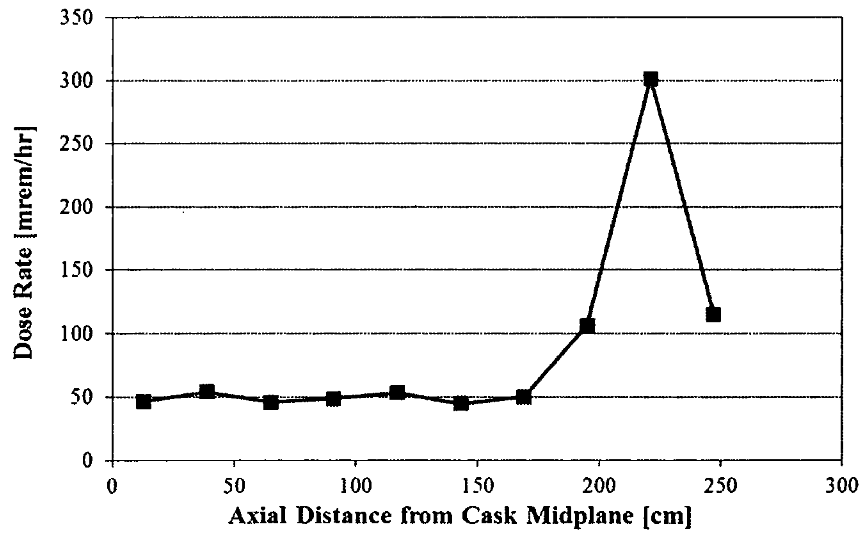


Figure 5.3.4-5 Dose Rate Profile at 2m from Conveyance Radial Surface of LWT Cask – Normal Conditions – LEU Fuel at 80% Burnup and 40W Uniform Loading

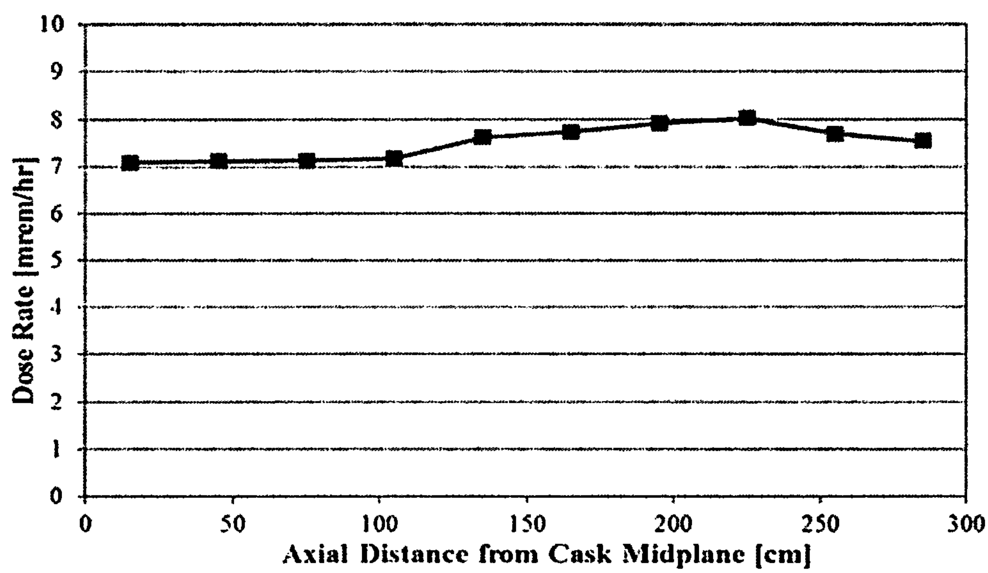


Figure 5.3.4-6 MTR LEU Low Burnup Dose Rate Profile Comparison

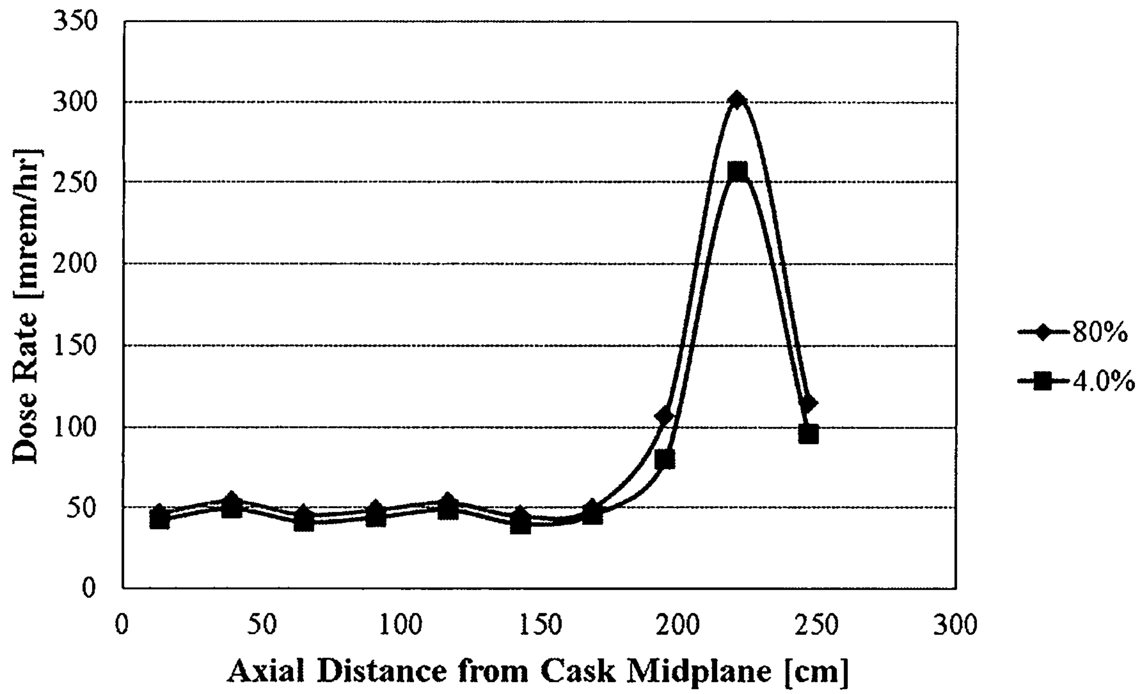


Figure 5.3.4-7 MTR MEU Low Burnup Dose Rate Profile Comparison

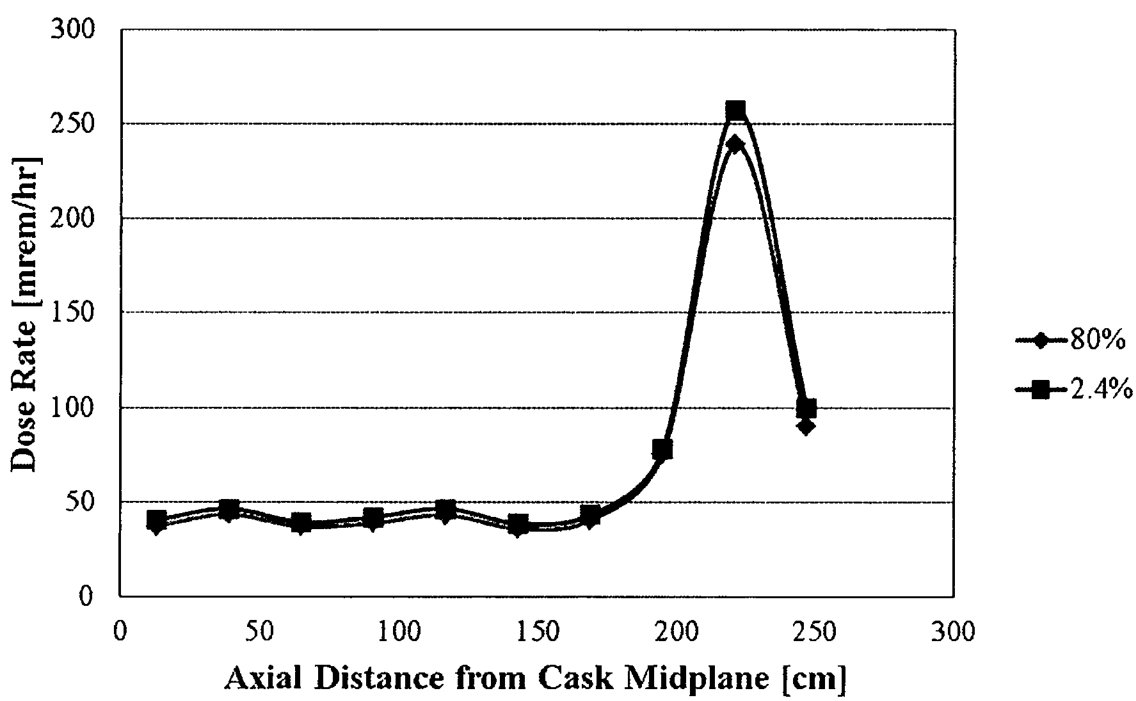


Figure 5.3.4-8 MTR HEU Low Burnup Dose Rate Profile Comparison

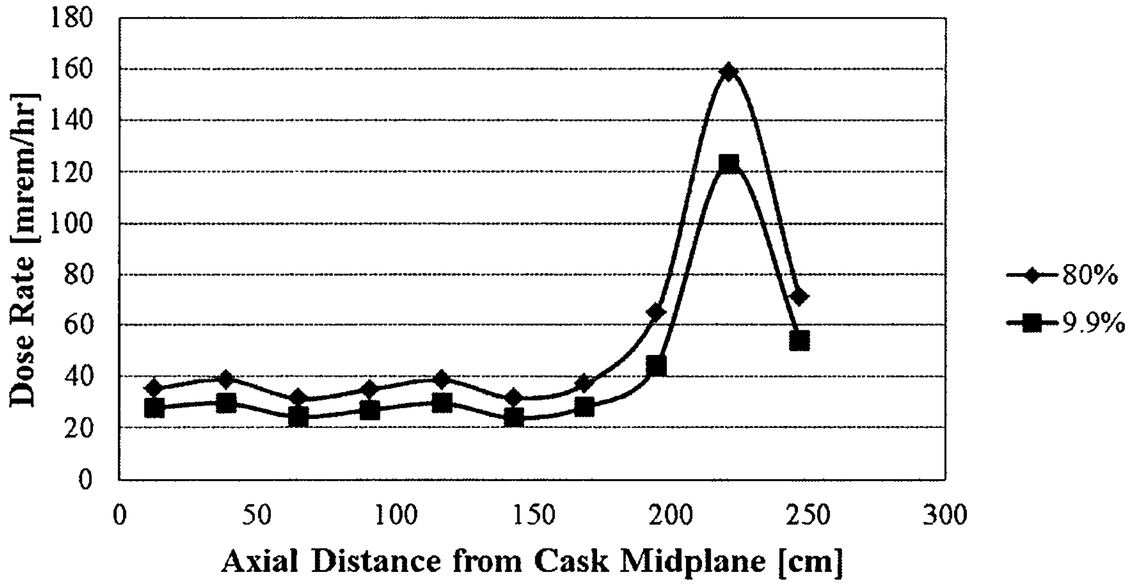


Table 5.3.4-1 Design Basis MTR Fuel Assembly Characteristics

Fuel Parameters	Units	HEU	MEU	LEU
Element Width	[cm]	7.6	7.6	7.6
Element Depth	[cm]	8.0	8.0	8.0
Side Plate Thickness	[cm]	0.475	0.475	0.475
Side Plate Depth	[cm]	7.5	7.5	7.5
Number of Plates		23	23	23
Plate Thickness	[cm]	0.127	0.127	0.127
Active Fuel Length	[cm]	63	65	65
Active Fuel Width	[cm]	6.35	6.35	6.35
Active Fuel Thickness	[cm]	0.051	0.051	0.051
Cut End Length	[cm]	0.7	0.7	0.7
Fuel Composition		U-Al	U-Al	U-Al
Wt % ^{235}U		90	40	19
Maximum ^{235}U per Fuel Assembly	[g]	380[1]	380	470[2]
Wt % U in Fuel Composition		30	50	75

[1] HEU fuel was also analyzed at 460 grams of ^{235}U per fuel element.

[2] LEU fuel was also analyzed at 490 and 640 grams of ^{235}U per fuel element. The 490-gram ^{235}U patten is evaluated to a higher heat load of 40 W per element.

Table 5.3.4-2 MTR Fuel Element Gamma Source Terms by Thermal Output – 380 grams ^{235}U

Burnup 660,000 MWd/MTU			MTR Assembly Thermal Output			
			20 Watts	30 Watts	70 Watts	120 Watts
Group	E_{hi} (Mev)	E_{low} (Mev)	2162 Days (g/sec)	1413 Days (g/sec)	581 Days (g/sec)	330 Days (g/sec)
1	10.00	8.00	1.63E+03	1.81E+03	2.08E+03	2.21E+03
2	8.00	6.50	7.69E+03	8.52E+03	9.79E+03	1.04E+04
3	6.50	5.00	3.92E+04	4.35E+04	4.99E+04	5.30E+04
4	5.00	4.00	9.77E+04	1.08E+05	1.24E+05	1.32E+05
5	4.00	3.00	3.30E+07	1.32E+08	6.24E+08	9.96E+08
6	3.00	2.50	2.81E+08	1.17E+09	5.84E+09	9.56E+09
7	2.50	2.00	2.45E+10	1.47E+11	1.09E+12	2.00E+12
8	2.00	1.66	6.34E+09	2.33E+10	1.32E+11	2.34E+11
9	1.66	1.33	5.93E+11	1.19E+12	3.01E+12	4.20E+12
10	1.33	1.00	1.87E+12	2.75E+12	5.21E+12	6.81E+12
11	1.00	0.80	8.36E+12	1.61E+13	3.47E+13	4.42E+13
12	0.80	0.60	4.21E+13	6.14E+13	1.14E+14	2.15E+14
13	0.60	0.40	1.70E+13	3.41E+13	7.83E+13	1.04E+14
14	0.40	0.30	9.18E+11	1.71E+12	7.11E+12	1.23E+13
15	0.30	0.20	1.42E+12	2.47E+12	9.38E+12	1.62E+13
16	0.20	0.10	5.22E+12	9.84E+12	4.12E+13	7.19E+13
17	0.10	0.05	6.33E+12	1.09E+13	4.07E+13	7.00E+13
18	0.05	0.01	2.19E+13	3.60E+13	1.26E+14	2.15E+14
Total	--	--	1.06E+14	1.77E+14	4.60E+14	7.61E+14

Table 5.3.4-3 MTR Fuel Element Neutron Source Terms by Thermal Output – 380 grams ^{235}U

Burnup 660,000 MWd/MTU			MTR Assembly Thermal Output			
			20 Watts	30 Watts	70 Watts	120 Watts
Group	E_{hi} (Mev)	E_{low} (Mev)	2162 Days (n/sec)	1413 Days (n/sec)	581 Days (n/sec)	330Days (n/sec)
1	2.00E+01	6.43E+00	5.42E+04	6.06E+04	7.06E+04	7.52E+04
2	6.43E+00	3.00E+00	6.26E+05	6.98E+05	8.12E+05	8.67E+05
3	3.00E+00	1.85E+00	7.11E+05	7.90E+05	9.14E+05	9.74E+05
4	1.85E+00	1.40E+00	3.92E+05	4.37E+05	5.07E+05	5.39E+05
5	1.40E+00	9.00E-01	5.25E+05	5.86E+05	6.81E+05	7.24E+05
6	9.00E-01	4.00E-01	5.69E+05	6.36E+05	7.40E+05	7.87E+05
7	4.00E-01	1.00E-01	1.11E+05	1.24E+05	1.45E+05	1.54E+05
8	1.00E-01	1.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	1.70E-02	3.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	3.00E-03	5.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	5.50E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	1.00E-04	3.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	3.00E-05	1.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	1.00E-05	3.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	3.05E-06	1.77E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	1.77E-06	1.30E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	1.30E-06	1.13E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	1.13E-06	1.00E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	1.00E-06	8.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	8.00E-07	4.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	4.00E-07	3.25E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	3.25E-07	2.25E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	2.25E-07	1.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	1.00E-07	5.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	5.00E-08	3.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	3.00E-08	1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	--	--	2.99E+06	3.33E+06	3.87E+06	4.12E+06

Table 5.3.4-4 MTR Fuel Element Gamma Source Terms by Thermal Output – 460 grams ^{235}U

Burnup 577,500 MWd/MTU			MTR Assembly Thermal Output			
			20 Watts	30 Watts	70 Watts	120 Watts
Group	E_{hi} (Mev)	E_{low} (Mev)	2247 Days (g/sec)	1467 Days (g/sec)	602 Days (g/sec)	341 Days (g/sec)
1	10.00	8.00	1.07E+03	1.16E+03	1.31E+03	1.40E+03
2	8.00	6.50	5.02E+03	5.48E+03	6.18E+03	6.59E+03
3	6.50	5.00	2.56E+04	2.80E+04	3.15E+04	3.36E+04
4	5.00	4.00	6.38E+04	6.97E+04	7.86E+04	8.38E+04
5	4.00	3.00	2.70E+07	1.15E+08	5.77E+08	9.39E+08
6	3.00	2.50	2.33E+08	1.02E+09	5.47E+09	9.13E+09
7	2.50	2.00	2.08E+10	1.34E+11	1.08E+12	2.03E+12
8	2.00	1.66	5.73E+09	2.12E+10	1.27E+11	2.30E+11
9	1.66	1.33	5.49E+11	1.12E+12	2.93E+12	4.14E+12
10	1.33	1.00	1.86E+12	2.73E+12	5.18E+12	6.81E+12
11	1.00	0.80	7.73E+12	1.52E+13	3.37E+13	4.34E+13
12	0.80	0.60	4.20E+13	6.08E+13	1.12E+14	2.09E+14
13	0.60	0.40	1.56E+13	3.21E+13	7.58E+13	1.02E+14
14	0.40	0.30	9.39E+11	1.68E+12	7.05E+12	1.24E+13
15	0.30	0.20	1.46E+12	2.44E+12	9.31E+12	1.63E+13
16	0.20	0.10	5.34E+12	9.69E+12	4.10E+13	7.28E+13
17	0.10	0.05	6.58E+12	1.09E+13	4.07E+13	7.09E+13
18	0.05	0.01	2.26E+13	3.60E+13	1.26E+14	2.17E+14
Total	--	--	1.05E+14	1.73E+14	4.55E+14	7.56E+14

Table 5.3.4-5 MTR Fuel Element Neutron Source Terms by Thermal Output – 460 grams ^{235}U

Burnup 577,500 MWd/MTU			MTR Assembly Thermal Output			
			20 Watts	30 Watts	70 Watts	120 Watts
Group	E_{hi} (Mev)	E_{low} (Mev)	2247 Days (n/sec)	1467 Days (n/sec)	602 Days (n/sec)	341 Days (n/sec)
1	2.00E+01	6.43E+00	3.49E+04	3.83E+04	4.33E+04	4.61E+04
2	6.43E+00	3.00E+00	4.12E+05	4.50E+05	5.09E+05	5.46E+05
3	3.00E+00	1.85E+00	4.83E+05	5.24E+05	5.89E+05	6.29E+05
4	1.85E+00	1.40E+00	2.59E+05	2.83E+05	3.19E+05	3.38E+05
5	1.40E+00	9.00E-01	3.42E+05	3.74E+05	4.22E+05	4.48E+05
6	9.00E-01	4.00E-01	3.68E+05	4.03E+05	4.55E+05	4.84E+05
7	4.00E-01	1.00E-01	7.19E+04	7.87E+04	8.90E+04	9.47E+04
8	1.00E-01	1.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	1.70E-02	3.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	3.00E-03	5.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	5.50E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	1.00E-04	3.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	3.00E-05	1.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	1.00E-05	3.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	3.05E-06	1.77E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	1.77E-06	1.30E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	1.30E-06	1.13E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	1.13E-06	1.00E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	1.00E-06	8.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	8.00E-07	4.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	4.00E-07	3.25E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	3.25E-07	2.25E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	2.25E-07	1.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	1.00E-07	5.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	5.00E-08	3.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	3.00E-08	1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	--	--	1.97E+06	2.15E+06	2.43E+06	2.59E+06

Table 5.3.4-6 LEU MTR Hardware Source to Fuel Source Comparison

Group	E_{hi} (Mev)	E_{low} (Mev)	834 days Fuel (γ/sec)	Cd at 834 days 100 g Cd (γ/sec)	Cd Source % of Fuel Gamma	Cd at 90 days 100 g Cd (γ/sec)	Cd Source % of Fuel Gamma
1	10.00	8.00	6.30E+02	0.00E+00	0.0%	0.00E+00	0.0%
2	8.00	6.50	2.97E+03	0.00E+00	0.0%	0.00E+00	0.0%
3	6.50	5.00	1.51E+04	0.00E+00	0.0%	0.00E+00	0.0%
4	5.00	4.00	3.78E+04	0.00E+00	0.0%	0.00E+00	0.0%
5	4.00	3.00	2.57E+08	4.49E-16	0.0%	1.80E-15	0.0%
6	3.00	2.50	2.16E+09	3.23E+00	0.0%	2.55E+01	0.0%
7	2.50	2.00	1.72E+11	1.19E+03	0.0%	9.38E+03	0.0%
8	2.00	1.66	3.60E+10	5.80E+04	0.0%	5.04E+05	0.0%
9	1.66	1.33	8.12E+11	7.57E+07	0.0%	6.35E+08	0.1%
10	1.33	1.00	2.68E+12	8.65E+05	0.0%	2.07E+09	0.1%
11	1.00	0.80	9.90E+12	2.11E+08	0.0%	5.66E+09	0.1%
12	0.80	0.60	6.14E+13	2.87E+08	0.0%	3.49E+09	0.0%
13	0.60	0.40	2.21E+13	2.13E+07	0.0%	3.12E+09	0.0%
14	0.40	0.30	2.36E+12	2.19E+08	0.0%	3.55E+09	0.2%
15	0.30	0.20	3.34E+12	8.06E+08	0.0%	5.78E+09	0.2%
16	0.20	0.10	1.27E+13	4.57E+09	0.0%	2.32E+10	0.2%
17	0.10	0.05	1.45E+13	1.17E+10	0.1%	3.88E+10	0.3%
18	0.05	0.01	4.76E+13	5.52E+10	0.1%	1.65E+11	0.3%
Total	--	--	1.78E+14	7.31E+10	0.0%	2.51E+11	0.1%

Table 5.3.4-7 HEU MTR Hardware Source to Fuel Comparison

Group	E_{hi} (Mev)	E_{low} (Mev)	1467 days Fuel (γ/sec)	Cd at 1467days 100 g Cd (γ/sec)	Cd Source % of Fuel Gamma	Cd at 90 days 100 g Cd (γ/sec)	Cd Source % of Fuel Gamma
1	10.00	8.00	1.16E+03	0.00E+00	0.0%	0.00E+00	0.0%
2	8.00	6.50	5.48E+03	0.00E+00	0.0%	0.00E+00	0.0%
3	6.50	5.00	2.80E+04	0.00E+00	0.0%	0.00E+00	0.0%
4	5.00	4.00	6.97E+04	0.00E+00	0.0%	0.00E+00	0.0%
5	4.00	3.00	1.15E+08	8.77E-15	0.0%	1.14E-13	0.0%
6	3.00	2.50	1.02E+09	2.69E+00	0.0%	1.23E+02	0.0%
7	2.50	2.00	1.34E+11	9.89E+02	0.0%	4.52E+04	0.0%
8	2.00	1.66	2.12E+10	4.82E+04	0.0%	2.49E+06	0.0%
9	1.66	1.33	1.12E+12	6.30E+07	0.0%	3.66E+09	0.3%
10	1.33	1.00	2.73E+12	7.02E+05	0.0%	4.30E+10	1.6%
11	1.00	0.80	1.52E+13	1.75E+08	0.0%	9.22E+10	0.6%
12	0.80	0.60	6.08E+13	2.38E+08	0.0%	2.76E+10	0.0%
13	0.60	0.40	3.21E+13	4.54E+07	0.0%	5.33E+10	0.2%
14	0.40	0.30	1.68E+12	5.87E+08	0.0%	6.72E+10	4.0%
15	0.30	0.20	2.44E+12	2.16E+09	0.1%	1.01E+11	4.2%
16	0.20	0.10	9.69E+12	1.23E+10	0.1%	3.51E+11	3.6%
17	0.10	0.05	1.09E+13	3.01E+10	0.3%	5.20E+11	4.8%
18	0.05	0.01	3.60E+13	1.33E+11	0.4%	1.75E+12	4.9%
Total	--	--	1.73E+14	1.79E+11	0.1%	3.01E+12	1.7%

Table 5.3.4-8 Material Densities for MTR Fuel Shielding Analysis

Material	Element	Density [atom/barn-cm]
HEU Fuel (380 g ^{235}U)	AL	2.470E-02
	U-235	2.548E-04
	U-238	2.795E-05
HEU Fuel (460 g ^{235}U)	AL	2.590E-02
	U-235	3.075E-04
	U-238	3.373E-05
MEU Fuel	AL	2.432E-02
	U-235	2.460E-04
	U-238	3.643E-04
LEU Fuel	AL	2.361E-02
	U-235	3.051E-04
	U-238	1.284E-03
End Fitting	AL	2.634E-02
H_2O/Glycol	H	5.988E-02
	C	1.070E-02
	O	2.459E-02
Stainless Steel	CR	1.743E-02
	MN	1.736E-03
	FE	5.936E-02
	NI	7.721E-03
Lead	PB	3.297E-02

Table 5.3.4-9 LWT Cask Surface Total Dose Rates (Normal Conditions of Transport)

Band [cm]	LWT Cask Surface Radial Dose Rates (mrem/hr)							
	Gamma	FSD (%)	Neutron	FSD (%)	N-Gamma	FSD (%)	Total	FSD (%)
247	98.87	1.1	18.62	0.6	0.19	3.3	117.69	0.9
221	234.17	1.1	59.67	0.3	0.48	1.7	294.31	0.9
195	86.34	0.5	43.38	0.4	1.38	0.7	131.10	0.4
169	54.75	0.4	5.06	0.7	2.58	0.5	62.39	0.4
143	45.55	0.5	4.75	0.7	2.75	0.5	53.04	0.4
117	57.19	0.5	5.31	0.6	2.91	0.4	65.42	0.4
91	52.97	0.5	5.13	0.6	2.90	0.5	61.00	0.4
65	46.75	0.5	4.85	0.6	2.89	0.4	54.48	0.4
39	58.61	0.5	5.40	0.7	3.00	0.4	67.01	0.4
13	53.69	0.5	5.22	0.6	3.03	0.5	61.94	0.4

Maximum dose rate for 460 gram ^{235}U element is 267.1 mrem/hr at the 221 cm band.

Table 5.3.4-10 LWT Cask Plane of Conveyance Dose Rates (Normal Conditions of Transport)

Band [cm]	Conveyance Dose Rates (mrem/hr)							
	Gamma	FSD (%)	Neutron	FSD (%)	N-Gamma	FSD (%)	Total	FSD (%)
266	30.64	1.1	6.20	0.5	0.18	1.0	37.01	0.9
238	39.27	1.0	8.17	0.5	0.25	0.8	47.69	0.8
210	35.26	0.9	8.48	0.4	0.37	0.6	44.11	0.8
182	26.66	0.6	6.29	0.5	0.50	0.5	33.45	0.5
154	22.13	0.5	3.77	0.6	0.62	0.5	26.52	0.4
126	20.53	0.5	2.47	0.7	0.71	0.4	23.70	0.4
98	20.27	0.4	1.96	0.6	0.78	0.4	23.01	0.4
70	19.92	0.4	1.76	0.6	0.82	0.4	22.50	0.3
42	20.05	0.4	1.72	0.7	0.84	0.4	22.61	0.4
14	20.24	0.4	1.69	0.5	0.86	0.4	22.78	0.4

Maximum dose rate for 460 gram ^{235}U element is 43.8 mrem/hr at the 238 cm band.

Table 5.3.4-11 LWT Cask 2 Meter Off The Plane of Conveyance Dose Rates (Normal Conditions of Transport)

Band [cm]	2 Meters off the Vertical Plane of Conveyance Dose Rates (mrem/hr)							
	Gamma	FSD (%)	Neutron	FSD (%)	N-Gamma	FSD (%)	Total	FSD (%)
285	7.00	2.0	1.14	2.0	0.10	2.1	8.23	1.7
255	7.55	2.0	1.19	1.9	0.11	2.1	8.86	1.8
225	8.47	2.4	1.19	1.8	0.12	2.0	9.79	2.1
195	8.02	1.6	1.20	1.9	0.14	1.7	9.36	1.4
165	8.60	1.8	1.12	1.8	0.15	1.7	9.87	1.5
135	8.42	1.3	1.11	1.8	0.16	1.7	9.69	1.1
105	8.55	1.2	1.01	1.9	0.17	2.1	9.74	1.1
75	8.59	1.1	0.97	2.1	0.18	1.6	9.73	1.0
45	8.85	1.7	0.94	2.0	0.18	1.6	9.98	1.5
15	8.80	1.2	0.89	2.0	0.19	1.7	9.88	1.1

Maximum dose rate for 460 gram ^{235}U element is 9.36 mrem/hr at the 195 cm band.

Table 5.3.4-12 LWT Cask 1 Meter From the Cask Surface Dose Rates (Normal Conditions of Transport)

Band [cm]	1 Meter off the Cask Dose Rates							
	Gamma	FSD (%)	Neutron	FSD (%)	N-Gamma	FSD (%)	Total	FSD (%)
285	17.95	1.0	3.86	0.6	0.14	0.9	21.96	0.8
255	25.73	1.1	4.98	0.5	0.20	0.8	30.90	0.9
225	25.83	1.0	5.58	0.4	0.27	0.6	31.68	0.8
195	23.06	0.8	5.03	0.5	0.35	0.6	28.45	0.7
165	19.06	0.6	3.69	0.5	0.44	0.5	23.18	0.5
135	17.24	0.5	2.54	0.6	0.51	0.4	20.29	0.4
105	16.68	0.4	1.90	0.6	0.57	0.4	19.16	0.4
75	16.44	0.4	1.60	0.6	0.61	0.4	18.65	0.4
45	16.33	0.4	1.47	0.7	0.63	0.4	18.42	0.4
15	16.38	0.4	1.40	0.5	0.65	0.4	18.43	0.3

Maximum dose rate for 460 gram ^{235}U element is 29.5 mrem/hr at the 225 cm band.

Table 5.3.4-13 Axial Surface Dose Rates at Cask Lid (Normal Conditions of Transport)

Band [cm]	Cask Lid Dose Rates (mrem/hr) Directly Above the MTR Elements					
	Gamma	FSD (%)	Neutron	FSD (%)	Total	FSD (%)
28.5	16.19	0.8	16.82	7.2	33.01	3.7
25.5	25.34	0.9	19.95	7.9	45.53	3.5
22.5	35.61	0.8	24.84	5.8	60.55	2.4
19.5	48.48	0.8	29.90	6.5	78.43	2.5
16.5	63.02	0.8	41.88	24.9	105.20	9.9
13.5	80.35	0.9	38.04	7.9	118.46	2.6
10.5	103.64	0.9	44.71	14.1	148.35	4.3
7.5	126.16	0.9	51.17	10.1	177.41	3.0
4.5	147.50	1.2	41.19	10.5	188.70	2.5
1.5	158.66	2.5	52.57	26.1	211.23	6.8

Maximum dose rate for 460 gram ^{235}U element is 174.1 mrem/hr at the 1.5 cm band.

Table 5.3.4-14 LWT Cask Dose Rates 5 Meters from the Cask Lid (Back of Tractor Cab) for Normal Conditions of Transport

Band [cm]	5 Meter Dose Rates (mrem/hr)					
	Gamma	FSD (%)	Neutron	FSD (%)	Total	FSD (%)
84.38	0.47	1.6	0.12	13.9	0.59	3.1
73.13	0.49	1.6	0.11	12.4	0.61	2.6
61.88	0.49	1.8	0.12	16.3	0.61	3.5
50.63	0.51	2.1	0.13	19.0	0.65	4.2
39.38	0.53	2.4	0.12	18.8	0.65	3.9
28.13	0.54	3.0	0.10	23.1	0.64	4.4
16.88	0.55	3.6	0.07	28.2	0.62	4.6
5.63	0.54	5.8	0.14	51.6	0.68	11.5

Maximum dose rate for 460 gram ^{235}U element is 0.62 mrem/hr at the 28.13 cm band.

Table 5.3.4-15 LWT Cask Dose Rates – 1 Meter from the Cask Surface (Hypothetical Accident Conditions)

Band [cm]	1 Meter Accident Dose Rates (mrem/hr)					
	Gamma	FSD (%)	Neutron	FSD (%)	Total	FSD (%)
285	21.38	5.2	9.78	0.4	31.18	3.5
255	33.72	13.5	13.90	0.3	47.63	9.6
225	31.01	3.0	19.15	0.3	50.19	1.9
195	30.50	2.9	24.55	0.2	55.08	1.6
165	29.36	3.5	29.32	0.2	58.71	1.7
135	29.51	3.0	33.11	0.2	62.66	1.4
105	28.68	3.4	35.67	0.2	64.38	1.5
75	29.52	4.3	37.51	0.2	67.07	1.9
45	28.49	2.2	38.59	0.2	67.12	0.9
15	27.74	1.2	39.24	0.2	67.02	0.5

Maximum dose rate for 460 gram ^{235}U element is 54.5 mrem/hr at the 15 cm band.

Table 5.3.4-16 LEU MTR Fuel Element Gamma Source Term - 40 W - 490g ^{235}U- 80% Burnup

Group	E_{hi} (Mev)	E_{low} (Mev)	402 Days (γ/sec)
1	10.00	8.00	4.666E+02
2	8.00	6.50	2.199E+03
3	6.50	5.00	1.122E+04
4	5.00	4.00	2.797E+04
5	4.00	3.00	5.259E+08
6	3.00	2.50	4.538E+09
7	2.50	2.00	4.817E+11
8	2.00	1.66	7.979E+10
9	1.66	1.33	1.139E+12
10	1.33	1.00	2.862E+12
11	1.00	0.80	1.183E+13
12	0.80	0.60	6.811E+13
13	0.60	0.40	2.915E+13
14	0.40	0.30	4.091E+12
15	0.30	0.20	5.466E+12
16	0.20	0.10	2.217E+13
17	0.10	0.05	2.339E+13
18	0.05	0.01	7.351E+13
Total	--	--	2.423E+14

Table 5.3.4-17 LEU MTR Fuel Element Neutron Source Term - 40 W - 490g ^{235}U- 80% Burnup

Group	E_{hi} (Mev)	E_{low} (Mev)	402 Days (n/sec)
1	2.00 E+01	6.43 E+00	1.462E+04
2	6.43 E+00	3.00 E+00	1.878E+05
3	3.00 E+00	1.85 E+00	2.095E+05
4	1.85 E+00	1.40 E+00	1.067E+05
5	1.40 E+00	9.00 E-01	1.408E+05
6	9.00 E-01	4.00 E-01	1.529E+05
7	4.00 E-01	1.00 E-01	2.999E+04
8	1.00 E-01	1.70 E-02	--
9	1.70 E-02	3.00 E-03	--
10	3.00 E-03	5.50 E-04	--
11	5.50 E-04	1.00 E-04	--
12	1.00 E-04	3.00 E-05	--
13	3.00 E-05	1.00 E-05	--
14	1.00 E-05	3.05 E-06	--
15	3.05 E-06	1.77 E-06	--
16	1.77 E-06	1.30 E-06	--
17	1.30 E-06	1.13 E-06	--
18	1.13 E-06	1.00 E-06	--
19	1.00 E-06	8.00 E-07	--
20	8.00 E-07	4.00 E-07	--
21	4.00 E-07	3.25 E-07	--
22	3.25 E-07	2.25 E-07	--
23	2.25 E-07	1.00 E-07	--
24	1.00 E-07	5.00 E-08	--
25	5.00 E-08	3.00 E-08	--
26	3.00 E-08	1.00 E-08	--
27	1.00 E-08	0.00 E+00	--
Total	--	--	8.423E+05

List of Tables (continued)

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cm fuel element hardware, in combination with the 0.123 cm minimum plate thickness produces the required result. While the model employed a symmetric 2 cm fuel plate extension on each end of the active fuel region, any combination of top or bottom hardware or basket spacer material resulting in a 4 cm total is sufficient to assure criticality safety. Based on this evaluation, it is permissible to load a 460 g ^{235}U element, provided that the fuel plates are at minimum 0.123 cm in thickness and that cropping of the fuel element or basket spacer material assures 4 cm axial element material separating the active fuel region. Note that 4 cm of fuel element or spacer material plus the 1.27 cm basket base plate result in a total 5.27 cm of axial separation for the limiting configuration. An enhanced fuel characteristic set is generated and shown in Table 6.4.3-22 to reflect the requirements for loading of the increased fissile material element.

At 21g ^{235}U per plate, additional loading constraint must be applied. The evaluations of the 21g ^{235}U per plate HEU elements are based on the 0.7 cm minimum offset of the active fuel region and decrease the number of plates per element and/or increase the plate minimum thickness. The results of this evaluation are added to Table 6.4.3-23 with a bounding set of fuel characteristics added to Table 6.4.3-22.

6.4.3.14 LEU MTR Fuel Elements with Increased Active Fuel Width and/or Increased Fissile Material Mass

Increased Active Fuel Width

This section determines the requirements for loading LEU fuel elements with an active fuel width larger than 6.6 cm. Section 6.4.3.12 has demonstrated an active fuel width of 7.3 cm yields a k_s of greater than 0.95. This section extends the licensing envelope to a maximum active fuel width of 7.0, 7.1 or 7.15 cm for LEU fuel.

The models employed are similar to those of Section 6.4.3.12 with differences originating in the modifications made in active fuel width, plate thickness, ^{235}U loading per plate, active fuel height, and number of fuel plates.

The 7.0 cm active fuel width evaluation shows that plate thickness, ^{235}U loading per plate, and active fuel height adjustments were sufficient to reduce system reactivity below 0.95. Evaluations of the 7.1 cm active fuel width envelope relied on changes in the number of fuel plates and plate thickness. Extending the active fuel width to 7.15 cm required an increased plate minimum thickness (0.119 cm) in conjunction with a decreased number of fuel plates, increased minimum active fuel height, or decreased fissile material load per plate. Evaluation results are shown in

Table 6.4.3-24. A summary of the allowable LEU fuel characteristics is shown in Table 6.4.3-25.

An additional 7.0 cm active width plate configuration is evaluated with a maximum a 23.5 g ^{235}U per plate. To reduce system reactivity to levels bounded by the HEU design basis element (the "generic" element defined in Table 6.4.3-21) the plate thickness in this case is increased to a minimum 0.13 cm. Table 6.4.3-30 contains the results of the element characteristic analyses demonstrating that at a minimum thickness of 0.13 inch up to 23 plates of 23.5 g ^{235}U may be loaded with a maximum active fuel width of 7.0 cm, minimum active fuel height of 56 cm, and clad thickness of 0.02 cm. A maximum number of plates is defined as the limiting quanity per Section 6.4.3-12. To verify that this analysis result holds true for the thicker minimum plate thickness of 0.13 cm, a study on the number of plates in the element was performed. Table 6.4.3-30 contains the data demonstrating that no reactivity increase occurs as plate number is decreased at the minimum 0.13 cm plate thickness specified for this evaluation.

Increased Fissile Material Mass (32 g ^{235}U per plate)

LEU fuel elements may contain a ^{235}U content of up to 32 grams per plate. Based on the analysis trends observed in the previous sections, a full cask load of elements containing fissile material significantly above 22 grams per plate will exceed safety limits. Additional analyses are, therefore, performed limiting the contents of the basket module with 32 gram ^{235}U plates to four elements per basket. The center row of elements (locations 1, 2 and 3 in Figure 6.3.3-5) are not loaded. The LEU plate characteristics applied are a maximum 7.3 cm active fuel width, a minimum 56 cm fuel height, and a minimum 0.115 cm plate thickness. Twenty-three plate elements are modeled.

Table 6.4.3-27 contains the results of the criticality evaluations with the revised model. Each of the bounding MTR configurations (summarized in Table 6.4.3-26) is evaluated at full load and with a partial load in the top and bottom baskets. A single fuel type is included in this analysis set. As shown in Table 6.4.3-26 , the system reactivity of the 32 gram ^{235}U per plate element (Case 25%-J) is above safety limits for both full and partially loaded top and bottom baskets (k_s must be less than 0.95). Partially loading the top and bottom baskets reduces system reactivity by approximately 0.01 Δk across all fuel types. Loading the high fissile mass (high reactivity) 32 g ^{235}U per plate LEU elements in a partially loaded basket, and locating the partially loaded baskets at the top and bottom of the basket stack have no significant effect on system reactivities — i.e., system reactivity is controlled by the adjacent (cask center) baskets containing higher reactivity, fully loaded baskets.

An evaluation of six baskets with four elements per basket of the 32 gram ^{235}U per plate LEU fuel element results in a k_{eff} of approximately 0.7. This clearly demonstrates that removing three elements from the basket reduces the basket reactivity significantly, and that replacing any fully

loaded basket by the partially loaded high fissile material content element basket is bounded by the evaluations of a fully loaded (42 element) cask configuration.

Loading of the high fissile material elements is, therefore, allowed provided that the elements meet the characteristics of Table 6.4.3-28, including the limitation that any basket containing LEU MTR plates above 22 gram ^{235}U must be limited to four elements (or an equivalent number of fuel plates in a plate canister) with no fuel material in basket openings 1, 2 and 3 per Figure 6.3.3-5.

The specified (partially loaded) basket configuration relies on the moderator in the center basket row to neutronically separate the fissile material in the outer sections. As moderator density in the cask decreases, neutronic interaction among the high fissile mass LEU elements in the outer basket sections will increase. Because previous evaluations have demonstrated that the MTR element reactivity rapidly decreases as moderator density is decreased, it is, therefore, not expected that reduced moderator density will result in a system reactivity increase. To provide quantitative support to this conclusion, moderator density studies are performed for the system with partially loaded baskets located at the top and bottom of the stack, for a system with partially loaded baskets in the cask center baskets, and for a system containing six partially loaded baskets. The partially loaded baskets contain the high fissile mass LEU elements, while the fully loaded baskets contain the maximum reactivity HEU elements ("94%-D").

As demonstrated in Figure 6.4.3-1 and Table 6.4.3-29, maximum reactivity is achieved by a fully moderated cask interior for all conditions.

Figure 6.4.3-1 also contains the results of a full set of moderator density evaluations for a system containing cell blocks that will physically prevent elements from being loaded into baskets containing high fissile mass LEU elements. The block body is composed of an aluminum tube and an aluminum top plate. As the length of the block depends on the type of MTR basket employed, and the tube represents the majority of the block mass (the top plate occupies less than three cubic inches), only the tube portion of the block is included in the model. As shown in the moderator density plot, Figure 6.4.3-1, and the result summary in Table 6.4.3-29, there is no effect from the insertion of the cell block on the models containing both full and partially loaded baskets, and only a minor effect on the lower reactivity models containing all partially loaded baskets.

6.4.3.15 MTR Payload Criticality Safety Index

Evaluations included in Sections 6.4.3.1 through 6.4.3.14 demonstrate that the bias and uncertainty adjusted reactivity (k_s) for an infinite array of NAC-LWT casks containing MTR fuel elements remains below 0.95. Therefore, the Criticality Safety Index (CSI) for all MTR payloads is 0.

Figure 6.4.3-1 Cask Interior Moderator Density and Blocked Cell Study Results

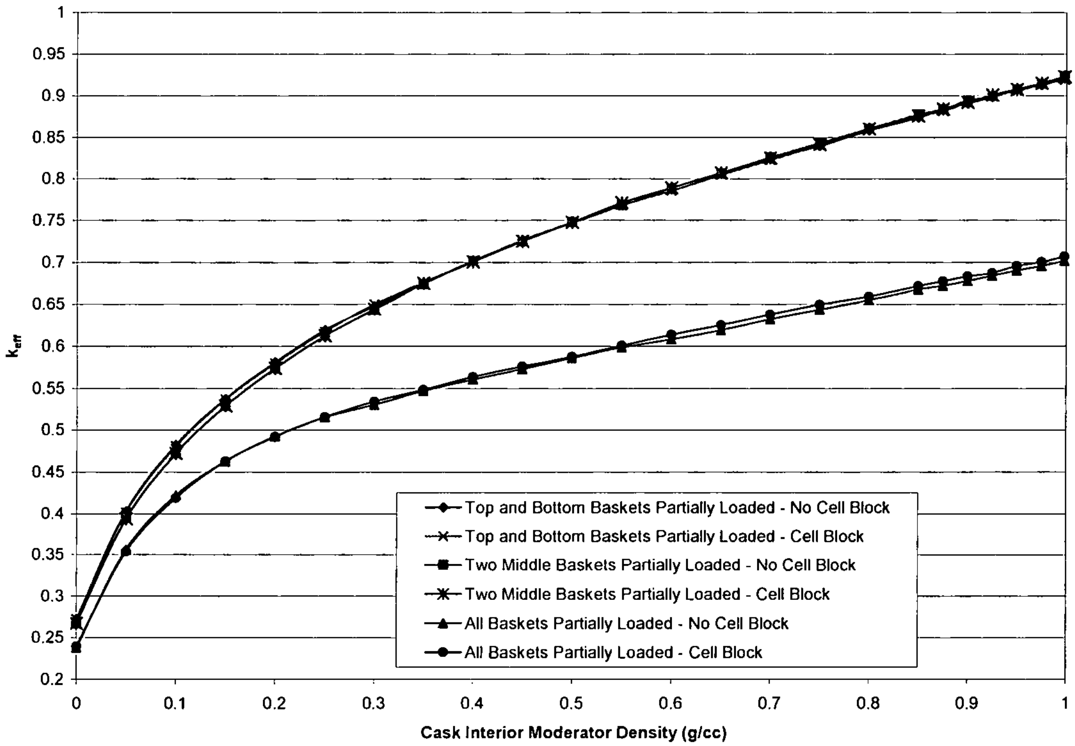

Table 6.4.3-26 Summary of Previous Bounding Configurations for Use in High Mass LEU Calculations

Fuel ID	Plate Thickness	Clad Thickness	Number of Fuel Plates	^{235}U per Plate	Enrichment	Active Width	Active Height	Fuel Offset
	[cm]	[cm]		[g]	[wt % ^{235}U]	[cm]	[cm]	[cm]
25%-A	0.115	0.02	23	22	25	6.6	56	0.7
25%-B	0.119	0.02	23	22	25	7	56	0.7
25%-C	0.115	0.02	23	21.5	25	7	56	0.7
25%-D	0.115	0.02	23	22	25	7	63	0.7
25%-E	0.2	0.02	23	22	25	7.1	56	0.7
25%-F	0.115	0.02	17	22	25	7.1	56	0.7
25%-G	0.119	0.02	22	22	25	7.15	56	0.7
25%-H	0.119	0.02	23	21.5	25	7.15	56	0.7
25%-I	0.119	0.02	23	22	25	7.15	61	0.7
25%-J[1]	0.115	0.02	23	32	25	7.3	56	0.7
25%-K[1]	0.130	0.02	23	23.5	25	7.0	56	0.7
94%-A	0.115	0.02	23	18	94	6.6	56	0.7
94%-B	0.115	0.02	19	20	94	6.6	56	0.7
94%-C	0.115	0.02	23	16.5	94	7.3	56	0.7
94%-D	0.123	0.02	23	20	94	6.6	56	2.0
94%-E	0.2	0.02	19	21	94	6.6	56	0.7
94%-F	0.115	0.02	17	21	94	6.6	56	0.7

Note: All configurations previously evaluated as bounding are included with the exception of NISTR fuel plates. The split plate design adds an additional model complexity not required in the evaluations. The LEU high fissile mass analysis scope is designed to demonstrate that the addition of a partially loaded basket to the previous payloads is bounded by the maximum reactivities already documented. Conclusions drawn from the remaining payloads are applicable to the NISTR fuel.

[1] Content added in Section 6.4.3.14

Table 6.4.3-27 High Fissile Mass LEU (32 g ^{235}U per Plate) Analysis Results

Fuel ID[1]	Same Fuel All Baskets				32g ^{235}U PBL[2] - 7.3 cm Width		
	Full Load		Partial Top/Bottom			Full Load	Partial Load
	k_{eff}	Dancoff Factor	k_{eff}	Δk	k_{eff}	Δk	Δk
25%-A	0.92134	0.50241715	0.91073	-0.011	0.91254	-0.009	0.002
25%-B	0.92813	0.50706971	0.91656	-0.012	0.91521	-0.013	-0.001
25%-C	0.92913	0.50241715	0.91915	-0.010	0.91769	-0.011	-0.001
25%-D	0.92391	0.50241715	0.91091	-0.013	0.91053	-0.013	0.000
25%-E	0.81720	0.61588436	0.80189	-0.015	0.80451	-0.013	0.003
25%-F	0.91075	0.36430386	0.89951	-0.011	0.89608	-0.015	-0.003
25%-G	0.92995	0.48636374	0.91938	-0.011	0.91798	-0.012	-0.001
25%-H	0.92940	0.50706971	0.91356	-0.016	0.91640	-0.013	0.003
25%-I	0.92533	0.50706971	0.90939	-0.016	0.91298	-0.012	0.004
25%-J[3]	0.99842	0.50241715	0.98432	-0.014	--	--	--
94%-A	0.92885	0.50241715	0.91645	-0.012	0.91873	-0.010	0.002
94%-B	0.92823	0.41448367	0.91949	-0.009	0.91825	-0.010	-0.001
94%-C	0.92533	0.50241715	0.91439	-0.011	0.91572	-0.010	0.001
94%-D	0.93162	0.51188898	0.91978	-0.012	0.92071	-0.011	0.001
94%-E	0.85605	0.50536168	0.84241	-0.014	0.84414	-0.012	0.002
94%-F	0.92381	0.36430386	0.91394	-0.010	0.91466	-0.009	0.001

Notes: LEU payload defined as 25%-K case in Table 6.4.3-27 is not evaluated for interface with the 32g ^{235}U top/bottom basket loading. As demonstrated in Table 6.4.3-30 the 25%-K case element reactivity is lower than other elements in this table. The table demonstrates that addition of a partial loaded basket reduces system reactivity for the full range of MTR fuel types making the evaluation of mixed load with the 25%-K case unnecessary.

[1] Fuel ID is the identifier for the fuel material contained in all baskets for the cases containing one fuel type, and for the fuel material in the middle baskets for cases containing two fuel types.

[2] Partial basket loading (PBL) in the top and bottom baskets. Partially loaded baskets contain four 32 g ^{235}U per plate LEU elements per basket loaded in locations 4, 5, 6 and 7 per Figure 6.3.3-5.

[3] LEU fuel material of 32 g ^{235}U per plate, up to 23 plates.

Table 6.4.3 -30 LEU MTR Element Specification Studies (23.5g ^{235}U per Plate)

Enrichment	Plate thickness	Clad thickness	Number of fuel	^{235}U per plate	Active Width		Delta to Base
[wt % ^{235}U]	[cm]	[cm]	plates	[g]	[cm]	k_{eff}	[Δk]
94	0.115	0.02	23	18	6.6	0.92885	N/A
25	0.13	0.02	23	23.5	7.0	0.92525	-0.0036
25	0.13	0.02	22	23.5	7.0	0.9237	-0.00515
25	0.13	0.02	21	23.5	7.0	0.92355	-0.0053
25	0.13	0.02	20	23.5	7.0	0.91981	-0.00904
25	0.13	0.02	19	23.5	7.0	0.91896	-0.00989

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7 OPERATING PROCEDURES

This chapter describes the generic operating procedures for loading, unloading and preparing the NAC-LWT package for transport. These procedures shall be implemented to ensure the package is used in accordance with Certificate of Compliance (CoC) No. 9225 for the NAC-LWT packaging.

These procedures are based on generic site conditions and assume that the package arrives at the handling site with the appropriate internals installed in the cask. Additional operations and/or modifications (i.e., sequence of operations, use of parallel operations, etc.) to these procedures to address site-specific conditions may be required for each user's facility. These additional operations and/or modifications will be documented in site-specific procedures.

In addition, site-specific procedures may incorporate signoffs for activities or operational sequences as they are performed. Oversight organizations, such as Quality Assurance or Quality Control, may participate in certain package handling operations. The use of signoffs can assist the user in assuring that critical steps are not overlooked, that the package is handled in accordance with the CoC and Safety Analysis Report (SAR), and that appropriate records are retained as required by 10 CFR 71.91.

The NAC-LWT package is designed and certified to transport numerous fissile and radioactive contents, as described in the CoC, as a Type B(U)F-96 package. Certain radioactive contents, as described in the CoC, are required to be transported in a NAC-LWT assembled and tested in a leaktight containment configuration. The leaktight containment can be provided by either the Alernate port cover design with a Viton O-ring seal or by the Alternate B port cover design with a metallic seal.

The NAC-LWT is also certified for the transport of Tritium Producing Burnable Absorber Rod (TPBAR) contents, as described in the CoC, as a Type B(M)-96 package. NAC-LWT cask units designated for the transport of TPBAR contents require both leaktight containment and a high-pressure capable containment barrier. NAC-LWT casks for the leaktight transport of TPBAR contents shall be configured with Alternate B vent and drain port covers in accordance with the license drawings, and subjected to the additional hydrostatic test per the requirements of Section 8.1.2.

Loaded shipments received at U.S. Department of Energy (DOE) facilities shall be receipt surveyed and monitored in accordance with DOE regulations. As required, the shipper will be notified of any survey or shipping discrepancy and the shipper will ensure appropriate regulatory notifications are completed.

When the package is handled in accordance with the procedures provided herein, and is loaded within the conditions of the CoC and the SAR, the resulting occupational exposures will be maintained as low as reasonably achievable (ALARA), as required by 10 CFR 20.

7.1 Procedures for Loading Packages

For the shipment of loaded packages, the cavity shall be dry, the contents and nameplate package identification, corresponding to the contents, shall be verified as correct, and the other applicable conditions of the Certificate of Compliance (CoC) shall be verified as met. Site-specific procedures for dry handling, when required, and loading of fuel assemblies and other authorized contents will be prepared to incorporate the dry transfer system components required to safely and efficiently load the NAC-LWT at each loading facility. Dry loading and transfer procedures are not specifically described in the individual loading procedures due to these facility and required equipment variations. Content configurations may require spacers, baskets, basket inserts, canisters, etc., to support and/or control the content geometry during transport. The transport configurations identifying the specific contents and components required are specified in the license drawings. Solid, irradiated and contaminated hardware will generally be loaded wet utilizing the procedure guidance of Section 7.1.1. Alternatively, the solid, irradiated and contaminated hardware can be loaded dry utilizing dry loading procedures (i.e., per Section 7.1.2) modified to the requirements of the dry loading facilities.

Two port cover designs are available for use. The alternate port cover has an O-ring along the barrel and a Viton® O-ring on the inner end of the port cover. The alternate port cover was developed to provide a leaktight containment boundary and to facilitate ease of installation. The second port cover design is the Alternate B port cover that has two face seals on the inner end of the port cover. The Alternate B port cover was developed to provide a high-pressure and leaktight containment boundary and is required to be installed for the transport of TPBAR contents. Both the Alternate and Alternate B port covers provide the capability to establish a leaktight containment boundary and, therefore, the two port cover designs can be used interchangeably for authorized contents not requiring a high-pressure containment boundary capability.

The alternate port cover bolts are torqued to 100 ± 10 inch-pounds. The Alternate B port cover bolts are torqued to 285 ± 15 inch-pounds to ensure compression of the metallic containment O-ring seal.

As required for the specific contents, applicable procedures will specify the use of the Alternate B port covers. In these loading procedures, the Alternate B port cover helium leakage rate testing is described. For other content loading procedures, either port cover design can be used. However,

6. Position loaded ANSTO module onto the ANSTO basket assembly or the ANSTO-DIDO combination basket assembly.

7.1.5 MTR General and Preferential Loading Procedures

Up to 42 LEU, MEU, and HEU MTR fuel elements may be loaded into the NAC-LWT MTR Fuel Basket, i.e., 7 fuel elements per basket module × 6 basket modules per fuel basket, except for LEU MTR fuel elements with greater than 490 g ^{235}U (or greater than 23.5 g ^{235}U per plate), which are limited to 4 elements per basket module as detailed in the following paragraphs. Each MTR basket module has 7 fuel element positions. The MTR basket module loading diagram presented in Figure 7.1-1 has a center position (Position 1), two exterior positions (Positions 2 and 3) that are in line with the center position, and four exterior positions (Positions 4, 5, 6, and 7) that are adjacent to the center row positions. The basket module's fuel element locations are specifically identified to ensure loading of each location with the appropriate fuel element. Ensuring MTR fuel loadings are performed in strict accordance with the procedures presented herein will ensure that the MTR fuel content conditions of the CoC are met and that the analyses presented in this SAR are bounding.

MTR fuel elements are selected for loading into specific fuel element locations based on the decay heat of each individual fuel element at the time of loading. Figure 7.1-2 through Figure 7.1-5 and Figure 7.1-12 through Figure 7.1-13 are provided to assist in determining the acceptability of a MTR fuel element for loading in a 30 W uniform loading pattern depending on enrichment (i.e., LEU, MEU or HEU) or ^{235}U content (i.e. 380 or 460 grams). For determining the acceptability of higher heat load HEU fuel elements, Figure 7.1-6 and Figure 7.1-7 are provided for 380 and 460 grams of ^{235}U, respectively. For determining the acceptability of higher heat load LEU fuel elements, Figure 7.1-13 is provided for 490 grams of ^{235}U. Curves are provided in this figure at 10, 20, 30, and 40 W maximum heat load for maximum flexibility in the preferentially loaded basket. The use of the fuel element cool time versus fuel burnup figures are described in Section 7.1.5.4. LEU MTR fuel elements with a ^{235}U content greater than 23.5 grams per plate, but not exceeding 32 grams ^{235}U per plate, are restricted to baskets containing a maximum of four fuel elements (or an equivalent number of fuel plates per opening). The four elements per basket module is in effect even if only one LEU MTR assembly exceeds 23.5 grams ^{235}U per plate. Specific basket locations and restrictions for the high load LEU elements are described in Section 7.1.5.1.

The procedural steps and sequence to ensure the MTR fuel loading and content condition limits are met are: 1) determine ^{235}U content weight per element; 2) determine fuel element decay heat load per Section 7.1.5.4; 3) determine basket module loading position for each element and overall basket loading pattern; and 4) individual basket module loading and assembly of the fuel basket in the NAC-LWT. Each of these steps shall be independently verified.

Attention to the overall cask loading pattern allows the decay heat load of the cask to be maintained as uniform, as is practical, and within CoC total heat load limits. Loading diagrams for each individual module and the complete cask assembly shall be developed and used during the basket module and cask loading operations. After the decay heat load of each of the MTR fuel elements to be loaded and transported is calculated or determined and verified, the loading and content considerations of Sections 7.1.5.1 through 7.1.5.3 shall be met or complied with to establish the final acceptable loading pattern and sequence.

7.1.5.1 General Loading Requirements

1. The maximum decay heat load per MTR fuel basket module shall not exceed 210 W and the maximum decay heat load per cask (package) shall not exceed 1.26 kW. A MTR fuel element with a decay heat greater than 120 W shall not be loaded.
2. LEU, MEU and HEU MTR fuel elements with decay heat not exceeding 30 W per element may be loaded in any basket module fuel element location in any combination.
3. HEU MTR fuel elements with decay heats exceeding 30 W shall be preferentially loaded in a basket module in decreasing decay heat order according to the loading diagram in Figure 7.1-1, with the highest heat load element loaded in fuel location one. Fuel elements with heat loads of up to 120 W shall only be loaded in the center fuel element location of any MTR fuel basket module. The decay heat of the fuel element in either of the two fuel element locations (i.e., number 2 or 3), in line with the center fuel element location of a MTR fuel basket module, shall not exceed 70 W.
4. LEU MTR fuel elements (or canistered fuel plates) with a ^{235}U content greater than 23.5 g per plate, and not exceeding 32 g per plate, shall only be loaded into basket positions 4, 5, 6 and 7 shown in Figure 7.1-1. In order to ensure that baskets containing the high fissile mass LEU MTR elements (>23.5 g ^{235}U per plate) will not be loaded with fuel elements (or fuel plates) in basket opening positions 1, 2 and 3, a cell block spacer shall be installed in each of these three basket openings. The cell block spacer, as shown on Drawing 315-40-085, is of sufficient height and diameter to ensure that LEU MTR fuel elements are prevented from being placed in these openings. The capacity limitation of a maximum of four MTR fuel elements per module is in effect even if a single LEU MTR fuel elements (or canistered fuel plates) having >23.5 g ^{235}U per plate is to be loaded.
5. LEU MTR fuel elements with decay heats exceeding 30 W shall be preferentially loaded in a basket module in decreasing decay heat order according to the loading diagram in Figure 7.1-1. The total decay heat load of any individual basket with 40 W preferentially loaded assemblies is 210 W.
6. An MTR plate canister may be loaded into any fuel basket module fuel element location. The contents of each plate canister shall be limited to the number of fuel plates, dimensions and masses of an equivalent intact MTR fuel element.
7. MTR fuel elements with corrosion and/or mechanically damaged cladding may be loaded, provided that the total surface area of through-clad corrosion and/or mechanical damage does not exceed 5% of the elements cross-sectional area.

7.1.5.2 Determination of Basket Module Loading Pattern

1. Perform an evaluation of the full inventory of fuel elements to be loaded into the NAC-LWT cask(s) and develop an overall loading plan that minimizes overall dose rates to minimize general population dose and operator dose. The loading of LEU MTR fuel elements with greater than 23.5 g ^{235}U per plate shall be governed by the loading restrictions in item 4 of Section 7.1.5.1, and cell block spacers shall be placed in basket loading positions 1, 2 and 3 to prevent inadvertent loading of more than four high fissile mass LEU MTR elements.
2. Select up to seven MTR fuel elements to be loaded in a basket module meeting the general loading requirements of Section 7.1.5.1. Identify if spacers or spacer plates are required to properly position the MTR elements axially in the basket module.
3. Rank the fuel elements in order of decreasing decay heat load from 1 to 7. (i.e., the assembly with the highest decay heat is designated number 1.)
4. Generate loading diagrams for each basket module based on Figure 7.1-1, by placing the numbered assemblies in the matching numbered basket module positions, except that fuel elements ranked 4,5,6 or 7 may be loaded in any of the outer (i.e., 4-7) basket module positions.
5. Repeat steps 1 through 4 for all of the basket modules to be loaded.
6. Independently verify the basket module loading diagrams.
7. The loading diagrams shall be used to direct the loading of the basket modules per Section 7.1.5.3.

Once the basket module loading charts are complete, they are used to direct the loading of the basket modules.

7.1.5.3 Basket Loading Procedure

1. Locate the MTR fuel element to be loaded into the basket module per the loading diagram prepared for that module type (i.e., base, intermediate or top).
2. Independently verify the element identification.
3. Load the element into the predetermined fuel basket module fuel element location using the loading diagram. Ensure spacers are installed in positions 1, 2 and 3 of any basket module containing a high fissile mass LEU MTR element (greater than 23.5 g ^{235}U per plate).
4. Independently verify that the fuel element and spacer loading in the basket module complies with the loading diagram.
5. Repeat steps 1 through 4 until all identified fuel elements have been loaded into basket modules in compliance with the loading diagrams.

7.1.5.4 Estimating Assembly Decay Heat

When the decay heat of a fuel element is not known, the assembly burnup (MWd/MTU) and cooling time (years) can be used to define the allowable basket module positions using Figure

7.1-2 through Figure 7.1-7 and Figure 7.1-12 through Figure 7.1-13, depending on fuel enrichment (i.e., LEU, MEU or HEU) or ^{235}U content.

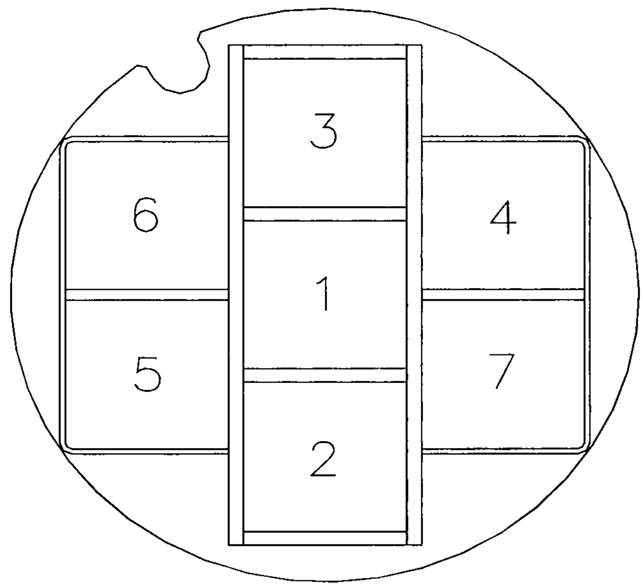
HEU MTR fuel elements may be loaded with heat loads greater than 30 W. HEU elements exceeding 30 W shall be preferentially loaded, and Figure 7.1-6 and Figure 7.1-7 identify the appropriate cooling times and burnup limits for 120 W, 70 W and 20 W HEU elements, having a ^{235}U mass of up to 380 grams and a ^{235}U mass of up to 460 grams, respectively. The following steps are used to develop the appropriate loading patterns.

1. Locate the point on Figure 7.1-6 or Figure 7.1-7 for the fuel element burnup and cooling time, and ^{235}U content.
2. If the located point is above the 20 W line, there are no restrictions on fuel element placement in the basket module.
3. If the located point is between the 20 W and 70 W lines, the element is loaded as a 70 W element.
4. If the located point is between the 70 W and 120 W lines, the element is loaded as a 120 W element.
5. If the located point is below the 120 W line, the element shall not be loaded in the NAC-LWT cask.
6. The maximum total decay heat load for a preferentially loaded basket module shall not exceed 210 W and 1.26 kW for a loaded NAC-LWT cask.
7. Each shipper shall ensure that the Certificate of Compliance maximum decay heat load limits of 210 W per basket module and 1.26 kW per cask are not exceeded.

LEU MTR fuel elements may be loaded with heat loads greater than 30 W. LEU elements exceeding 30 W but not exceeding 40 W shall be preferentially loaded, and Figure 7.1-13 identifies the appropriate cooling times and burnup limits for 40 W, 30 W, 20 W and 10 W LEU elements, having a ^{235}U mass of up to 490 grams. The following steps are used to develop the appropriate loading patterns.

1. Locate the point on Figure 7.1-12 for the fuel element burnup and cooling time.
2. If the located point is above the 10 W line, there are no restrictions on fuel element placement in the basket module.
3. If the located point is between the 20 W and 30 W lines, the element is loaded as a 30 W element.
4. If the located point is between the 30 W and 40 W lines, the element is loaded as a 40 W element.
5. If the located point is below the 40 W line, the element shall not be loaded in the NAC-LWT cask.
6. The maximum total decay heat load for a LEU preferentially loaded basket module shall not exceed 210 W and 1.26 kW for a loaded NAC-LWT cask.
7. Each shipper shall ensure that the Certificate of Compliance maximum decay heat load limits of 210 W per basket module and 1.26 kW per cask are not exceeded.

Figure 7.1-1 MTR Fuel Basket Module Loading Pattern (Top View)



Loading Diagram

Figure 7.1-2 LEU MTR Fuel Basket Loading Guidelines for 30 W Uniform Loading – Maximum 470 grams ^{235}U

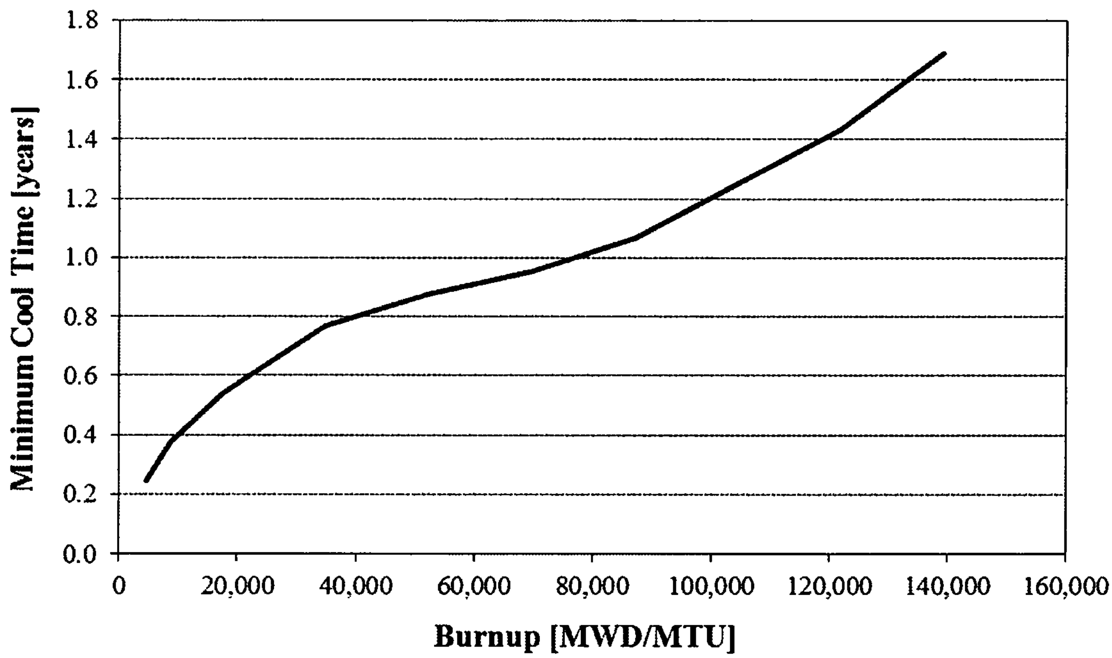


Figure 7.1-3 MEU MTR Fuel Basket Loading Guidelines for 30 W Uniform Loading

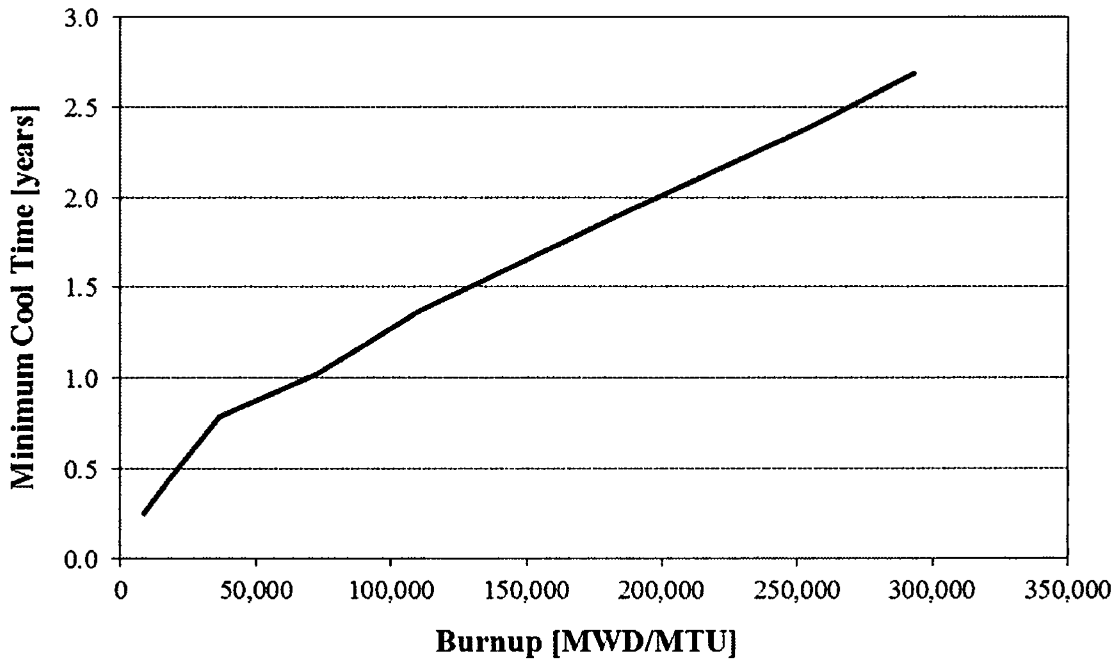


Figure 7.1-4 HEU MTR Fuel Basket Loading Guidelines for 30 W Uniform Loading – Maximum 380 grams ^{235}U

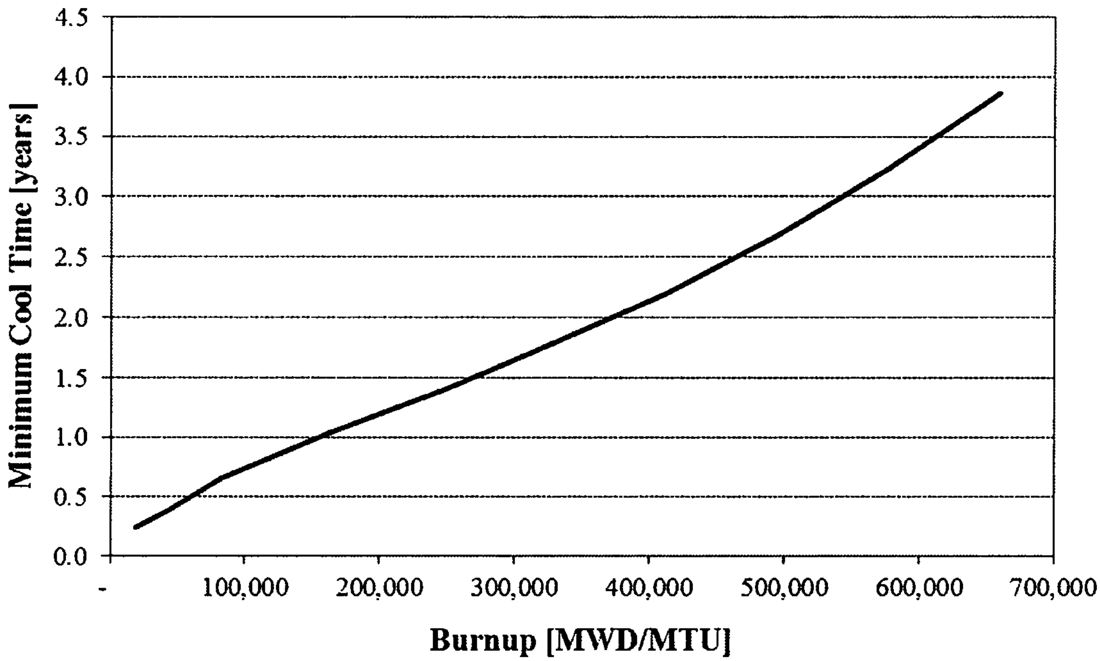


Figure 7.1-5 HEU MTR Fuel Basket Loading Guidelines for 30 W Uniform Loading – Maximum 460 grams ^{235}U

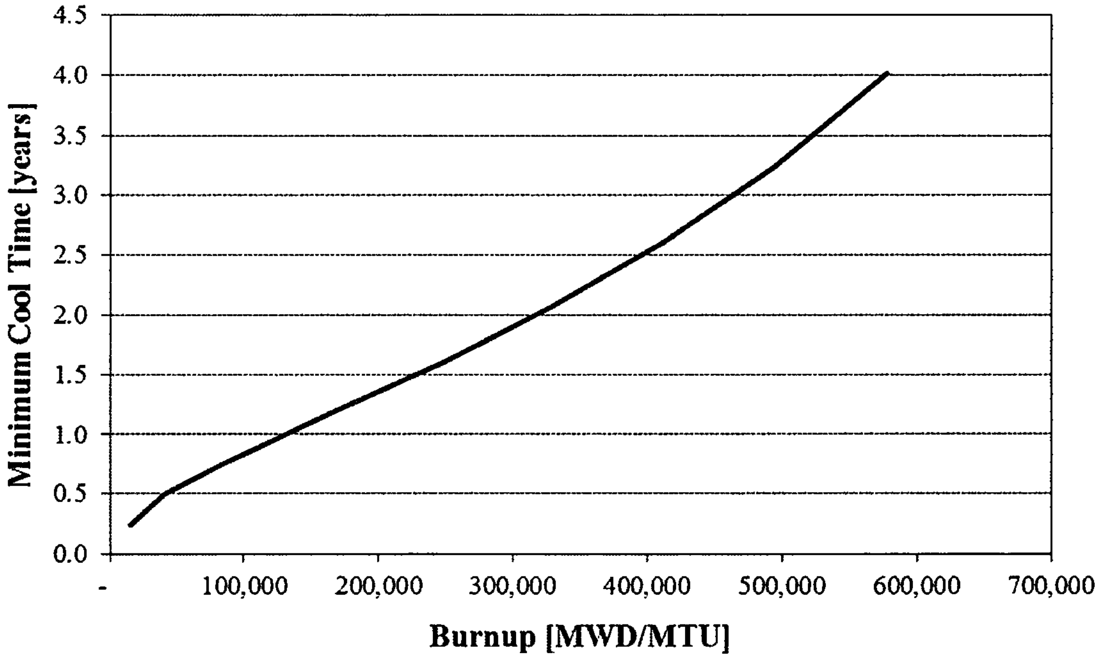


Figure 7.1-6 HEU MTR Fuel Basket Loading Guidelines for Preferential Loading – Maximum 380 grams ^{235}U

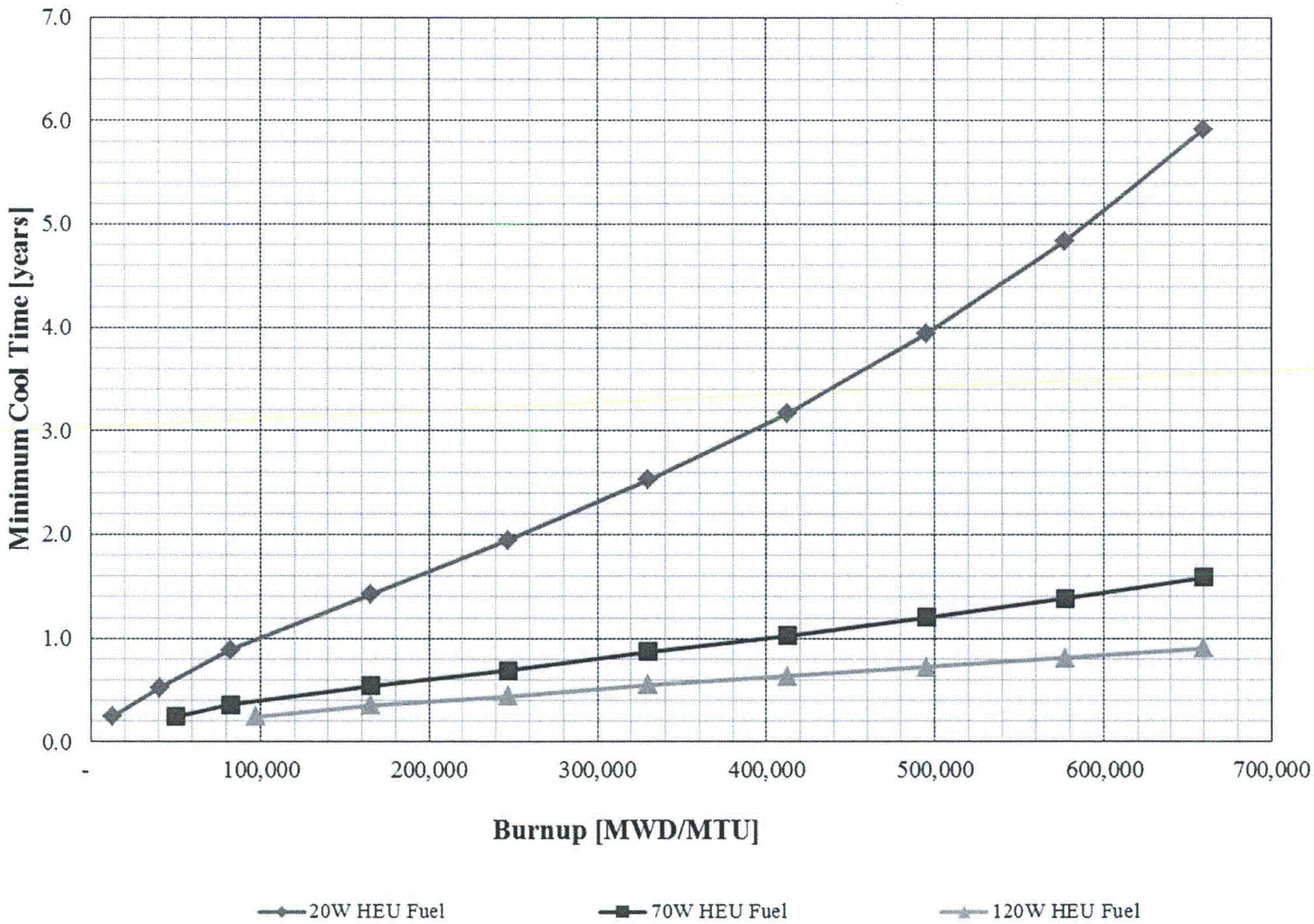


Figure 7.1-7 HEU MTR Fuel Basket Loading Guidelines for Preferential Loading – Maximum 460 grams ^{235}U

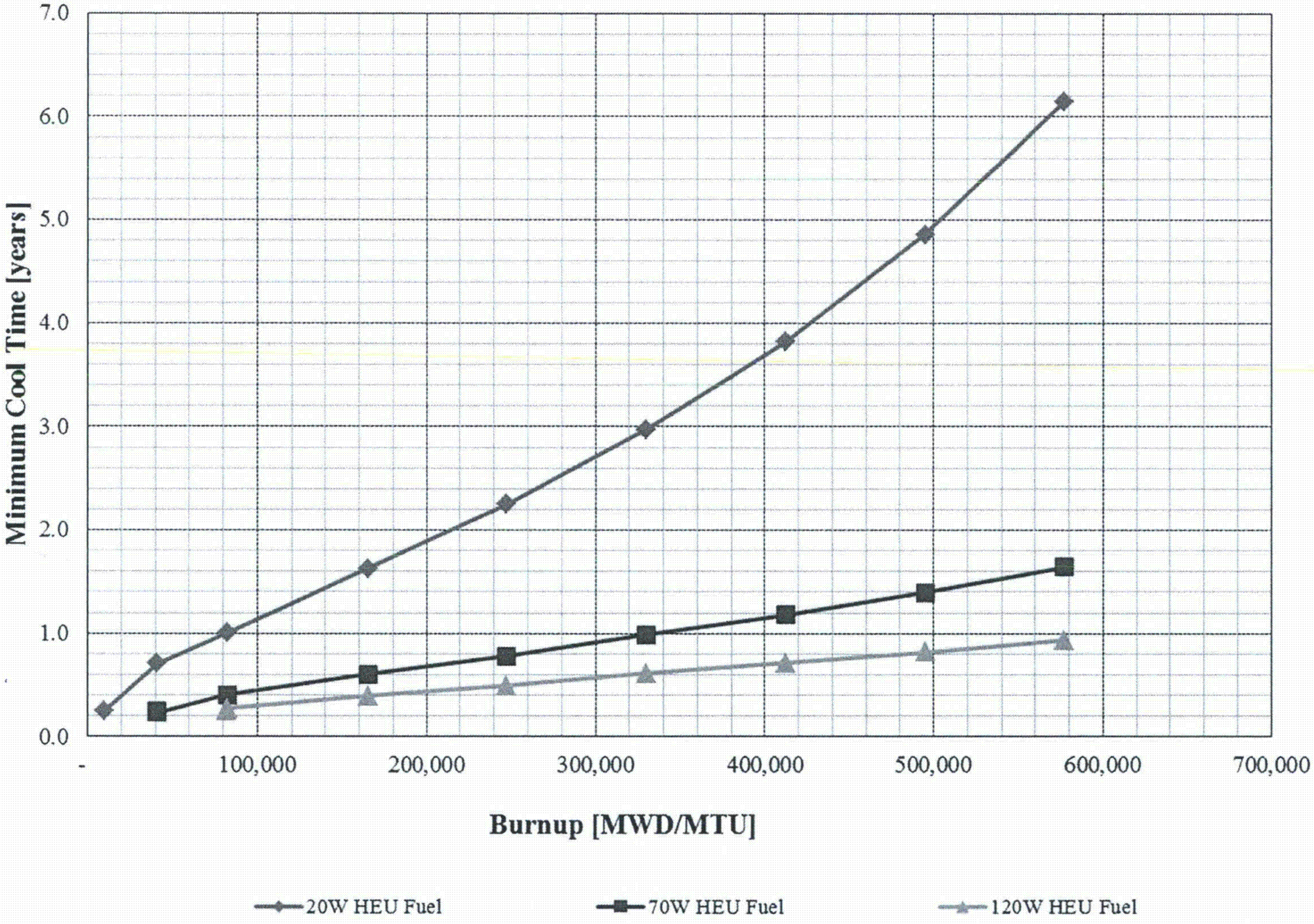


Figure 7.1-8 DIDO LEU Cooling Time vs. Fuel Burnup Basket Module Loading Guidelines for Uniform Loading

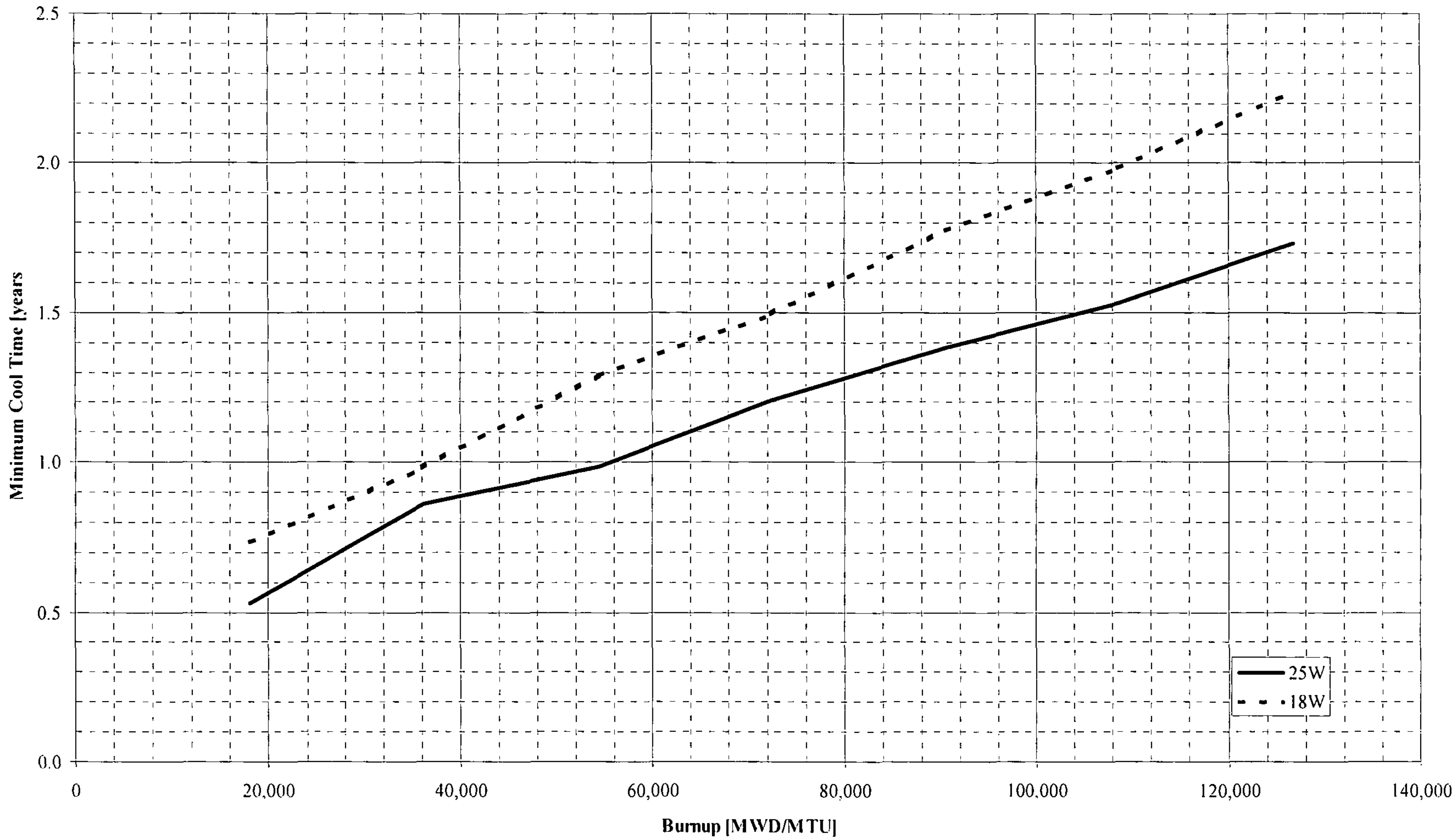


Figure 7.1-11 Bounding DIDO Element Minimum Cool Time vs. wt % ^{235}U Depletion

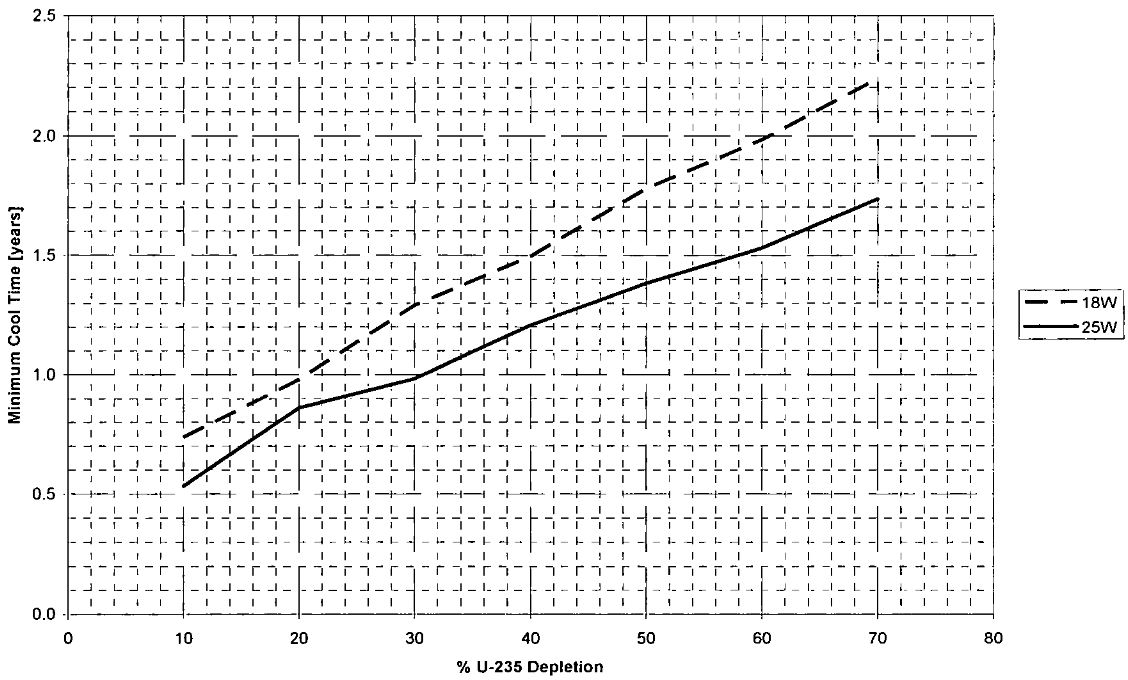


Figure 7.1-12 LEU MTR Fuel Basket Loading Guidelines for 30 W Uniform Loading - Maximum 640 grams ^{235}U

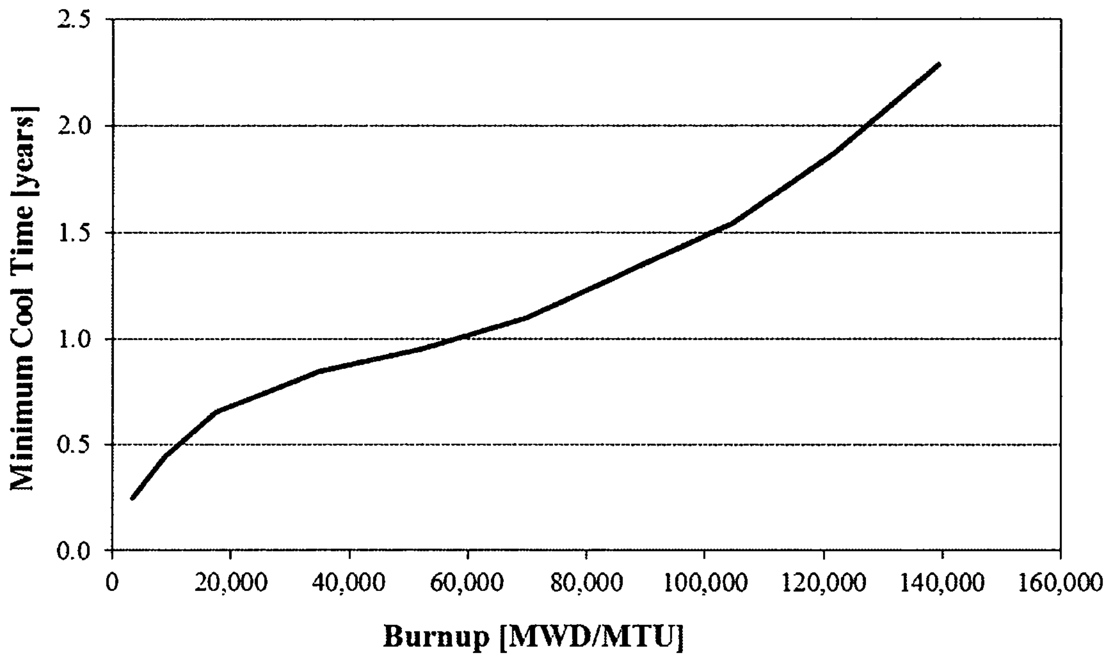
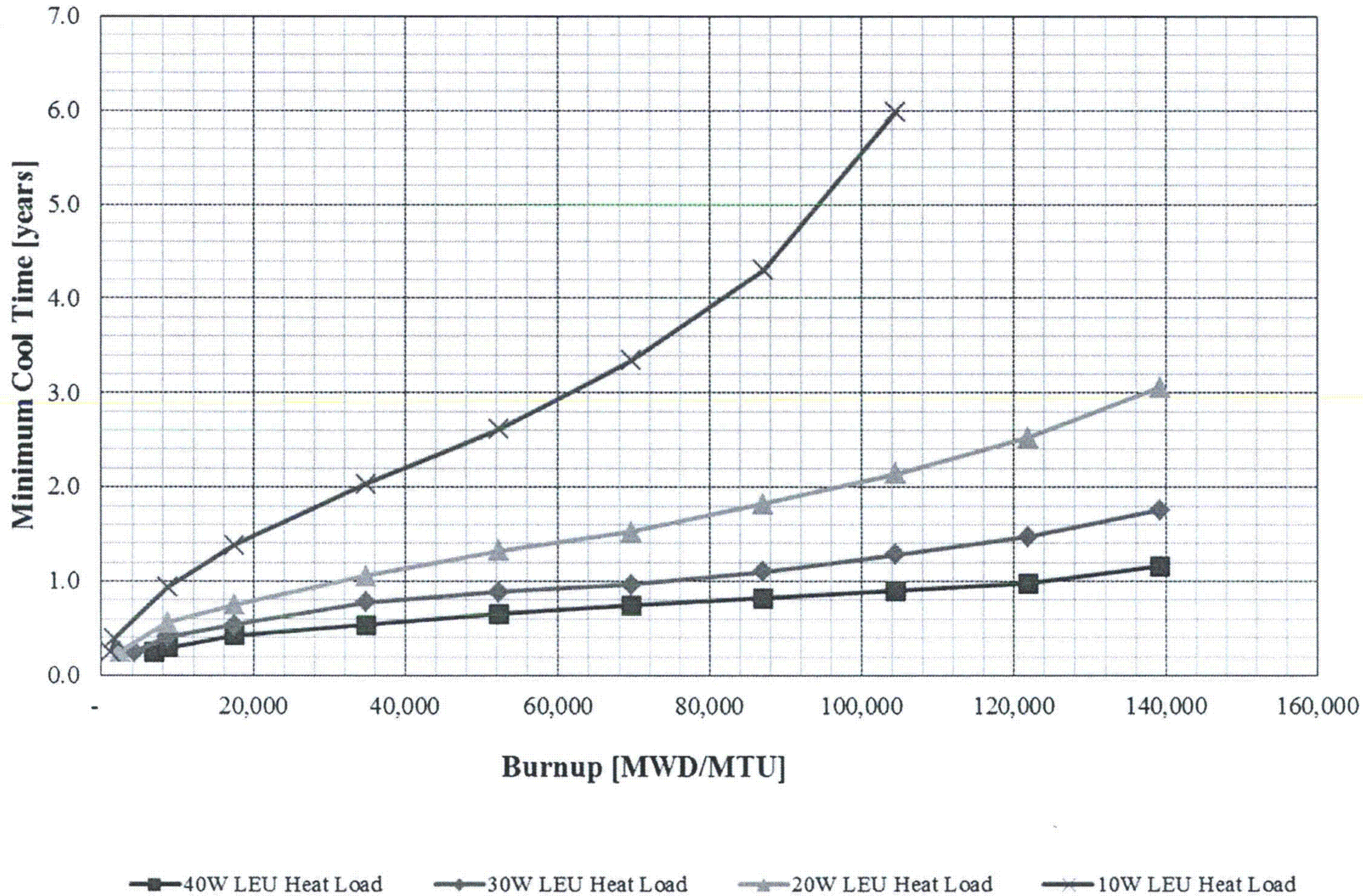


Figure 7.1-13 LEU MTR Fuel Basket Loading Guidelines for 40 W Preferential Loading - Maximum 490 grams ^{235}U



7.1.6 Procedure for Dry Loading of TRIGA Fuel Basket Modules and GA IFM Modules into the NAC-LWT Cask

This procedure presents the steps for dry loading, using a transfer cask, of the nonpoisoned or poisoned TRIGA fuel basket modules into the NAC-LWT. For transport, five TRIGA fuel basket modules, consisting of a top module, a base module, and three intermediate modules must be loaded into the NAC-LWT. An alternative loading option is available for the poisoned TRIGA basket modules. This configuration, Configuration 2, consists of 1 base module and 4 intermediate modules. A spacer attached to the underside of the NAC-LWT lid is used with Configuration 2. Each basket module consists of seven cells, a center cell, and six peripheral cells. The center cell of the nonpoisoned basket design is blocked and cannot be loaded. Each unblocked cell may contain up to four TRIGA fuel elements, or up to 16 TRIGA fuel cluster rods within a fuel rod insert placed into the cell prior to loading. The maximum decay heat load of any TRIGA fuel element is 7.5 watts, while the maximum decay heat load of a TRIGA fuel cluster rod is 1.875 watts. An alternative loading option is available for the General Atomics (GA) Irradiated Fuel Material (IFM) Fuel Handling Units (FHU). This configuration consists of one GA IFM top module and one GA IFM spacer. The GA IFM top module, based on the TRIGA basket design, has two canister storage tubes that hold the GA IFM FHU.

TRIGA fuel elements may be transported directly in the basket module cell, or in a sealed damaged fuel can (DFC). TRIGA fuel cluster rods may be transported within the fuel rod insert in a basket cell, or a sealed DFC. The sealed DFCs fit in a module cell. The sealed DFC holds up to two equivalent TRIGA elements as damaged fuel or fuel debris, or up to six equivalent TRIGA fuel cluster rods as damaged rods or fuel debris. Damaged TRIGA fuel and fuel debris are contained in sealed DFCs.

When loading TRIGA fuel elements directly into the basket cells of a TRIGA basket module, the fuel elements may be loaded with either 4 elements per cell, or one element per cell, without shoring. If a basket cell is loaded with 2 or 3 intact elements, dummy rods will be inserted as necessary to fill the remaining space in the cell.

Each nonpoisoned basket module may contain up to 24 TRIGA fuel elements for a total of 120 elements, up to 96 TRIGA fuel cluster rods for a total of 480 rods per basket assembly, or a mixed loading in separate cells of the basket module of TRIGA fuel elements and TRIGA fuel cluster rods.

For the loading of the following TRIGA fuel elements, a maximum of three intact fuel elements are authorized for loading in each cell of a nonpoisoned top or bottom basket module. A dummy TRIGA spacer tube, as shown on Drawing No. 315-40-085, shall be inserted into the open

position prior to fuel element loading to ensure that the maximum number of three TRIGA fuel elements is not exceeded:

- TRIGA Stainless Steel (SS) LEU fuel elements having > 169 g ^{235}U < 275 g ^{235}U; or
- TRIGA SS HEU fuel elements having > 138 g ^{235}U < 175 g ^{235}U

The licensee's approved fuel loading plan shall ensure compliance with all fuel loading restrictions.

Each poisoned basket module may contain up to 28 TRIGA fuel elements for a total of 140 elements, or up to 112 TRIGA fuel cluster rods for a total of 560 rods per basket assembly.

Damaged TRIGA fuel elements and cluster rods and fuel debris are required to be loaded into sealed DFCs. The sealed DFCs are provided in two lengths. The short sealed DFC may be used in the base or top basket module. The long sealed DFC may be used in only the top module. The sealed DFCs are vacuum dried prior to loading into a TRIGA fuel basket (see sealed DFC loading procedure in Section 7.1.7).

There are two separate GA IFM FHU designs. One FHU is designed to hold research reactor fuel and the other is designed to hold High-Temperature Gas-Cooled Reactor fuel pellets. Each FHU consists of a sealed inner canister within a sealed outer canister. Each FHU contains irradiated fuel materials as described in Chapter 1. When loading the GA IFM FHUs, each individual sealed FHU will be loaded separately into a single GA IFM basket. This single basket containing two GA IFM FHUs and a spacer will comprise the entire cask load. Loading of the GA IFM basket into the NAC-LWT cask will utilize the TRIGA dry configuration loading procedure that is described in the following paragraphs.

TRIGA fuel elements that can be loaded into the cask are limited to a maximum decay heat of 7.5 watts per element, as discussed in Section 1.2.3. The decay heat load of the element must be calculated, and verified to be equal to or less than 7.5 watts per element prior to loading. TRIGA fuel cluster rods that can be loaded into the cask are limited to a maximum decay heat of 1.875 watts per element, as discussed in Section 1.2.3 (by reference to Table 5.1.1). The decay heat load of the fuel cluster rod must be calculated, and verified to be equal to or less than 1.875 watts per element prior to loading.

The procedure for loading the package with TRIGA fuel in a dry configuration is as follows:

1. Perform a receipt inspection of the empty cask and trailer/ISO container, inspecting for transport damage.
2. Position the trailer in the designated cask unloading area. Set the trailer brakes and chock the wheels to prevent unintended movement. If site-specific conditions exist that require the trailer to move to allow the cask to be uprighted on its rotation

trunnions, release brakes and remove the chocks when required to complete uprighting operations. If an ISO container is used, it may be removed from the trailer and secured in the unloading area.

3. Remove the personnel barrier or the roof and roof cross-members from the ISO container.

   Note: Verify that the package nameplate displays the correct package identification number in accordance with the CoC.

4. Perform a Health Physics survey of the cask and adjacent surfaces of the trailer.

   Note: A receiving survey of the cask and transporter must be performed as soon as practicable after arrival at the site to assure compliance with 10 CFR 20, 10 CFR 71.87(i) and 10 CFR 71.47, and to assure timely reporting of any reportable noncompliance.

5. Remove the top and bottom impact limiters.
6. Remove the cask tie-down strap.
7. Using the lifting yoke with the guides removed, engage the lifting trunnions. Raise the cask to vertical by rotating the cask rotation sockets on the rear cask supports, moving the crane and/or trailer as required to keep the lift yoke engaged to the trunnions and the cask engaged in the rear supports. When the cask is fully vertical, lift the cask from the supports and remove it from the trailer/container.
8. Place the cask onto the dry loading station. Disengage the lifting yoke and move clear.
9. Visually inspect the neutron shield tank fill, drain and level inspection plugs for signs of neutron shield fluid leakage. If leakage is detected or suspected, verify shield tank fluid level and correct, as required.
10. Remove the vent and drain valve port covers. Prior to reinstallation of the port covers, carefully inspect the O-rings and, if the O-rings show any damage, replace them with approved spares. Ensure that the replacement O-rings are properly installed and seated. Visually inspect the valve quick-disconnect nipples and replace them, if necessary.

    Note: For Alternate B port covers, replace the metallic O-ring with an approved spare prior to reinstallation.

11. Remove closure lid bolts. Attach the lid lift slings to the closure lid. Remove the closure lid and set it on a support that is suitable for radiological control and for maintaining the cleanliness of the closure lid. Prior to reinstallation of the lid, carefully inspect the Teflon O-ring seal in the underside of the closure lid and, if it shows any damage, replace it. Remove the metallic O-ring and replace it with an approved spare. Ensure that the replacement O-rings are properly installed and seated. Inspect the lid bolts and replace any that are damaged.
12. Visually inspect the inner cavity for foreign material or damage. Install, or verify the presence of the proper drain tube and drain alignment ring.
13. Install the required dry transfer system components on the top of the cask.
14. Position the shielded transfer cask system components for fuel loading, as appropriate.

15. Identify the TRIGA fuel basket modules to be loaded. Modular baskets consisting of one base unit, three intermediate units, and one top unit, may be loaded into the cask cavity. The base unit must be the first unit loaded and the top unit must be the last unit loaded. The intermediate modules may be loaded in any of the other loading operations. If the poisoned basket Configuration 2 is used, ensure that the TRIGA spacer is bolted and torqued to 40 ft-lbs to the underside of the NAC-LWT lid. If TRIGA fuel cluster rods are to be transported, ensure that fuel rod inserts are placed into each cell location that will contain fuel cluster rods. For the GA IFM basket load, install the GA IFM spacer, shown on NAC drawing 315-40-123, prior to inserting the loaded GA IFM top module.

    Notes:
    a. When utilizing nonpoisoned TRIGA baskets, visually verify that the center blocking plate is welded in place on each basket module.
    b. When utilizing poisoned TRIGA baskets, visually inspect each cell of each basket module for foreign material or damage and verify the presence of the neutron poison material (borated stainless steel plates) as shown on NAC Drawings 315-40-080, -081, and -082.
    c. When utilizing the GA IFM top module, follow the TRIGA loading procedure below, noting that this is a single basket load.

16. Identify the TRIGA fuel elements and TRIGA fuel cluster rods to be loaded into each fuel basket module. Fuel elements and rods to be loaded into each basket module shall comply with the applicable approved content conditions specified in Condition 5.(b)(1) and 5.(b)(2) of CoC No. 9225.

    If a top or bottom basket module cell is to be loaded with a TRIGA LEU SS fuel element having > 169 g ^{235}U, or a TRIGA HEU SS fuel element > 138 g ^{235}U, a dummy TRIGA spacer tube, as shown on NAC Drawing 315-40-085, shall be preinstalled in the module cell prior to fuel loading to prevent inadvertent loading of more than three high ^{235}U content TRIGA fuel elements per cell. High ^{235}U content TRIGA fuel elements are further restricted to loading in the top and bottom basket modules of a nonpoisoned basket only.

17. Perform an independent verification that the TRIGA fuel elements, fuel cluster rods and dummy TRIGA spacer tubes loaded in the basket module comply with the approved loading plan and the CoC content conditions including fuel parameters, heat load, enrichment, minimum cooling period, etc.
18. Load a TRIGA fuel basket module into the shielded transfer cask.
19. Place the shielded transfer cask containing the loaded basket module onto the dry transfer system components positioned on the top of the cask.
20. Lower the fuel basket from the shielded transfer cask into the shipping cask.
21. Repeat the loading and transfer of loaded basket modules until the approved cask loading plan is completed.
22. Install the closure lid onto the cask. Visually verify that the lid is properly seated.
23. Remove the dry transfer system components from the top of the cask.
24. Install and tighten the 12 closure bolts to 260 ± 20 ft-lbs in three passes, using the torque sequence stamped on the closure lid.

25. Connect a gas supply line to the vent valve and the drain line to the drain valve.
26. Open the air, nitrogen or helium gas supply valve and pressurize the cask cavity (< 30 psig) to force any residual water out the drain line. Continue to supply pressurized gas to the cask for a minimum of five minutes after the last residual free water discharges from the drain. Remove the drain and gas supply lines and attach a vacuum drying system (VDS) to the vent.
27. Evacuate the cask cavity to less than or equal to 10 torr (13 mbar) and continue vacuum pumping for a minimum of 15 minutes.
28. At the end of the vacuum pumping period, isolate the cask cavity from the vacuum pump and stop the vacuum pump. Monitor the cask cavity pressure for a minimum of ten minutes. If the pressure rise is less than 5 torr (6.7 mbar), the cavity is verified as dry of free water. If pressure rise is >5 torr (6.7 mbar), repeat vacuum drying until the dryness verification results are satisfactory.
29. Backfill the cask cavity with helium to 0 psig (1 atmosphere, absolute), +1, -0 psi and disconnect the VDS from the vent valve.
30. Perform a helium leakage test of the closure lid containment O-ring using a Helium Mass Spectrometer Leak Detector (He MSLD) in accordance with the procedural requirements of Section 8.1.3.1, Steps 3 through 10.
31. Install the vent and drain alternate port covers and torque the bolts to 100 ±10 inch-pounds.
32. If an alternate port cover containment O-ring seal was replaced, perform a helium leakage test on the affected port cover using a He MSLD in accordance with the requirements of 8.1.3.2.2.
33. If the alternate port cover containment seal was inspected and accepted for reuse, perform a gas pressure drop leakage test on the affected port cover as follows.
    a. Install a pressure test fixture to the port cover test port including a calibrated pressure gauge with a minimum sensitivity of 0.25 psi.
    b. Pressurize the port cover seal annulus to 15 psig, +1, -0 psi.
    c. Isolate the gas supply and observe the pressure gauge for a minimum of five minutes.
    d. The acceptance criterion for the test is no measurable drop in pressure during the minimum test time. An acceptable test assures that the minimum assembly verification leakage test sensitivity is achieved.

    Note: Alternate B port covers, if used, shall have a helium maintenance leakage rate test performed to confirm a leaktight containment closure. Install the Alternate B port cover and perform the maintenance leakage rate test per the requirements of Section 8.1.3.3.2.
34. Decontaminate the cask surfaces. Survey the cask for surface contamination and radiation dose rates.

    Note: Ensure compliance with 10 CFR 71.87(i) and 10 CFR 71.47.
35. Engage the cask lifting yoke to the lifting trunnions.
36. Lift the cask and position the cask rotation sockets in the rear rotation trunnions of the rear support structure. Carefully lower the cask to the horizontal transport orientation

resting on the front saddle by moving the crane and/or the trailer as required to maintain cask engagement to the rear supports.

37. Disengage the lifting yoke from the lifting trunnions and remove it from the area. Install the cask tie-down strap. Install the top and bottom impact limiters. Install a TID to an attachment point on the top impact limiter.
38. Install ISO container bracing and lid, or personnel barrier.
39. Complete radiation and contamination surveys of the external surfaces of the package and record the data. Ensure removable contamination and radiation dose rate survey results comply with the limits specified in 10 CFR 71.87(i) and (j).
40. Measure the dose rate in millirems per hour at one meter from the package surface to determine the Transport Index (TI). Indicate the TI on the Radioactive Material labels applied to the package in accordance with 49 CFR 172, Subpart E.
41. Determine the appropriate Criticality Safety Index (CSI) assigned to the package contents in accordance with the CoC, and indicate the correct CSI on the Fissile Material label applied to the package per 49 CFR 172, Subpart E.
42. Apply appropriate placards to the transport vehicle in accordance with 49 CFR 172, Subpart F.
43. Complete the shipping documents and provide the carrier with instructions regarding the requirements for maintaining an exclusive use shipment.

7.1.7 Procedure for Loading TRIGA Damaged Fuel or Fuel Debris into a TRIGA Sealed Damaged Fuel Can (DFC)

1. Examine the sealed damaged fuel can (DFC) body and inspect for damage. Verify that the lid sealing surface is clean and free of defects. Visually verify that the drain plug seal is installed and the drain plug is partially threaded into the drain plug adapter to allow for draining.
2. Lower the DFC into the pool and position it for fuel loading.
3. Load the damaged TRIGA fuel cluster rods or fuel debris into the DFC. Verify that no more than the equivalent of 2 design base fuel elements, or 6 fuel cluster rods, as damaged fuel or fuel debris are loaded into the sealed DFC as specified in the CoC. Visually verify that there is no debris in the lid sealing surface and thread areas.
4. Examine the DFC lid and inspect for damage. Visually verify that the sealing surface is clean and free of defects. Lubricate the lid bolts, install the lid seal and verify that the lid valve is in the open position and the valve lock set screw is retracted.
5. Attach the testing hose to the lid test connection and ensure that the fitting is properly seated.
6. Install the lid and torque the lid bolts to 150 ± 10 inch-pound.

   Note: Torque any two diametrically opposed bolts first, then torque the remaining two bolts. Complete the torque sequence by verifying the torque of all four bolts in a clockwise direction.

7. Pressurize the sealed DFC with air or helium to 5-15 psig to remove the water. Continue the purge for at least 5 minutes after bubbles appear from the base of the DFC.
8. Access and torque the DFC drain plug to 50 ± 10 inch-pound.
9. Evacuate the DFC to a pressure below 10 torr (13 mbar) and continue vacuum pumping for 10 minutes.
10. Stop and isolate the vacuum pump and monitor the DFC vacuum pressure for a minimum of 10 minutes. If the pressure rise is <5 torr (6.7 mbar) in 10 minutes, the DFC is verified as dry of free water. If the pressure rise is >5 torr (6.7 mbar) in 10 minutes or less, the DFC is not considered dry of free water. Repeat vacuum drying and pressure rise testing until the dryness verification results are satisfactory.
11. Backfill the DFC with helium to a pressure of 1 atmosphere (0 psig), +1, -0 psi.
12. Shut and lock the lid diaphragm valve. The DFC is now sealed, dried and backfilled.
13. Disconnect the testing hose from the lid test connection.
14. The sealed DFC is now ready for loading into a TRIGA basket module.

7.1.8 Procedure for Wet Loading of PWR/BWR Fuel Rods or TPBARs into the PWR/BWR Transport Canister

For the shipment of PWR and BWR fuel rods and nonfuel-bearing components (e.g., PWR guide tubes or BWR water rods), the PWR/BWR transport canister has three configurations: sealed canister, screened canister, and free-flow canister. All three canister configurations may be used to contain either intact or damaged fuel rods, or a combination of both damaged and intact fuel rods. The loaded transport canisters are loaded into the NAC-LWT cask containing a LWT PWR basket assembly with an appropriate bottom weldment spacer. For transport canisters containing any damaged fuel rod contents, a can and an insert spacer are required to be installed and bolted to the underside of the closure lid to limit the axial movement of the canister. The use of the can and insert spacer requires the use of the PWR basket assembly fitted with the Alternate B spacer. Transport canisters containing intact rods may be placed in any of the three types of PWR basket assemblies. For the transport of a mixed loading of PWR or BWR fuel rods with nonfuel-bearing components, a modified 5×5 insert with 21 fuel rod locations and a larger tube position for the larger diameter nonfuel-bearing component (up to a nominal diameter of 1.3 inches) is required to be used with the PWR/BWR transport canister.

For the shipment of TPBARs, only the screened or free flow PWR/BWR Rod Transport Canister containing the 5 × 5 rod insert may be used.

Upon completion of loading the transport canister, the canister and the insert spacer are loaded, either together or individually, into the basket assembly in a manner similar to loading a PWR assembly.

1. If the transport canister is to be shipped in a sealed configuration, verify the five drain plugs are installed and torqued to 50 ± 2 foot-pound. If the transport canister is to be shipped in the free flow configuration, verify the five drain plugs are not installed. If the transport canister is to be shipped in the screened configuration, verify the screened plugs are installed and torqued to 50 ± 2 foot-pound in the bottom of the canister.
2. Lower the transport canister (and insert) into the fuel pool for loading.
3. Load the spent fuel rods into the transport canister in accordance with site-specific procedures. Separate failed fuel rod capsules may be used to contain either intact or damaged fuel rods within the canister. The capsules are intended to limit dispersal of radioactive material to the canister internals. Visually upon completion of loading, verify that there is no debris on the lid sealing surface and threaded areas.
4. Using the appropriate lid (sealed, screened or free-flow), examine and inspect for damage. Visually verify that the sealing surface is clean and free of defects. Lubricate the lid bolts.
5. Install the lid and torque the lid bolts to 35 ± 5 inch-pound.

   Note: Torque any two diametrically opposed bolts first, then torque the remaining six bolts. Complete the torque sequence by verifying the torque of all eight bolts in a clockwise direction.
6. If the transport canister is being shipped in either the screened or free-flow configuration, it is now ready for shipment. To ship PWR and BWR rods and nonfuel-bearing components, the transport canister shall be loaded into the NAC-LWT cask in accordance with Section 7.1.1, Procedures for Wet Loading of LWR Fuel Assemblies and Canistered LWR Fuel Rods. To ship TPBARs, the transport canister shall be loaded in accordance with Section 7.1.9, Procedure for Wet Loading of TPBAR Consolidation Canister or PWR/BWR Rod Transport Canister into the NAC-LWT Cask. If the transport canister is being shipped in the sealed configuration, complete steps 7-14 of this section.
7. Connect vent and drain lines to the respective quick-disconnect fittings on the sealed transport canister lid. The drain hose discharge should be directed to the plant drain system for radiological wastewater or another appropriate collection point.
8. Pressurize and purge the transport canister using helium. (Caution do not exceed 25 psig. while dewatering the transport canister.) Secure the purge once no fluid is observed exiting the discharge for at least 10 minutes.
9. Connect the vent line to a suitable vacuum pump. Maintain connection of drain line to the can, but isolate the line to allow vacuum drying of the sealed failed fuel can.
10. Evacuate the can to a pressure below 10 torr (13 mbar) and continue vacuum pumping for 10 minutes.
11. Stop and isolate the vacuum pump and monitor the cask cavity vacuum pressure for a minimum of 10 minutes. If the pressure rise is less than 5 torr (6.7 mbar), the cavity is verified as dry of free water. If the pressure rise is >5 torr (6.7 mbar), repeat vacuum drying until the dryness verification results are satisfactory.
12. Backfill the transport canister cavity with helium to 1 atmosphere (absolute), +1, -0 psi.

13. Disconnect the vent and drain lines from the transport canister.
14. The sealed transport canister is now ready for shipment and may be loaded into the NAC-LWT cask in accordance with Section 7.1.1.

7.1.9 Procedure for Wet Loading of TPBAR Consolidation Canister or PWR/BWR Rod Transport Canister into the NAC-LWT Cask

This section describes the procedures for loading the NAC-LWT with a TPBAR consolidation canister or with a screened or free flow PWR/BWR Rod Transport Canister. The consolidation canister can contain up to 300 TPBARs, two of which may be prefailed. Dunnage (i.e., spacer grids, stainless steel tubes, etc.) may be used in consolidation canisters containing fewer than 300 TPBARs. The total weight and volume of the contents (i.e., dunnage and reduced number of TPBARs) must be less than, or equal to, the weight and volume of the full load of 300 TPBARs.

The PWR/BWR Rod Transport Canister may contain up to 25 TPBARs.

Appropriate radiological controls and procedures addressing tritium shall be utilized by the licensee, including appropriate personnel monitoring for tritium exposure.

NAC-LWT casks to be used to transport the TPBAR consolidation canisters shall be configured as shown on Drawing No. 315-40-128, including Alternate B port covers. NAC-LWT casks to be used to transport a PWR/BWR Rod Transport Canister shall be configured as shown on Drawing No. 315-40-104, Assembly 95, including Alternate B port covers.

1. Perform a receiving survey of the empty cask and inspect for damage. Verify, by cask serial number, that the cask is approved for TPBAR shipment.
2. Position a trailer in the designated cask unloading area. Set the trailer brakes and chock the wheels to prevent unintended movement. If site-specific conditions exist that require the trailer to move to allow the cask to be uprighted on its rotation trunnions, release brakes and remove the chocks when required to complete uprighting operations. If an ISO is used, it may be removed from the trailer and secured in the unloading area.
3. Remove the roof from the ISO container and open the front and rear ISO doors. Remove roof cross-members, if installed.

   Note: Verify that the package nameplate displays the package identification number, USA/9225/B(M)-96, as required by the CoC for TPBAR contents.
4. Perform a Health Physics survey of the cask and adjacent surfaces of the trailer.

   Note: A receiving survey of the cask and transporter must be performed as soon as practical after arrival at the site to assure compliance with 10 CFR 71.87(i) and 10 CFR 71.47, and to assure timely reporting of any reportable noncompliance.
5. Remove the top and bottom impact limiters.
6. Remove the cask tie-down strap.
7. Using the lifting yoke with the guides removed, engage the lifting trunnions. Raise the cask to vertical by rotating the cask rotation sockets on the rear cask supports,

moving the crane and/or trailer as required to keep the lift yoke engaged to the trunnions and the cask engaged in the rear supports. When the cask is fully vertical, lift the cask from the supports and remove it from the trailer/container.

8. Place the cask in the decontamination pit or other designated area. Disengage the lifting yoke. Clean cask surfaces of road dirt as required for entry into the spent fuel pool.

9. Visually inspect the neutron shield tank fill, drain and level inspection plugs for signs of neutron shield fluid leakage. If leakage is detected, verify shield tank fluid level and correct, as required.

10. Remove the Alternate B vent and drain valve port covers. Prior to reinstallation of the port covers, replace the metallic O-ring seal with an approved spare and inspect the Viton® O-ring seal for each port cover. If the Viton® O-ring shows any damage, replace it. Ensure that the replacement O-rings are properly installed and seated. Store the port covers to protect the seal surfaces. Visually inspect the valved quick-disconnect nipples and replace them, if necessary.

11. Remove closure lid bolts. Attach the lid lift slings to the closure lid. Remove the closure lid and set it on a support that is suitable for radiological control and for maintaining the cleanliness of the closure lid. Prior to reinstallation of the lid, carefully inspect the Teflon O-ring seal in the underside of the closure lid. If the O-ring shows any damage, replace it. Remove the metallic O-ring and replace it with an approved spare. Ensure that the replacement O-rings are properly installed and seated. Inspect the lid bolts and replace any that are damaged. Ensure that the TPBAR spacer is installed on the bottom of the cask lid for consolidation canister transports and not damaged when the lid is set down.

12. Visually inspect the inner cavity for foreign material or damage. Install or verify the presence of the standard drain tube and the TPBAR basket assembly (Drawing No. 315-40-10, Assembly 96 or Assembly 95) for loading of the consolidation canister; or the standard drain tube, TPBAR basket assembly (Drawing No. 315-40-10, Assembly 95), and the PWR Insert (Drawing No. 315-40-105, Assembly 99) for the loading of the PWR/BWR Rod Transport Canister containing TPBARs.

    Note: The PWR inset may be installed during the placement of the loaded PWR/BWR Rod Transport Canister into the NAC-LWT cask.

13 Fill the cask cavity with clean water. Install lift yoke arm guides and remote actuation components on the cask lifting yoke.

14. Engage the cask lifting yoke with the cask lifting trunnions and pick up the cask. Carefully lower the cask to the bottom of the cask loading area while spraying the cask down with clean water.

15. Disengage the lifting yoke from the cask and remove the yoke from the pool.

16. Identify the TPBAR consolidation canister or the PWR/BWR Rod Transport Canister containing TPBARs to be loaded.

17. Pick up the consolidation canister or the PWR/BWR Rod Transport Canister using the required grapple system.

18. Position the container over the cask and then carefully lower it into the cask to avoid damage to the cask sealing surfaces. Orient the consolidation canister bail so that it is

aligned with the drain tube location. Confirm that the container is fully seated, then release and raise the grapple to the full up position.

19. Position the cask lifting yoke over the cask closure lid. Attach the slings to the closure lid and cask lifting yoke. Lower the yoke over the cask.
20. Position the closure lid over the cask and slowly lower it into place. For the consolidation canister, ensure the bail is properly aligned to the TPBAR spacer on the bottom of the lid. Use the cask and lid match marks as guides to properly align the lid. Visually confirm that the closure lid is seated.
21. Lower the cask handling yoke to slack the closure lid cables. Engage the lift yoke to the lifting trunnions and begin lifting.

    Note: Visually verify the yoke engagement before lifting the cask.
22. Raise the cask until the lid is slightly above the surface of the pool. At the option of the licensee/user, a number of closure lid bolts (4 to 12) may be installed hand tight.
23. Raise the cask clear of the pool, rinsing the yoke and cask with clean water.
24. Transfer the cask to the decontamination pit or other work area. Remove the yoke and lid lift slings.
25. Install and tighten the 12 closure lid bolts to 260 ± 20 ft-lb in three passes, using the torque sequence stamped on the closure lid.
26. At the option of the licensee/user, a 25 to 50 gallon clean water flush of the cask cavity may be performed by connecting a valved clean water line to the drain valve and a valved drain line to the vent valve. After the cavity flushing is completed, if performed, disconnect the water supply and drain lines.
27. Connect a gas supply line to the vent valve and the drain line to the drain valve.
28. Open the air, nitrogen or helium gas supply valve and pressurize the cask cavity (<30 psig) to force out the water. Continue to supply pressurized gas to the cask for a minimum of five minutes after the last residual free water discharges from the drain line. Remove the drain and gas supply lines and attach a vacuum drying system (VDS) to the cask vent valve.
29. Evacuate the cask cavity to a vacuum pressure of less than 10 torr (13 mbar) and continue vacuum pumping for a minimum of 15 minutes.
30. At the end of the vacuum pumping period, isolate the cask cavity from the vacuum pump and stop the pump. Monitor the cask cavity pressure for a minimum of ten (10) minutes. If the pressure rise is less than 5 torr (6.7 mbar), the cavity is verified as dry of free water. If the pressure rise >5 torr (6.7 mbar), repeat vacuum drying until the dryness verification results are satisfactory.
31. Backfill the cask cavity with helium to 0 psig (1 atmosphere, absolute), +1, -0 psi. Disconnect the VDS.
32. Perform the helium leakage test of the closure lid containment O-ring using a Helium Mass Spectrometer Leak Detector (He MSLD) in accordance with the requirements of Section 8.1.3.1, Steps 3 through 10.
33. Install and helium leakage test the Alternate B vent and drain port covers to leaktight criteria in accordance with Section 8.1.3.3.2.

34. Decontaminate the cask. Survey the cask for surface contamination and radiation dose rates.

    Note: Ensure compliance with 10 CFR 71.87(i) and 10 CFR 71.47.

35. Remove lift yoke arm guides. Engage the cask lifting yoke to the lifting trunnions.
36. Lift the cask and position the cask rotation sockets in the rear rotation trunnions of the rear support structure. Carefully lower the cask to the horizontal transport orientation resting on the front saddle by moving the crane and/or trailer, as required, to maintain cask engagement to the rear supports.
37. Disengage the cask lifting yoke from the cask lifting trunnions and remove it from the area.
38. Install the cask tie-down strap. Install the top and bottom impact limiters.
39. Install a TID to an attachment point of the top impact limiter.
40. Install roof cross-members, close ISO container doors, and replace ISO container roof.
41. Complete radiation and contamination surveys of the external surfaces of the package and record the data. Ensure removable contamination and radiation dose rate survey results comply with the limits specified in 10 CFR 71.87(i) and (j).
42. Measure the dose rate in millirems per hour at one meter from the package surface to determine the Transport Index (TI). Indicate the TI on the Radioactive Material labels applied to the package in accordance with 49 CFR 172, Subpart E.
43. Determine the appropriate Criticality Safety Index (CSI) assigned to the package contents in accordance with the CoC, and indicate the correct CSI on the Fissile Material label applied to the package per 49 CFR 172, Subpart E.
44. Apply appropriate placards to the transport vehicle in accordance with 49 CFR 172, Subpart F.
45. Complete the shipping documents and provide the carrier with instructions regarding the requirements for maintaining an exclusive use shipment.

7.1.10 Procedure for the Dry Loading of PULSTAR Fuel Into the NAC-LWT Cask

This section describes the procedures for loading the NAC-LWT cask with intact PULSTAR fuel assemblies, intact PULSTAR fuel rods in fuel rod inserts, and intact or damaged PULSTAR fuel assemblies, fuel rods, fuel debris, and nonfuel components of PULSTAR fuel assemblies in either sealed or screened PULSTAR cans. Up to 28 PULSTAR fuel assemblies, rod inserts, and sealed or screened cans can be loaded in the 28 MTR (four module × seven cells/module) basket assembly. The 28 MTR basket assembly consists of a base module, two intermediate modules, and a top module.

Damaged PULSTAR fuel assemblies, damaged fuel rods, fuel debris, and nonfuel components of fuel assemblies are required to be loaded in either a sealed failed fuel or screened PULSTAR can. Intact PULSTAR fuel rods may be loaded into either one of the cans at the option of the

licensee. The PULSTAR cans are limited to being loaded in any cell in either the top or the base module. The top and base basket modules can also contain intact PULSTAR fuel assemblies and fuel rod inserts containing intact PULSTAR fuel rods.

The NAC-LWT cask will be loaded dry, utilizing a transfer cask for loading each of the four basket modules. The basket modules will be preloaded with the PULSTAR fuel contents. The damaged fuel cans will be preloaded, closed, drained and dried, if applicable, prior to loading in either the top or base basket module. The PULSTAR cans shall be loaded and prepared for transport in accordance with the applicable steps of Section 7.1.7.

The NAC-LWT dry PULSTAR fuel loading and preparation for transport procedures are as follows.

1. Perform a receipt inspection of the empty cask and trailer/ISO container, inspecting for transport damage.
2. Position the trailer in the designated cask unloading area. Set the trailer brakes and chock the wheels to prevent unintended movement. If site-specific conditions exist that require the trailer to move to allow the cask to be uprighted on its rotation trunnions, release brakes and remove the chocks when required to complete uprighting operations. If an ISO container is used, it may be removed from the trailer and secured in the unloading area.
3. Remove the lid/top of the ISO container and remove any bracing.

   Note: Verify that the package nameplate displays the correct package identification number in accordance with the CoC.
4. Perform a Health Physics survey of the cask and adjacent surfaces of the trailer.

   Note: A receiving survey of the cask and transporter must be performed as soon as practical after arrival at the site to assure compliance with 10 CFR 71.87(i) and 10 CFR 71.47, and to assure timely reporting of any reportable noncompliance.
5. Remove the top and bottom impact limiters.
6. Remove the cask tie-down strap.
7. Using the lifting yoke with the guides removed, engage the lifting trunnions. Raise the cask to vertical by rotating the cask rotation sockets on the rear cask supports, moving the crane and/or trailer as required to keep the lift yoke engaged to the trunnions and the cask engaged in the rear supports. When the cask is fully vertical, lift the cask from the supports and remove it from the trailer/container.
8. Place the cask into the dry loading station.
9. Disengage the lift yoke.
10. Visually inspect the neutron shield tank fill, drain and level inspection plugs for signs of neutron shield fluid leakage. If leakage is detected or suspected, verify shield tank fluid level and correct, as required.

11. Remove the vent and drain port covers. Prior to reinstallation of the port covers, carefully inspect the port cover O-ring seals and, if the O-rings show any damage, replace them with approved spares. Ensure that the replacement O-rings are properly installed and seated. Visually inspect the vent and drain quick-disconnect nipples and replace them, if necessary.

    Note: For Alternate B port covers, replace the metallic O-ring with an approved spare prior to reinstallation.

12. Remove closure lid bolts. Attach the lid lift slings to the closure lid. Remove the closure lid and set it on a support that is suitable for radiological control and for maintaining the cleanliness of the closure lid. Prior to reinstallation of the lid, carefully inspect the Teflon O-ring seal in the underside of the closure lid. If the O-ring shows any damage, replace it. Remove the metallic O-ring and replace it with an approved spare. Ensure that the replacement O-rings are properly installed and seated. Inspect the lid bolts and replace any that are damaged.
13. Visually inspect the cask cavity for foreign material or damage. Clean as necessary. Install or verify the presence of a correct drain tube assembly including alignment ring.
14. Install the required dry transfer system components to the top of the cask.
15. Position the shielded transfer cask components for basket module loading, as appropriate.
16. Identify the PULSTAR fuel assemblies, fuel rod holders, and fuel cans to be loaded, and verify that the PULSTAR fuel contents comply with the authorized content, heat load and quantity conditions of the CoC. Four basket modules (e.g., one base module, two intermediate modules, and a top module) constitute the 28 MTR basket assembly. Spacers will be used as provided to position the PULSTAR fuel contents, as required.
17. Each module is capable of containing up to seven intact fuel assemblies, fuel rod inserts or a PULSTAR fuel can. Fuel cans are restricted to being loaded into the top and base modules, where the cans may be loaded with intact fuel assemblies or fuel rod holders without loading preference. There are no limitations on loading location for intact fuel assemblies or fuel rod holders in any of the four basket modules.

    The base module is loaded into the cask first, followed by the two intermediate modules and the top module is loaded last.

18. Load the shielded transfer cask with the loaded base basket module.
19. Place the shielded transfer cask containing the base module unit onto the dry transfer system components positioned on the top of the cask.
20. Lower the fuel basket from the transfer cask into the NAC-LWT cask cavity.
21. Repeat the loading and transfer of loaded basket modules until the approved cask loading plan is completed.
22. Install the closure lid onto the cask using the dry transfer system. Visually verify that the lid is properly seated.
23. Remove the dry transfer cask system components from the top of the cask.