"designated original" 71-9225

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May 22, 2007

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

Attn: Document Control Desk

Subject: Submittal of a Supplement to the Request for an Amendment of Certificate of Compliance (CoC) No. 9225 for the NAC-LWT Cask to Incorporate Various Changes to the Authorized MTR Fuel Contents (Reference 3)

Docket No. 71-9225

Reference:
1. Model No. NAC-LWT Package, CoC No. 9225, Revision 43, U.S. Nuclear Regulatory Commission (NRC), December 15, 2006
2. Safety Analysis Report (SAR) for the NAC Legal Weight Truck Cask, Revision 37, NAC International, June, 2005, Including Supplements Dated December 15, 2005; April 17, May 26, June 9 and 15, August 18 and 22, and October 12, 2006
3. Submittal of a Request for an Amendment of Certificate of Compliance (CoC) No. 9225 for the NAC-LWT Cask to Incorporate Various Changes to the Authorized MTR Fuel Contents, NAC International, May 1, 2007

As a result of a meeting with the NRC Spent Fuel Storage and Transportation staff on May 14, 2007, NAC International (NAC) herewith submits a supplement to the request for approval of an Amendment (Reference 3) to incorporate the following:

- Use of axial spacers, when needed, to properly position MTR fuel elements in the basket to facilitate unloading and to meet minimum nonfuel material requirements;
- Use of spacer hardware to block cells 1, 2 and 3 in MTR baskets containing high fissile mass LEU MTR fuel elements to prevent inadvertent misloading;
- Moderator density studies for partially loaded baskets containing high fissile mass LEU MTR fuel elements at the top and bottom of the stack, in the two center locations and for a system consisting of six partially loaded baskets; and
- Sample input file for the evaluation of high fissile mass LEU MTR fuel elements.

This submittal includes eight copies of this transmittal letter and Revision LWT-07D changed pages for Reference 2 updated with the previously approved ANSTO and TPBAR amendment information. The changed pages incorporate the requested amendment. Consistent with NAC administrative practice, this proposed revision is numbered to uniquely identify the applicable changed pages. Revision bars mark the SAR text changes (on Revision LWT-07D pages, as well as on previously submitted LWT-07B pages that are part of this submittal) that are proposed in this submittal. The included List of Effective Pages identifies the current revision level of all pages of the application.

NMSS01
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Rec'd on 9/14/07

ED20070026

Please note that a considerable number of LWT-07D pages with no changes (no revision bars) are included as a result of text flow. Upon final approval of this application, the LWT-07B and LWT-07D changed pages, as well as all ANSTO/TPBAR revision pages will be reformatted, assigned the next appropriate SAR revision number, and incorporated into the NAC-LWT SAR.

In this amendment request, the proposed axial and blocking spacers are described in Chapter 1. The moderator density evaluation and the sample data input file for the high fissile mass LEU MTR fuel are presented in SAR Chapter 6. Chapter 7 has been revised to address the use of spacer hardware as part of the loading requirements for the high fissile mass LEU MTR fuel elements. The NAC-LWT will continue to meet all of the regulatory requirements of 10 CFR 71.

The herein requested changes have no impact on the structural, thermal, containment and shielding evaluations contained in the NAC-LWT SAR, as the revised LEU MTR contents are enveloped by the current analyses for element mass and decay heat load. The acceptance tests and maintenance program for the NAC-LWT packages is unaffected by this amendment request.

The approval of the high fissile mass LEU MTR contents will permit the performance of the planned transport of U.S. Department of Energy (DOE)-owned fuel elements from the Joint Research Centre in Petten, The Netherlands. The transport is currently scheduled for early spring 2008, and is planned to be part of a multicask and multifacility spent fuel transport campaign in Europe as part of the DOE National Nuclear Security Administration's (NNSA) Foreign Research Reactor (FRR) Program.

To meet DOE's transport schedule, NAC requests an amendment approval date of September 15, 2007. As mentioned in Reference 3, NAC will submit a proposed revised CoC for NRC staff review and use by July 16, 2007 in support of the above requested CoC approval schedule.

If you have any comments or questions, please contact me on my direct line at 678-328-1274.

Sincerely,

Anthony L. Patko
Director, Licensing
Engineering

Enclosures

May 2007

Revision LWT-07D

NAC-LWT

Legal Weight Truck Cask System

SAFETY ANALYSIS REPORT

Docket No. 71-9225

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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. Axial spacers and plates may be used to properly position the MTR elements axially in the basket to facilitate fuel unloading and handling, and to meet minimum nonfuel hardware specifications. 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.

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. For the shipment of MTR fuel elements (or an equivalent number of plates in a plate canister) having ^{235}U greater than 470 g per element, or greater than 22 g per plate (up to a maximum of 640 g per element or 32 g per plate), the maximum quantity of elements per basket is limited to four, which are to be loaded in basket positions 4, 5, 6 and 7. Spacers are installed in basket openings 1, 2 and 3 to block these cells from inadvertent loading. The typical MTR element spacer design is shown in Figure 1.2-18. Therefore, for the transport of elements of greater than 470 g ^{235}U, if one element exceeds the 470 g (22 g per plate) limit, only four elements shall be loaded into the seven-element basket module and blocking spacers shall be placed in basket opening positions 1, 2 and 3.

Loose MTR fuel plates may be shipped in an MTR plate canister to facilitate handling. The contents of the canister are limited to the number of plates in the original intact fuel assembly,

and the fuel plate dimensions and fuel masses must be bounded by the MTR fuel element limits in Table 1.2-4.

A maximum of 42 DIDO fuel assemblies has been analyzed for transport in the NAC-LWT cask. Again, up to seven fuel assemblies may be placed radially in each of six axial fuel basket modules.

DIDO fuel assemblies are similar to MTR fuel elements in that the fuel bearing hardware consists of plates of fuel meat sandwiched by cladding. However, in DIDO fuel, the plates have been formed into tubular elements that are arranged in a concentric configuration. Typical DIDO assemblies contain four of the concentric tubes.

MTR and DIDO fuel characteristics are presented in Table 1.2-4.

1.2.3.3 General Atomics Irradiated Fuel Material (GA IFM) and Basket Description

The GA IFM is made up of two separate types of fuel material—the High-Temperature Gas-Cooled Reactor (HTGR) type fuel and the Reduced-Enrichment Research and Test Reactor (RERTR) type fuel. Each type of IFM is packaged in its own unique Fuel Handling Unit (FHU). Figures 1.2-7 and 1.2-8 illustrate the HTGR and RERTR FHUs. Detailed drawings for the GA and IFM FHUs are in Section 1.4.

The HTGR IFM is comprised of fuel in four forms: fuel particles (kernels), fuel particles (coatings), fuel compacts (rods), and fuel pebbles. Fuel kernels are solid, spheridized, high-temperature sintered fully-densified, ceramic kernel substrate, composed of: UC_2, UCO, UO_2, $(Th,U)C_2$, or $(Th,U)O_2$. The as-manufactured enrichment of the HTGR fuel varies from ~10.0 to 93.15 wt % ^{235}U. Fuel coatings are solid, spheridized, isotropic, discrete multi-layered fuel particle coatings with chemical composition including pyrolitic-carbon (PyC) and silicon carbide (SiC). Fuel compacts are multi-coated ceramic fuel particles, bound in solid, cylindrical, injection-molded, high-temperature heat-treated compacts. The fuel compact matrix is composed of carbonized graphite shim, coke, and graphite powder. Fuel pebbles are multi-coated fuel particles, bound in solid, spherical injection-molded, high-temperature heat-treated pebbles. The fully-cured binding matrix is composed of carbonized graphite shim, coke , and graphite powder.

The RERTR IFM is comprised of 20 irradiated TRIGA fuel elements; 13 of the elements are intact and the remaining seven have been previously sectioned for examination purposes. Parameters characterizing the RERTR/TRIGA fuel elements are shown in Table 6.2.9-1. Three distinct mass loadings of uranium were used in the 20 TRIGA elements: 20, 30, and 45 wt % U; the average mass of the fueled portion of these elements is 551g with an enrichment of 19.7 wt %

^{235}U. The RERTR IFM consists of U-ZrH metal alloy fuel material and as a solid meets the requirement of 10 CFR 71.63.

Two GA IFM Fuel Handling Units (FHU) are intended for a single shipment in the NAC-LWT. The first IFM FHU contains HTGR type fuel and the second contains RERTR type fuel. Each IFM FHU consists of stainless steel weld-encapsulated primary and secondary enclosures. The FHUs are filled and sealed with air at atmospheric pressure. The two IFM FHUs are placed in the top of the NAC-LWT cavity with a bottom spacer to facilitate unloading of the IFM packages.

The GA IFM fuel characteristics are presented in Table 1.2-7.

1.2.3.4 PWR Fuel

The NAC-LWT cask is analyzed for the PWR fuel assemblies listed in Table 1.2-5. This table provides the dimensional and enrichment constraints for the PWR fuel. The burnup and decay heat limits are specified in Table 1.2-4.

1.2.3.5 BWR Fuel

The NAC-LWT cask is analyzed for the BWR fuel assemblies listed in Table 1.2-6. This table provides the dimensional constraints for the BWR fuel. The enrichment, burnup and decay heat limits are specified in Table 1.2-4.

1.2.3.6 TPBARs

The NAC-LWT cask is analyzed for the transport of two separate Tritium Producing Burnable Absorber Rod (TPBAR) content configurations. For the transport of production TPBARs from the reactor facility to the DOE processing facility, an open (i.e., unsealed) stainless steel consolidation canister is utilized to contain up to 300 TPBARs, two of which can be prefailed. The characteristics of the production TPBARs are listed in Table 1.2-8. The consolidation canister assembly is shown in Figure 1.2-10.

The second transport configuration is for the shipment of segmented TPBARs, following post-irradiation examination (PIE), contained in a welded stainless steel waste container containing segments and debris from up to 55 TPBARs. The characteristics of the TPBAR PIE segments are provided in Table 1.2-12. The waste container and extension weldment assembly is shown in Figure 1.2-16.

TPBARs are similar in size and nuclear characteristics to standard, commercial PWR, stainless steel-clad burnable absorber rods. The exterior of a typical TPBAR is a stainless steel clad tube. The internal components of the TPBAR are designed and selected to produce and retain tritium.

Internal configurations differ for various TPBAR designs (see DOE reports provided in the Chapter 1 Appendices). The internal components of a typical TPBAR include a plenum spacer tube (getter tube), a spring clip or a plenum (compression) spring, pellet stack assemblies (pencils), and a bottom spacer tube. A pencil consists of a zirconium alloy liner around which lithium aluminate absorber pellets are stacked and then confined in a getter tube as shown in Figure 1.2-9. The unclassified design details of the various TPBAR designs are provided in the unclassified DOE documents and drawings provided in the Chapter 1 Appendices.

The transport assembly arrangements for both TPBAR content configurations are identical and include a closure lid spacer assembly, a TPBAR basket and Alternate B port covers with bolting installed. The detailed requirements for the NAC-LWT assembly are provided in license drawing 315-40-128 in Section 1.4. The overall payload arrangement for the NAC-LWT with the consolidation canister and waste container are shown in Figure 1.2-12 and Figure 1.2-17, respectively. For the transport of fewer than 300 TPBARs in the consolidation canister, stainless steel dunnage may be used to align and protect the contents. The weight and volume of the dunnage and the reduced TPBAR contents of the consolidation canister must be less than, or equal to, the weight and volume of 300 TPBARs.

The TPBAR content conditions are analyzed and evaluated for compliance with structural, thermal, containment and shielding conditions of the NAC-LWT in the appropriate SAR chapters. TPBARs do not contain fissile material and, therefore, criticality evaluations have not been performed. The operating procedures for the wet and dry loading and dry unloading of the TPBAR contents are provided in Chapter 7. The special leakage and pressure testing requirements for NAC-LWT casks intended for the transport of TPBAR contents are provided in Chapter 8.

1.2.3.7 Cladding for PWR/BWR Fuel

The PWR and BWR fuel rod cladding is of Zirconium alloy type (Zircaloy-2, Zircaloy-4, Zirlo, M-5, etc.). Minor variations of alloy composition have no impact on performance of cladding material.

1.2.3.8 PULSTAR Fuel Element and Transport Configuration Description

PULSTAR fuel elements are transported in the NAC-LWT in the 28 MTR fuel basket assembly, which contains four modules with seven cells per module. The basket assembly is composed of a top module, a base module, and two intermediate modules (Dwgs 315-40-051, -049, and -050, respectively).

PULSTAR fuel elements may be loaded into the module cells in one of four configurations: a) intact PULSTAR fuel assemblies b) intact PULSTAR fuel elements loaded into the 4×4

TRIGA fuel rod insert (Dwg. 315-40-096); c) intact or damaged PULSTAR fuel elements, fuel debris and nonfuel-bearing components of PULSTAR fuel assemblies in the PULSTAR screened can (Dwg. 315-40-135); or d) intact or damaged PULSTAR fuel elements, fuel debris and nonfuel-bearing components of PULSTAR fuel assemblies in the PULSTAR sealed can (Dwg. 315-40-130). The contents of either can type are restricted to a quantity of fissile material and a total volume of material equivalent to 25 PULSTAR fuel elements. The sealed cask contents are restricted to the displaced volume of 25 intact PULSTAR fuel elements. The total cask payload shall not exceed 700 PULSTAR fuel elements. Loading of modules with mixed PULSTAR payload configurations is allowed, but PULSTAR cans, either screened or sealed, are restricted to loading in the base and top modules.

PULSTAR fuel elements are low enriched (< 7 wt%) uranium oxide rods, with zirconium alloy cladding. During reactor operation, 25 PULSTAR fuel elements are arranged in a rectangular 5×5 lattice, surrounded by a zirconium alloy box, and capped by top- and bottom-end fittings to form a PULSTAR fuel assembly. The nonfuel components of a PULSTAR fuel assembly are primarily aluminum and zirconium alloy and do not contain a significant activation source. A sketch of a PULSTAR fuel assembly is provided in Figure 1.2-13. Key physical, radiation protection and thermal characteristics of the PULSTAR fuel assembly/elements are listed in Table 1.2-9.

The sealed and screened PULSTAR cans are stainless steel containers that: a) minimize the dispersal of gross fuel particles that may escape from damaged fuel element cladding and/or fuel debris; b) facilitate retrieval of the contents from the transportation cask; and c) confine damaged fuel and/or debris within a known volume to facilitate criticality control, maintain dose limits, and control thermal loads within the cask. PULSTAR fuel pellets, pieces, and debris may be placed in an encapsulating rod for handling purposes prior to placement into either a sealed or screened can. The encapsulating rod is not required and has no safety significance. In addition to fuel elements, the cans may contain fuel assembly hardware up to the total content weight limit specified in Table 1.2-9. For operational/retrievability purposes, stainless steel rod inserts may be used to position the PULSTAR fuel elements within the fuel rod insert. Total content weight shall not exceed the total weight limit specified in Table 1.2-9. The fuel rod insert is composed of a 4×4 grid of 0.75-inch OD × 0.065-inch wall stainless steel tubes. The tubes provide structural support for individual intact PULSTAR fuel elements during transport in the NAC-LWT.

Spacers may be used to axially position PULSTAR fuel contents near the top of the module for ease of loading and unloading operations. The spacers are provided for ease of operations and do not provide a safety function.

1.2.3.9 ANSTO Basket and Payload Description

Two basic fuel types are to be transported in the ANSTO baskets within the NAC-LWT cask: spiral fuel assemblies and MOATA plate bundles. Spiral fuel assemblies are composed of cylindrical aluminum inner and outer shells connected by curved metallic fuel plates. Further detail on the spiral fuel assemblies is provided in Section 1.2.3.9.1. MOATA plate bundles are comprised of up to 14 MTR fuel plates. Further detail on the plate bundles is provided in Section 1.2.3.9.2. Spiral fuel assemblies and MOATA plate bundles shall be intact. Note that spiral assemblies may be cropped by removing nonfuel-bearing hardware to fit within the basket tubes. Cropped spiral fuel assemblies are classified as intact fuel.

Up to 42 spiral fuel assemblies or 42 MOATA plate bundles may be loaded. A full cask load contains 6 baskets of up to 7 fuel assemblies or plate bundles per basket. The mixed loading of ANSTO basket modules containing either spiral fuel assemblies or MOATA plate bundles is authorized.

1.2.3.9.1 Spiral Fuel Assemblies

The design basis characteristics of spiral fuel assemblies are presented in Table 1.2-10. The fuel material in spiral fuel assembly plates is a solid, homogeneous mixture of uranium-aluminum alloy, i.e., a metal alloy fuel. The fuel meat of each plate is clad in aluminum. A set of 10 curved fuel plates is located between an inner and outer cylindrical aluminum shell. Fuel elements are cropped to fit axially within the basket envelope. Fuel material is not cut during the cropping operation. The fuel plates are located in a spiral pattern, maintaining a constant pitch between fuel plate centers. A sketch of the assembly cross-section is provided in Figure 1.2.3-14.

1.2.3.9.2 MOATA Plate Bundles

The design basis characteristics of MOATA plate bundles are presented in Table 1.2-11. The fuel material in the plate bundle is a solid, homogeneous mixture of uranium-aluminum alloy, i.e., a metal alloy fuel. Each plate is clad in aluminum. A plate bundle is comprised of up to 14 fuel plates. Two thick (0.635 cm) aluminum nonfuel side plates support the fuel plate stack from two sides, making a possible total of 16 plates per bundle. At each axial end, the plates in the stack are connected by a pin. Spacing between plates is maintained by disk spacers placed onto the top and bottom pins between each fuel plate and the aluminum side plates. A sketch of a typical MOATA plate bundle is provided in Figure 1.2.3-15.

Figure 1.2-17 NAC-LWT with TPBAR Waste Container Payload

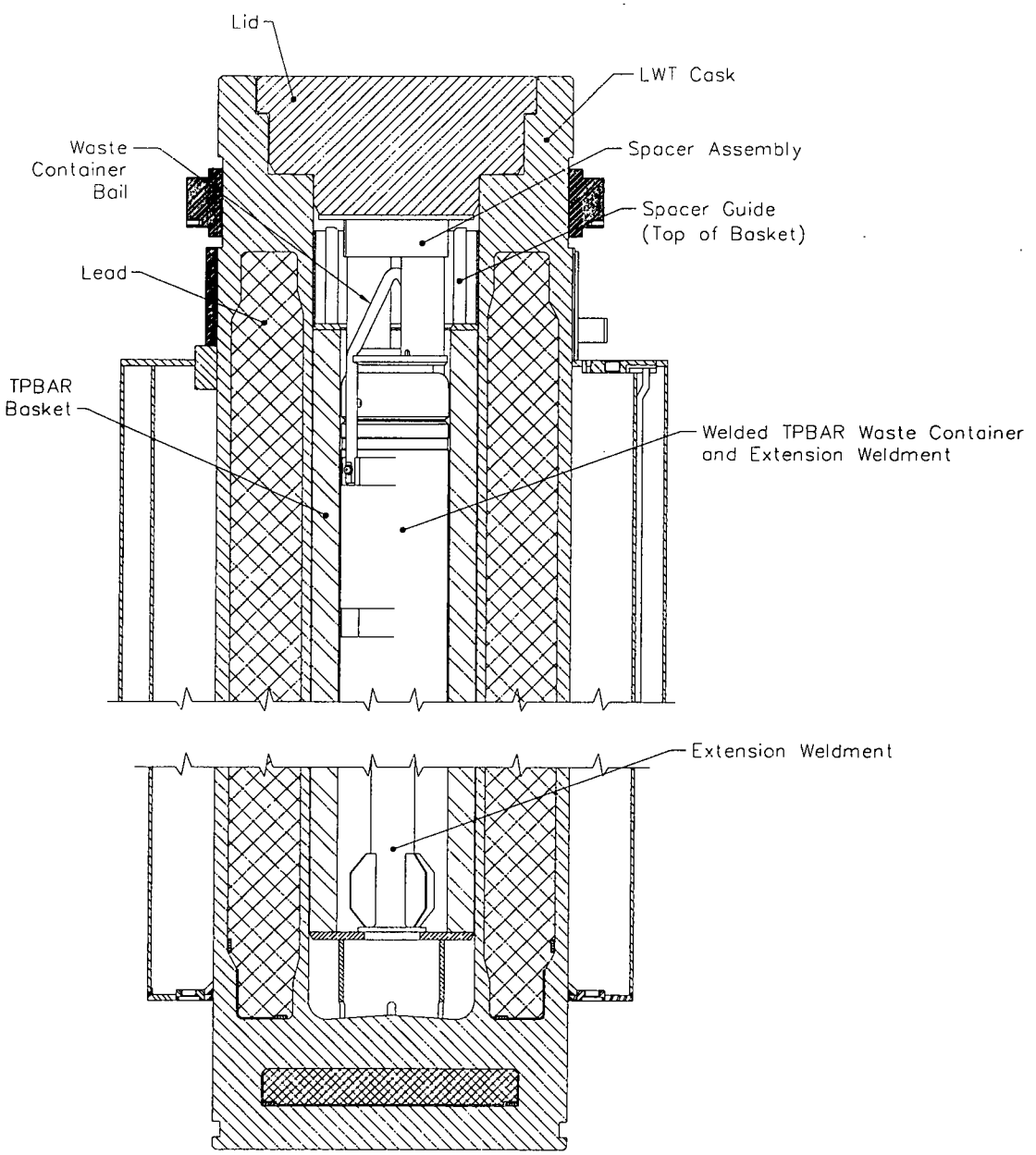
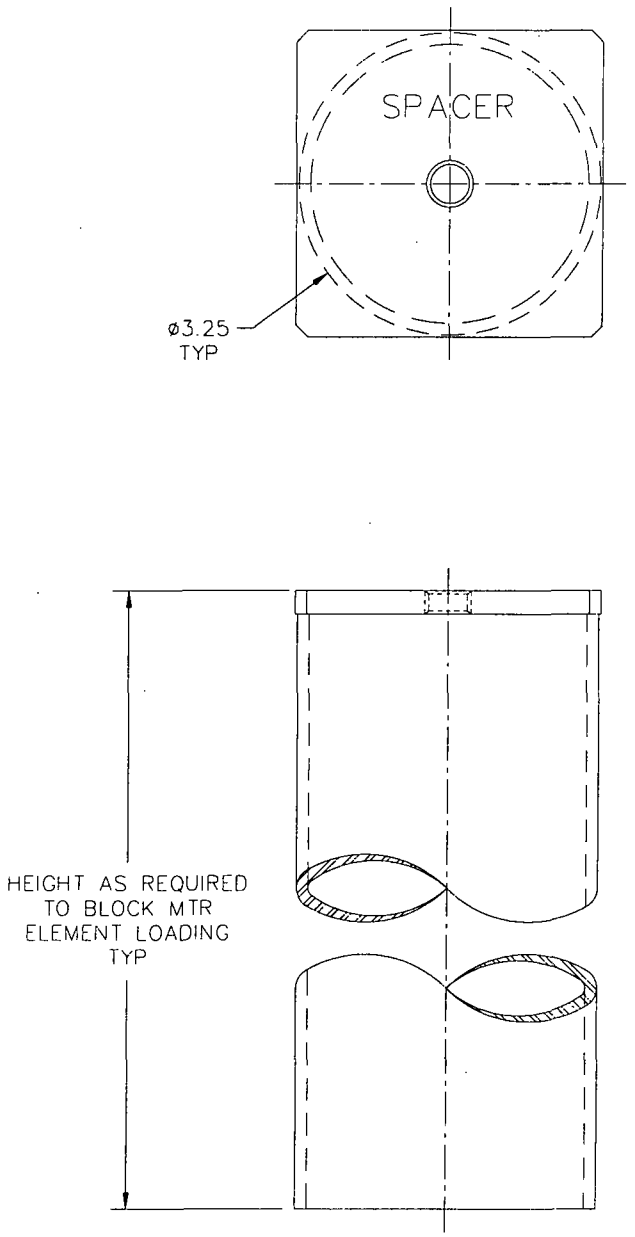


Figure 1.2-18 High Fissile Mass LEU MTR Fuel Element Spacer



Note: Material of construction is aluminum.

Table 1.2-1 Characteristics of Design Basis TRIGA Fuel Elements

Element Type	Al Clad	ACPR[1]	Steel Clad	Fuel Follower Standard Control Rod[2]
Element Diameter (in.)	1.47	1.478	1.478	1.355
Element Length(in.)	28.4[3] 28.3[4]	28.89	29.7[5] 28.9[6]	45
Active Length (in.)	14[3] 15[4]	15	15	15
Graphite Reflector (in.)	3.53	3.45	2.56, 3.72[5] 3.42[6]	-
Clad Material	Al	SS304	SS304	SS304
Clad Thickness (in.)	0.03	0.02	0.02	0.02
Fuel Material	U-ZrH	U-ZrH	U-ZrH	U-ZrH
Pellet Diameter (in.)	1.41	1.40	1.435	1.311[7]
Maximum Weight (kg)	2.9	4.0	3.4	6.0

[1] Annular Pulse Core Reactor.
[2] Fuel follower control rod has an uppermost 6.5-inch air void section, a 15-inch boron carbide upper section, a 15-inch U-ZrH fuel section, and 5.88-inch lower void section.
[3] Al clad fuel with 14-inch active fuel has no central hole with Zircaloy rod.
[4] Al clad fuel 15-inch active fuel has a central hole with Zircaloy rod.
[5] Steel clad standard streamline fuel has 2.56 and 3.72-inch upper and lower graphite reflectors.
[6] Steel clad standard plain fuel has 3.42-inch upper and lower graphite reflectors.
[7] Fuel meat diameter.

Table 1.2-2 Characteristics of Design Basis TRIGA Fuel Elements – Fuel Compositions

Element Type	Al Clad	Steel Clad					Fuel Follower Control Rod		
		ACPR	Stand.	FLIP[1]	FLIP LEU-I	FLIP LEU-II	Stand.	FLIP LEU-I	ACPR
U in U-ZrH (max. wt %)	8.5	12.5	12	8.5	20	31	8.5	8.5	12.5
^{238}U- Mass (g)	164	224	164	59	403	676	150	387	224
^{235}U in U (wt %)	20	20	20	70	20	20	20	20	20
^{235}U-Mass (g)	41	56	41	137	101	169	38	97	56
H to Zr Ratio	1	1.7	1 - 1.7	1.6	1.6	1.6	1.6	1.6	1.7
Max. Zr Mass (g)	2300	1962	2300	2060	1988	1886	2004	1908	1962

[1] FLIP – Fuel Life Improvement Program

Table 1.2-3 Characteristics of Design Basis TRIGA Fuel Cluster Rods

Element Type	TRIGA Fuel Cluster Rod
Rod Diameter (in.)	0.542
Max. Rod Length (in.)	31.0
Max. Active Length (in.)	22.5
Clad Material	Incoloy 800
Min. Clad Thickness (in.)	0.015
Fuel Material	U-ZrH
Max. Pellet Diameter (in.)	0.53
Maximum Rod Weight (kg)	0.65
U in U-ZrH (wt %)	10.2
^{235}U in U (wt %)	93.3
^{235}U Mass (g)	45.4
H to Zr Ratio	1.6
Zr Mass (g)	421

Table 1.2-4 Fuel Characteristics

Parameter	PWR Fuel Assembly	BWR Fuel Assemblies	PWR Rods	High Burnup PWR Rods	High Burnup BWR Rods 7 × 7	High Burnup BWR Rods[1] 8 × 8[2]
Maximum Number of Assemblies, Elements or Rods	1	2	25 rods	25 rods	25 rods	25 rods
Maximum Overall Weight, lbs	1650	750	N/A	N/A	N/A	N/A
Maximum Overall Length, in	178.25	176.1	162	162	176.1	176.1
Maximum Active Fuel Length, in	150	150	150	150	150	150
Fuel Rod Cladding	Zirc	Zirc	Zirc	Zirc	Zirc	Zirc
Maximum Uranium, kg U	475	198	58.2	65.6	198	198
Maximum Initial ^{235}U, wt %	*See below*[3]	4.0	5.0	5.0	5.0	5.0
Maximum Burnup, MWD/MTU	35,000	30,000	60,000[4]	80,000	60,000 - 80,000	80,000
Maximum Unit Decay Heat, kW	2.5	1.1	0.564	0.92	0.84	0.84
Maximum Cask Decay Heat, kW	2.5	2.2	1.41	2.3	2.1	2.1
Minimum Cool Time, yr	2	2	150 days	150 days	210 - 270 days[5]	150 days

[1] High burnup rods are loaded in a fuel assembly lattice or rod holder. Up to 14 rods, loaded in a rod holder, may be classified as damaged. The lattice may be irradiated.
[2] Includes rods from all larger BWR assembly arrays (e.g., 9 × 9, 10 × 10).
[3] See Table 1.2-5 for maximum PWR fuel enrichment by fuel type.
[4] Up to 2 of the 25 PWR rods may have a maximum burnup of 65,000 MWD/MTU.
[5] Minimum cool time for high burnup BWR 7 x 7 rods is determined by extent of burnup. See Section 5.3.8 and Table 5.3-56.

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[7]	140	140	560
Maximum Overall Weight, lbs	1805	1805	1805	30 (max)	30 (max)	30 (max)	13.2 (max)	8.82 (nom.) 13.2 (max)	1.5
Maximum Overall Length, in	120.5	120.5	120.5	25.4[2]	26.1[2]	26.1[2]	45	45	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	2.474 3.368[7]	0.824	0.196	0.0486
Maximum Initial ^{235}U, wt %	Natural	Natural	Natural	94	94[3]	25	20	70	93.3
Maximum Burnup, MWD/MTU	1,600	1,600	1,600	Variable up to 660,000[4]	Variable up to 293,300	Variable up to 139,300	151,100 (80% ^{235}U)	460,000 (80% ^{235}U)	600,000 (80% ^{235}U)
Maximum Unit Decay Heat, kW	0.036	0.036	0.036	Variable[5]	0.030[5]	0.030[5]	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[5]	Variable[5]	Variable[5]	Variable[6]	Variable[6]	Variable[6]

[1] For NISTR fuel, 42 elements may be cut in half, producing 84 fuel-bearing pieces. Each fuel-bearing piece may contain up to 0.211 kgU.
[2] 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.
[3] Typical MEU enrichment is 45 wt% ^{235}U. Criticality analysis supports up to 94 wt% under the MEU fuel definition.
[4] Maximum burnup is 660,000 MWD/MTU for 380g ^{235}U and 577,500 MWD/MTU for 460g ^{235}U.
[5] Minimum cool times for MTR fuel, down to 90 days, shall be determined using the procedure presented in Section 7.1.5.
[6] 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.
[7] MTR fuel elements having ^{235}U content >470 g (>22 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 a spacer 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.

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)	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[1], in	24.21	24.21	24.21
Maximum Burnup, MWD/MTU	577,460	256,650	121,910
Maximum Unit Decay Heat[2], kW	0.025	0.025	0.025
Maximum Cask Decay Heat, kW	1.05	1.05	1.05
Minimum Cool Time[3], yr	Variable	Variable	Variable

1 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.
2 Maximum unit decay heat of 0.025 kW allowed only in conjunction with spacers for top basket (see Section 7.1.4), otherwise the limit is 0.018 kW.
3 Minimum cool times for DIDO fuel assemblies, down to 180 days, shall be determined using the procedure presented in Section 7.1.4.

Table 1.2-5 PWR Fuel Characteristics

Fuel Type	No. of Fuel Rods	Max. Assembly Length (in.)	Max. Assembly Weight (lb)	Max. Enrich. (w/o)	Max. MTU	Pitch (in.)	Rod Dia. (in.)	Clad Thick. (in.)	Pellet Dia.(in.)	Max. Active Length (in.)
B&W 15 × 15	208	165.63	1515	3.5	0.4750	0.5680	0.430	0.0265	0.3686	144.0
B&W 17 × 17	264	165.72	1505	3.5	0.4658	0.5020	0.379	0.0240	0.3232	143.0
CE 14 × 14	176	157.00	1270	3.7	0.4037	0.5800	0.440	0.0280	0.3765	137.0
CE 16 × 16	236	178.25	1430	3.7	0.4417	0.5060	0.382	0.0250	0.3250	150.0
WE 14 × 14 Std	179	159.71	1302	3.7	0.4144	0.5560	0.422	0.0225	0.3674	145.2
WE 14 × 14 OFA	179	159.71	1177	3.7	0.3612	0.5560	0.400	0.0243	0.3444	144.0
WE 15 × 15	204	159.71	1472	3.5	0.4646	0.5630	0.422	0.0242	0.3659	144.0
WE 17 × 17 Std	264	159.77	1482	3.5	0.4671	0.4960	0.374	0.0225	0.3225	144.0
WE 17 × 17 OFA	264	160.10	1373	3.5	0.4282	0.4960	0.360	0.0225	0.3088	144.0
Ex/ANF 14 × 14 WE	179	160.13	1271	3.7	0.3741	0.5560	0.424	0.0300	0.3505	144.0
Ex/ANF 14 × 14 CE	176	157.24	1292	3.7	0.3814	0.5800	0.440	0.0310	0.3700	134.0
Ex/ANF 15 × 15 WE	204	159.70	1433	3.7	0.4410	0.5630	0.424	0.0300	0.3565	144.0
Ex/ANF 17 × 17 WE	264	159.71	1348	3.5	0.4123	0.4960	0.360	0.0250	0.3030	144.0

Table 1.2-6 BWR Fuel Characteristics

Fuel Type	No. of Fuel Rods	No. of Water Rods	Max. Assembly Length (in.)	Max. Assembly Weight (lb)	Max. MTU	Pitch (in.)	Rod Dia. (in.)	Clad Thick. (in.)	Pellet Dia. (in.)	Max. Active Length (in.)
GE 7 × 7	49	0	175.9	678.9	0.1923	0.738	0.563	0.037	0.477	146
GE 8 × 8-1	63	1	175.9	681.0	0.1880	0.640	0.493	0.034	0.416	146
GE 8 × 8-2	62	2	175.9	681.0	0.1847	0.640	0.483	0.032	0.410	150[1]
GE 8 × 8-4	60	4	176.1	665.0	0.1787	0.640	0.484	0.032	0.410	150[1,2]
GE 9 × 9	74	2[3]	176.1	646.0	0.1854	0.566	0.441	0.028	0.376	150[1,4]
	79	2	176.1	646.0	0.1979	0.566	0.441	0.028	0.376	150[1,4]
Ex/ANF 7 × 7	49	0	171.3	619.1	0.1960	0.738	0.570	0.036	0.490	144
Ex/ANF 8 × 8-1	63	1	171.3	562.3	0.1764	0.641	0.484	0.036	0.4045	145.2
Ex/ANF 8 × 8-2	62	2	176.1	587.8	0.1793	0.641	0.484	0.036	0.4045	150
Ex/ANF 9 × 9	79	2	176.1	575.3	0.1779	0.572	0.424	0.03	0.3565	150
	74	2[3]	176.1	575.3	0.1666	0.572	0.424	0.03	0.3565	150

[1] 6" natural uranium blankets on top and bottom.
[2] May have 1 large water hole - 3.2 cm ID, 0.1 cm thickness.
[3] 2 large water holes occupying 7 fuel rod locations - 2.5 cm ID, 0.07 cm thickness.
[4] Shortened active fuel length in some rods.

Table 1.2-7 Characteristics of General Atomics Irradiated Fuel Material (GA IFM)

Parameter	RERTR	HTGR
Maximum Number of Assemblies, Elements or Rods	13 intact; 7 sectioned	N/A
Maximum Loaded Enclosure Weight, lbs	76.0	71.5
Maximum Fuel Weight, lbs	23.73	23.52
Maximum Overall Length, in	29.92	N/A
Maximum Active Fuel Length, in	22.05	N/A
Fuel Material	U-ZrH	UC_2, UCO, UO_2, $(Th,U)C_2$, $(Th,U)O_2$
Fuel Rod Cladding	Incoloy 800	N/A
Maximum Uranium, kg U	3.86	0.21
Maximum Initial ^{235}U, wt %	19.7	93.15
Maximum Burnup, MWD/MTU	N/A	N/A
Maximum Unit Decay Heat, W	11.0	2.05
Maximum Cask Decay Heat, W	13.05	13.05
Earliest Shipment Date	1/1/96	1/1/96
Maximum Activity, Ci	2920	483

Table 1.2-8 Typical Production TPBAR Characteristics[1]

Parameter Description	Value
Maximum Number of TPBARs per Consolidation Canister	300
Number of Consolidation Canisters per Cask	1
TPBAR Clad Material	316 L Stainless Steel
Rod Length[2], in	153.04
Rod Diameter[2], in	0.381
Maximum Rod Heat Load, W	2.31
Maximum Cask Heat Load, kW	0.693
Maximum Tritium Content per Rod, gram	1.2
Maximum Activity per Cask[3], Ci	3.84×10^6
Loaded TPBAR Consolidation Canister Maximum Weight, pounds[4]	1,000
Maximum Event Failed Tritium Release (Ci/rod)	<55
Minimum Cooling Time, days	30

[1] Refer to Section 1.5, Chapter 1 Appendices, Unclassified DOE Reference Documents and Drawings.
[2] Beginning of life, nominal, unirradiated dimensions.
[3] Primary dose contribution: 1.1×10^4 Ci ^{60}Co/cask
[4] The bounding weight employed in the structural analysis.

Table 1.2-9 PULSTAR Fuel Characteristics

Description	Value
Maximum Pellet Diameter (inch)	0.423
Minimum Element (Rod) Cladding Thickness (inch)	0.0185
Minimum Element (Rod) Diameter (inch)	0.470
Maximum Active Fuel Height (inch)	24.1
Element (Rod) Length (inch)	26.2
Rod Pitch (inch)	0.525 × 0.607
Assembly Length (inch)	38
Box Outside Width (inch)	2.745 × 3.155
Box Thickness (inch)	0.06
Maximum Assembly or Loaded Can Weight (lb) [1]	80
Maximum PULSTAR Can Content Weight (lb)[2]	39.6
Maximum Enrichment (wt % ^{235}U)	6.5
Maximum ^{235}U Content per Element (g)	33
No. of Elements (Rods) per Assembly	25
No. of Elements (Rods) per Can[2]	25
Maximum Depletion (%^{235}U)	45
Minimum Cool Time (yrs)	1.5
Maximum Heat Load per Assembly (W)	30
Maximum Heat Load per Element (W)	1.2

[1] Listed weight is the maximum weight evaluated for the structural calculation to bound all payload configurations, including loaded cans, and spacers. Nominal PULSTAR assembly weight is 45 pounds.

[2] The contents of a PULSTAR can are restricted to the equivalent of the fuel material in 25 PULSTAR fuel elements and of the displaced volume of 25 intact PULSTAR fuel elements. Fuel material may be in damaged form including fuel debris. The listed weight represents the can content limit established by the structural analyses.

Table 1.2-10 Spiral Fuel Assembly Characteristics

Parameter	Value
Number of elements per assembly	10
Fuel element type	Curved plate
Nominal dimensions of element (cm)	0.147 × 7.33 × 63.5 (individual plate)
Chemical form of fuel meat	U-Al_x-alloy
Cladding material	Aluminum
Nominal over-all dimensions (cm)	63.818 (height) × 10.16 diameter[5]
Max total weight of ^{235}U (g)	160 (total per assembly)
Maximum enrichment (wt % ^{235}U)	85
Side plate material	Aluminum (inner and outer tubes)
Nominal side plate – dimensions (cm)	Inner 6.045 OD, 5.82 ID × 63.818 Outer 10.16 OD, 9.85 ID × 63.818[1]
Max. assembly weight (lb)	18[2]
Assembly maximum heat load (W)	15.7[3]
Burnup/cool time limit	Variable[4]

[1] Criticality evaluations reduced inner and outer shell thickness to 0.01 cm to provide additional moderator within the assembly.
[2] Typical assembly weight is 7.9 pounds. Bounding structural analysis weight is listed.
[3] Thermal and shielding evaluation employed 18 W per element. Based on cool time constraint, 15.7 W represents maximum heat load.
[4] Spiral fuel is constrained to DIDO MEU cool time limits as a function of burnup. Minimum cool times for the spiral assembly, down to 270 days, shall be determined using the procedure presented in Section 7.1.4 for 18 W DIDO MEU fuel.
[5] Cropped to fit within ANSTO fuel basket module nominal height of 28.3 inches.

Table 1.2-11 MOATA Plate Bundle Characteristics

Parameter	Value
Maximum number of elements per assembly	14
Nominal dimensions of element (cm)	66 cm long, 7.6 cm wide and 0.203 cm thick
Nominal dimensions of fuel meat (cm)	58.4 cm long, 6.99 cm wide and 0.1016 cm thick (bounding active fuel width evaluated to a maximum of 7.32 cm)
Chemical form of fuel meat	U-Al_x-alloy
Cladding material	Aluminum
Nominal clad thickness (cm)	0.05 cm (evaluated to 0.01 cm minimum)
Plate spacer thickness (cm)	0.147 min, 0.152 max (evaluated to 0.18 maximum)
Maximum weight of ^{235}U (g) per plate	22.3
Maximum enrichment (wt % ^{235}U)	92
Nominal side plate thickness (cm)	0.635 (bounding evaluation replaced by cavity moderator)
Max. assembly weight (lb)	18[1]
Maximum heat load per assembly (W)[2]	3 (total for 14 fuel plates)
Maximum burnup	30,000 MWd/MTU or 4.1 % depletion ^{235}U
Minimum cool time (years)	10

[1] Typical assembly weight is 13.6 pounds. Bounding structural analysis weight is listed.
[2] Actual heat load at limiting burnup and cool time < 1 Watt. Thermal evaluations at 3 Watt per bundle.

Table 1.2-12 Typical TPBAR Segment Characteristics in Waste Container

Parameter/Description	Value
Maximum Number of TPBAR Segments and Debris per Waste Container, equivalent number of TPBARs	55
Number of Waste Containers per Cask	1
Waste Container Material	316L Stainless Steel
Maximum Tritium Content per TPBAR equivalent, gram	1.2
Maximum Activity per Cask, Ci	6.66×10^{-5}
Maximum Heat Load per Waste Container, watts	127
Maximum Loaded Waste Container Weight, pounds	700[1]
Minimum Cooling Time, years	90

[1] Design basis weight of a loaded waste container is 700 pounds. Applying a maximum payload of 55 TPBARs, with storage canister, yields a maximum weight of 662 pounds. Use of shrouds to contain segments and/or TPBAR debris reduces overall waste container weight due to a reduction in TPBAR payload capacity resulting from the reduced container free volume.

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Chapter 6

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6.3.3 MTR Fuel Elements

6.3.3.1 Description of Calculational Models

Since it is planned to transport many types of MTR fuel elements in the NAC-LWT, a determination of the most limiting, i.e., higher k_{eff}, element must be made for criticality purposes. Primary candidates for the most limiting element from the MTR elements in Table 6.2.3-1 through Table 6.2.3-3 are selected for analysis. Limiting elements are primarily selected based on fissile material content. After establishing trends in reactivity versus the elements' physical characteristics, bounding element characteristics are defined.

Evaluations are performed with three distinct fuel element models. First stage evaluations compare reactivities between intact fuel element types in an infinite array of basket unit cells. The second phase of the evaluations employs a basket model representing a cross section of the cask at infinite height and is used to establish maximum reactivity basket configurations and moderator densities. Finally, the limiting fuel element parameters are defined by a three-dimensional cask model containing six baskets.

In the KENO-Va fuel/basket unit cell analysis, a unit cell of the fuel element and the basket is modeled. This includes the fuel element in a 3.44" x 3.44" (8.738 cm x 8.738 cm) opening surrounded by a 5/16" (0.7938 cm) web. Water at 1 gm/cc is modeled between the fuel plates and in the basket hole surrounding the fuel element as shown in Figure 6.3.3-1. Reflecting boundary conditions are imposed on the sides, top and bottom simulating an infinite array with no axial leakage. This produces the k_{eff} of an infinite array of fuel elements and basket cells without modeling the entire basket and cask.

The KENO-Va model of the NAC-LWT cask with the design basis MTR fuel is derived from a radial slice of the NAC-LWT at the active fuel region as shown in Figure 6.3.3-2. As described in Section 6.4.3.1, the HFBR fuel element is selected as the most limiting assembly for the seven element basket design. The KENO-Va model has an axial extent of ± 10 cm, but with reflecting boundary conditions imposed on top and bottom, the model is effectively infinite in axial extent. The fuel elements, steel basket and cask with radial shield regions are explicitly represented. There are no homogenizations of fuel, moderator or basket. A CUBOID surrounds the casks with reflecting boundary conditions imposed on the sides, top and bottom simulating an infinite array of infinite axial extent. Moderator (H_2O) is allowed to vary in the cavity and outside the cask under normal conditions and, also, is allowed to vary inside the neutron shield tank under accident conditions. Cask center-to-center spacing is varied by adjusting the X-Y spacing of the CUBOID surrounding the cask. The k_{eff} results of this infinite array model are always below 0.95, including all biases and uncertainties.

Because the integrity of MTR fuel is not assured, the fuel plates of an element may assume a more optimum configuration during accident conditions. Therefore, KENO-Va models of the NAC-LWT cask with MTR element plates optimally spaced within the limits of the basket opening are analyzed to verify that the HFBR element is the most limiting MTR element.

The full cask models are identical in cross section to the axially infinite cask models, but rather than axially reflecting an active fuel elevation section of a basket module, six basket modules are stacked into an array. The module chosen for stacking is the intermediate basket module. While axial extents differ from the bottom and top modules, the basket horizontal cross section is identical in all modules. Axial variations are associated with the stacking of the units, with all units containing the 0.5-inch thick base plate. Figure 6.3.3-3 displays a side view of the intermediate module, with Figure 6.3.3-4 showing this basket module stacked six high inside the NAC-LWT. The cask bottom weldment and lid enclose the basket module array with its associated radial shielding. Reflecting boundary conditions on all sides simulate an infinite array of casks. This model neglects the impact limiters that would provide additional spacing between casks, and models the cask under accident conditions with the neutron shield voided.

As discussed in Section 6.4.3.10, the accident, optimum plate pitch configuration bounds the configuration of loose plates in the MTR plate canister. Therefore, no separate models are constructed for the loose plate evaluation.

For high fissile material payloads, the MTR basket may require partial loading. Figure 6.3.3-5 contains a basket layout with each potential loading position numbered to correlate the analysis in Section 6.4.3 to allowed loading locations. The model construction for partially loaded baskets is identical to that of the fully loaded basket with the exception of cask interior moderator material being assigned to the basket opening rather than an array of fuel plates and the side plates. The basket opening not occupied by a fuel element may be blocked to physically prevent loading of an element. The spacer, as shown in Figure 1.2-18, consists of an aluminum tube, evaluated at an outer diameter of 3.25 inches and a 1/8-inch thickness, with a rectangular aluminum top plate. For baskets containing multiple fuel types, the SCALE material information processor input DAN and RES variables are provided for the fuel material not included in the LATTICECELL description. The Dancoff factors are extracted from LATTICECELL calculations of the single fuel type runs.

6.3.3.2 Package Regional Densities

The composition densities (gm/cc) and nuclide number densities (atm/b-cm) calculated by the SCALE material information processor for a range of elements evaluated in subsequent criticality analyses are shown in Table 6.3.3-1. Additional material densities may be obtained from the sample input/output files provided in Section 6.6.

set. As shown in the 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 then 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.

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

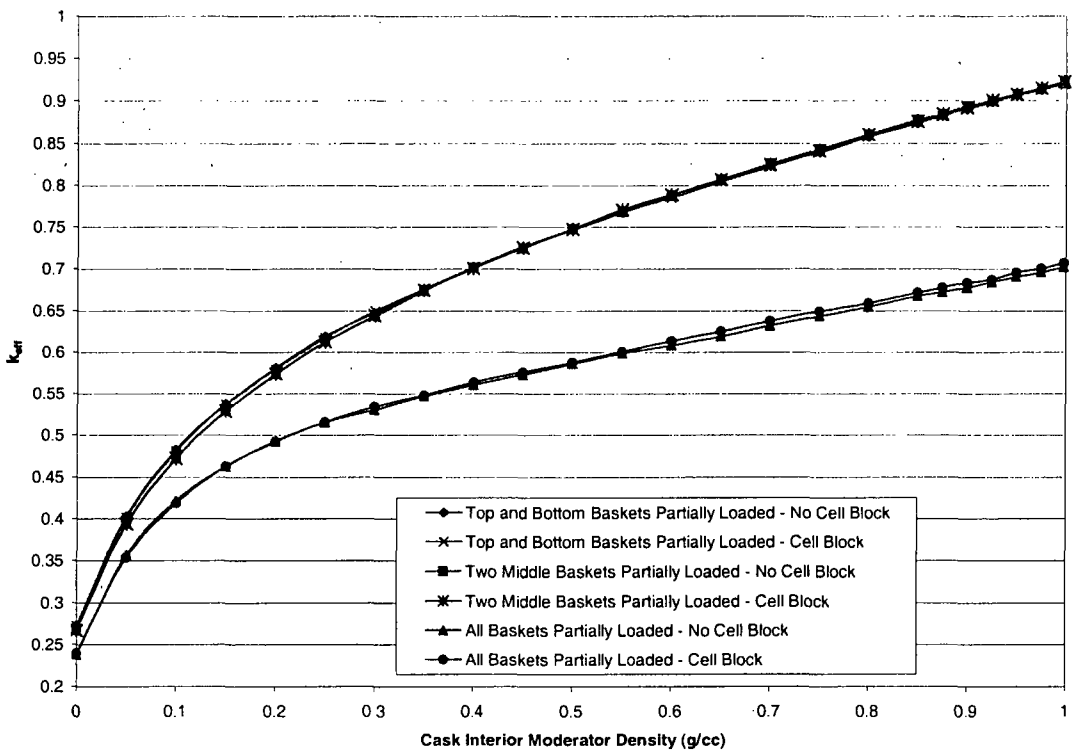

Table 6.4.3-1 Fuel/Basket Unit Cell k_{eff} versus MTR Fuel Element Type

MTR Type	Plate Pitch (cm)	^{235}U Loading (grams)	$k_{eff} \pm \sigma$
HEU ORR	0.422	285	1.2475 ± 0.0025
LEU BSR	0.422	340	1.2486 ± 0.0022
HEU HFBR	0.371[1]	351	1.2396 ± 0.0022
HEU NISTR	0.422[2]	362	1.1808 ± 0.0027
LEU RSG-GAS	0.369	271	1.1502 ± 0.0033
HEU PRR	0.432	247	1.1594 ± 0.0027
LEU THOR	0.761	210	1.0600 ± 0.0032
LEU ZPRL	0.776	210	1.0596 ± 0.0030
LEU IEA-R1	0.431	180	1.0219 ± 0.0039
HEU THOR	0.761	140	0.9479 ± 0.0039
GRR	0.442	187.2	1.0982 ± 0.0037

1. Variable outer plate spacing.
2. Two half-sections stacked together in the basket cell. Section cuts are a minimum of 1 inch from active fuel on each end.

Table 6.4.3-2 Cask k_{eff} versus Fuel Plate Spacing

Fuel Type	# of Fuel Plates	Pitch (cm)	k_{eff}	σ	$k_{eff} + 2\sigma$
HFBR	13	0.6330*	0.7901	0.0034	0.7969
	14	0.5878*	0.8120	0.0036	0.8192
	15	0.5486*	0.8161	0.0040	0.8241
	16	0.5142*	0.8341	0.0034	0.8409
	17	0.4840*	0.8398	0.0030	0.8458
	18	0.4572*	0.8471	0.0033	0.8537
	18	0.3708	0.7918	0.0043	0.8004
	18	0.2921	0.7131	0.0040	0.7211
	18	0.2250	0.6462	0.0039	0.6540
	18	0.1270	0.5166	0.0035	0.5236
BSR	19	0.4782	0.8375	0.0027	0.8429
	19	0.3878	0.7967	0.0029	0.8027

* Maximum possible spacing of fuel and end plates of HFBR fuel element within basket opening.

Table 6.4.3-3 MTR Basket Geometric Tolerances

Component	Dimension / Tolerance
Basket Opening	3.44 inch + 0.04 / - 0.06 inch
5/16 inch Plate Thickness	0.3125 nom. / 0.28 inch min.
1/4 inch Plate Thickness	0.25 nom. / 0.24 inch min.
11 Gauge Sheet	0.12 inch min.

Table 6.4.3-4 MTR Basket/Intact Fuel Element Geometric Tolerances and Mechanical Perturbations Results

Configuration	k_{eff}	σ	$k_{eff} + 2\sigma$
Elements Moved in Close	0.8023	0.0021	0.8065
Min. Basket Plate Thickness	0.8014	0.0032	0.8078
Elements Moved in Closest	0.7969	0.0021	0.8011
Nominal Configuration	0.7943	0.0031	0.8005
Elements Resting on Basket	0.7928	0.0020	0.7968
Max. Basket Opening	0.7898	0.0035	0.7960
Min. Basket Opening	0.7931	0.0032	0.7995
Elements Moved Out	0.7759	0.0019	0.7797
Elements Moved Out Furthest	0.7667	0.0020	0.7707

Table 6.4.3-5 MTR Basket/Optimally Spaced Fuel Plates Geometric Tolerances and Mechanical Perturbations Results

Configuration	k_{eff}	σ	$k_{eff} + 2\sigma$
Min. Basket Plate Thickness	0.8585	0.0035	0.8655
Plates Moved In	0.8577	0.0020	0.8617
Nominal Configuration	0.8471	0.0033	0.8537
Max. Basket Opening	0.8485	0.0037	0.8559
Min. Basket Opening	0.8406	0.0031	0.8468
Plates Moved Out	0.8290	0.0019	0.8328

Table 6.4.3-6 Reactivity with MTR Fuel vs. Basket Moderator Density, Normal Conditions, Dry Exterior, Infinite Array of Casks

Moderator Density	Casks Touching	2 Foot Surf.-to-Surf.	ISO Container 242.84 cm Pitch	Touching, Center Position Empty
Dry Exterior, Vary Internal Density				
0.0000	0.0705 ± 0.0004	0.0700 ± 0.0004	0.0716 ± 0.0004	N/A
0.0010	0.0728 ± 0.0004	0.0725 ± 0.0004	0.0722 ± 0.0004	N/A
0.0100	0.0912 ± 0.0006	0.0910 ± 0.0005	0.0912 ± 0.0005	0.0793 ± 0.0010
0.0250	0.1227 ± 0.0007	0.1231 ± 0.0007	0.1246 ± 0.0008	N/A
0.0500	0.1789 ± 0.0009	0.1795 ± 0.0009	0.1779 ± 0.0009	0.1612 ± 0.0018
0.0750	0.2285 ± 0.0011	0.2294 ± 0.0011	0.2292 ± 0.0011	N/A
0.1000	0.2741 ± 0.0012	0.2772 ± 0.0013	0.2771 ± 0.0012	0.2513 ± 0.0025
0.2000	0.4207 ± 0.0016	0.4211 ± 0.0016	0.4178 ± 0.0017	0.3886 ± 0.0032
0.4000	0.5868 ± 0.0019	0.5861 ± 0.0018	0.5864 ± 0.0019	0.5170 ± 0.0037
0.6000	0.6831 ± 0.0021	0.6792 ± 0.0020	0.6817 ± 0.0019	0.5829 ± 0.0037
0.8000	0.7511 ± 0.0020	0.7515 ± 0.0020	0.7539 ± 0.0020	0.6289 ± 0.0041
0.9000	0.7830 ± 0.0019	0.7773 ± 0.0021	0.7827 ± 0.0020	N/A
1.0000	0.8072 ± 0.0019	0.8105 ± 0.0020	0.8102 ± 0.0019	0.6639 ± 0.0041
Wet Interior, Vary External Density				
0.0000	0.8139 ± 0.0021	0.8067 ± 0.0020	0.8080 ± 0.0022	N/A
0.0010	0.8116 ± 0.0020	0.8128 ± 0.0020	0.8136 ± 0.0023	N/A
0.0100	0.8108 ± 0.0021	0.8061 ± 0.0019	0.8085 ± 0.0022	N/A
0.0250	0.8078 ± 0.0019	0.8107 ± 0.0021	0.8074 ± 0.0021	N/A
0.0500	0.8066 ± 0.0022	0.8082 ± 0.0020	0.8072 ± 0.0020	N/A
0.0750	0.8113 ± 0.0020	0.8054 ± 0.0022	0.8082 ± 0.0022	N/A
0.1000	0.8097 ± 0.0020	0.8075 ± 0.0019	0.8081 ± 0.0019	N/A
0.2000	0.8133 ± 0.0020	0.8075 ± 0.0023	0.8087 ± 0.0020	N/A
0.4000	0.8096 ± 0.0018	0.8113 ± 0.0020	0.8087 ± 0.0018	N/A
0.6000	0.8110 ± 0.0018	0.8098 ± 0.0020	0.8103 ± 0.0020	N/A
0.8000	0.8072 ± 0.0023	0.8108 ± 0.0019	0.8096 ± 0.0018	N/A
0.9000	0.8133 ± 0.0021	0.8080 ± 0.0021	0.8069 ± 0.0020	N/A
1.0000	0.8107 ± 0.0024	0.8096 ± 0.0022	0.8103 ± 0.0021	N/A
Vary Interior and Exterior Density Simultaneously				
0.0000	0.0705 ± 0.0004	0.0700 ± 0.0004	0.0716 ± 0.0004	N/A
0.0010	0.0736 ± 0.0004	0.0724 ± 0.0005	0.0733 ± 0.0004	N/A
0.0100	0.0906 ± 0.0005	0.0909 ± 0.0005	0.0895 ± 0.0005	N/A
0.0250	0.1239 ± 0.0007	0.1244 ± 0.0007	0.1245 ± 0.0007	N/A
0.0500	0.1774 ± 0.0008	0.1774 ± 0.0009	0.1778 ± 0.0009	N/A
0.0750	0.2291 ± 0.0011	0.2272 ± 0.0010	0.2307 ± 0.0010	N/A
0.1000	0.2750 ± 0.0011	0.2741 ± 0.0012	0.2753 ± 0.0013	N/A
0.2000	0.4204 ± 0.0016	0.4215 ± 0.0016	0.4187 ± 0.0015	N/A
0.4000	0.5809 ± 0.0018	0.5829 ± 0.0018	0.5825 ± 0.0019	N/A
0.6000	0.6833 ± 0.0020	0.6811 ± 0.0021	0.6802 ± 0.0020	N/A
0.8000	0.7547 ± 0.0020	0.7521 ± 0.0019	0.7495 ± 0.0022	N/A
0.9000	0.7821 ± 0.0021	0.7822 ± 0.0018	0.7828 ± 0.0021	N/A
1.0000	0.8107 ± 0.0024	0.8096 ± 0.0022	0.8103 ± 0.0021	N/A

Table 6.4.3-7 Reactivity with MTR Fuel vs. Basket Moderator Density, Accident Conditions, Dry Exterior, Infinite Array of Casks

Moderator Specific Gravity	Casks Touching	2 Foot Surface-to-Surface	ISO 242.84 cm Pitch
Dry Exterior, Vary Internal Density			
0.0000	0.3126 ± 0.0009	0.1031 ± 0.0005	0.1000 ± 0.0005
0.0010	0.3169 ± 0.0009	0.1071 ± 0.0005	0.1024 ± 0.0005
0.0100	0.3493 ± 0.0010	0.1316 ± 0.0006	0.1266 ± 0.0006
0.0250	0.3980 ± 0.0010	0.1720 ± 0.0008	0.1686 ± 0.0007
0.0500	0.4629 ± 0.0011	0.2343 ± 0.0010	0.2336 ± 0.0010
0.0750	0.5152 ± 0.0013	0.2910 ± 0.0010	0.2845 ± 0.0012
0.1000	0.5592 ± 0.0015	0.3425 ± 0.0012	0.3335 ± 0.0013
0.2000	0.6643 ± 0.0018	0.4836 ± 0.0014	0.4830 ± 0.0016
0.4000	0.7625 ± 0.0019	0.6440 ± 0.0018	0.6424 ± 0.0019
0.6000	0.8138 ± 0.0021	0.7390 ± 0.0019	0.7367 ± 0.0020
0.8000	0.8598 ± 0.0021	0.8138 ± 0.0021	0.8061 ± 0.0021
0.9000	0.8777 ± 0.0022	0.8428 ± 0.0021	0.8411 ± 0.0019
1.0000	0.9005 ± 0.0021	0.8717 ± 0.0021	0.8690 ± 0.0019
Wet Interior, Vary External Density			
0.0000	0.9005 ± 0.0021	0.8694 ± 0.0021	0.8739 ± 0.0020
0.0010	0.8975 ± 0.0020	0.8686 ± 0.0023	0.8680 ± 0.0022
0.0100	0.8851 ± 0.0022	0.8673 ± 0.0020	0.8683 ± 0.0021
0.0250	0.8737 ± 0.0022	0.8648 ± 0.0022	0.8671 ± 0.0020
0.0500	0.8709 ± 0.0020	0.8656 ± 0.0021	0.8648 ± 0.0022
0.0750	0.8681 ± 0.0020	0.8648 ± 0.0020	0.8658 ± 0.0020
0.1000	0.8645 ± 0.0019	0.8614 ± 0.0020	0.8618 ± 0.0020
0.2000	0.8625 ± 0.0020	0.8632 ± 0.0021	0.8616 ± 0.0021
0.4000	0.8625 ± 0.0020	0.8601 ± 0.0022	0.8594 ± 0.0019
0.6000	0.8592 ± 0.0021	0.8589 ± 0.0020	0.8591 ± 0.0021
0.8000	0.8600 ± 0.0020	0.8611 ± 0.0020	0.8589 ± 0.0021
0.9000	0.8629 ± 0.0020	0.8599 ± 0.0022	0.8584 ± 0.0021
1.0000	0.8606 ± 0.0023	0.8591 ± 0.0022	0.8602 ± 0.0020
Vary Interior and Exterior Density Simultaneously			
0.0000	0.3126 ± 0.0009	0.1031 ± 0.0005	0.1000 ± 0.0005
0.0010	0.2985 ± 0.0008	0.1054 ± 0.0005	0.1025 ± 0.0005
0.0100	0.2306 ± 0.0008	0.1270 ± 0.0006	0.1245 ± 0.0007
0.0250	0.2097 ± 0.0009	0.1579 ± 0.0008	0.1594 ± 0.0008
0.0500	0.2286 ± 0.0010	0.2072 ± 0.0010	0.2092 ± 0.0009
0.0750	0.2640 ± 0.0011	0.2534 ± 0.0011	0.2533 ± 0.0012
0.1000	0.2996 ± 0.0011	0.2963 ± 0.0012	0.2972 ± 0.0012
0.2000	0.4348 ± 0.0015	0.4337 ± 0.0015	0.4332 ± 0.0017
0.4000	0.6048 ± 0.0017	0.6066 ± 0.0020	0.6037 ± 0.0018
0.6000	0.7126 ± 0.0021	0.7144 ± 0.0020	0.7134 ± 0.0019
0.8000	0.7960 ± 0.0019	0.7892 ± 0.0022	0.7984 ± 0.0022
0.9000	0.8295 ± 0.0020	0.8303 ± 0.0021	0.8289 ± 0.0021
1.0000	0.8606 ± 0.0023	0.8591 ± 0.0022	0.8602 ± 0.0020

Table 6.4.3-8 MTR Fuel Element Rotation Perturbation Study

Case	k_{eff}	σ	$k_{eff} + 2\sigma$
All Horizontal Plates	0.6011	0.0027	0.6065
Corners-Only Horizontal	0.6033	0.0025	0.6083
Corners-Only Vertical	0.6045	0.0027	0.6099
All Vertical Plates	0.6053	0.0027	0.6107

Table 6.4.3-9 MTR Basket/Center Fuel Element Perturbation Study

Fuel Type	Center Element Configuration	k_{eff}	σ	$k_{eff} + 2\sigma$
Intact Elements	Centered	0.8107	0.0020	0.8147
Intact Elements	Corner	0.8066	0.0021	0.8108
Intact Elements	Right	0.8122	0.0021	0.8164
Intact Elements	Up	0.8133	0.0021	0.8175
Expanded Plates	Centered	0.8606	0.0023	0.8652
Expanded Plates	Right	0.8547	0.0019	0.8585

Table 6.4.3-10 Mixed HEU/LEU MTR Fuel Perturbation Study

Case	k_{eff}	σ	$k_{eff} + 2\sigma$
9 HEU	0.6011	0.0027	0.6065
8 HEU 1 LEU centered	0.6033	0.0030	0.6093
6 HEU 3 LEU center row	0.5976	0.0030	0.6036
4 HEU 5 LEU + pattern	0.5894	0.0026	0.5946
8 LEU 1 HEU centered	0.5789	0.0027	0.5843
9 LEU	0.5685	0.0025	0.5735

Table 6.4.3-11 MTR Single Package 10 CFR 71.55(b)(3) Evaluation k_{eff} Summary

Description	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$
Single Cask / Inner Shell Reflected with H_2O	0.7682 ± 0.0021	0.7724
Single Cask / Inner Shell and Lead Reflected with H_2O	0.8043 ± 0.0021	0.8085
Single Cask / Inner Shell, Lead & Outer Shell Reflected with H_2O	0.8047 ± 0.0022	0.8091
Single Intact Cask Reflected with H_2O	0.8094 ± 0.0021	0.8136

Table 6.4.3-12 MTR Fuel Uranium Weight Percentage Perturbations

Fuel Type	U wt%[1]	Effective Al Density (g/cm^3)	% of Theoretical Al Density	k_{eff}	Δk_{eff}
HEU HFBR	30%[2]	2.58	96%	1.2396 ± 0.0022	n/a
	45%	1.25	46%	1.2426 ± 0.0027	0.0030
HEU PRR	12.5%[2]	2.65	98%	1.1594 ± 0.0027	n/a
	18.75%	1.64	61%	1.1679 ± 0.0025	0.0085
	33%	0.77	28%	1.1763 ± 0.0024	0.0169
HEU THOR	8.0%[2]	2.67	99%	0.9479 ± 0.0039	n/a
	12%	1.75	65%	0.9530 ± 0.0035	0.0051
	20%	0.95	35%	0.9647 ± 0.0035	0.0168
LEU THOR	40%[2]	2.46	91%	1.0600 ± 0.0032	n/a
	50%	1.64	61%	1.0628 ± 0.0035	0.0028
	60%	1.09	41%	1.0718 ± 0.0036	0.0118
LEU IEA	40%[2]	2.47	91%	1.0219 ± 0.0039	n/a
	50%	1.64	61%	1.0266 ± 0.0036	0.0047
	60%	1.09	40%	1.0272 ± 0.0042	0.0053

Notes:

(1) Uranium in Fuel Composition (wt %)
(2) nominal value
n/a – not applicable

Table 6.4.3-13 MEU MTR Unit Cell k_{eff} Comparison (Enrichment Variation)

Description	k_{eff}	σ
13.91 g ^{235}U - 44.44 wt% ^{235}U – Al Clad	1.2476	0.0008
13.91 g ^{235}U - 44.44 wt% ^{235}U – AlMg Clad	1.2475	0.0008
14.5 g ^{235}U – 35 wt% ^{235}U – Al Clad	1.2501	0.0008
14.5 g ^{235}U – 50 wt% ^{235}U – Al Clad	1.2642	0.0008
14.5 g ^{235}U – 80 wt% ^{235}U – Al Clad	1.2844	0.0008

Table 6.4.3-14 MEU MTR Basket k_{eff} Comparison (Plate Location)

Number of Plates	Configuration[1]	k_{eff}	σ
23	A	0.8242	0.0011
22	A	0.8230	0.0010
21	A	0.8176	0.0010
23	B	0.8312	0.0010
22	B	0.8265	0.0010
21	B	0.8206	0.0010

Notes:

1 Configuration A places the outer fuel plates separated from the basket plates by a space equal to one-half the spacing between the interior plates. Configuration B places the plates directly against the basket plates.

Table 6.4.3-15 Physical Characteristics of McMaster MTR Fuels

Fuel Parameters	10 Plate	18 Plate
Element Width (cm)	7.61	7.61
Element Depth (cm)	8.03	8.23
Side Plate Thickness (cm)	0.48 (0.19 inch)	0.48
No. of Plates	10	18
Plate Thickness (cm)	0.153 ± 0.005	0.127 ± 0.005
Active Fuel Length (cm)	61.0	59.1 to 60.0
Active Fuel Width (cm)	7.3	5.92 to 6.54
Active Fuel Thickness (cm)	0.051	0.0508
Clad Thickness (cm)	0.05 ± 0.008	0.038 ± 0.008
Plate Pitch	0.319 ± 0.004 inch	0.442 ± 0.004 cm
Fuel Composition	U-Al	U-Al
Wt% ^{235}U (nominal)	93.1 ± 0.1	93.1 ± 0.1
^{235}U per Fuel Element (g)	161.4 ± 0.1	212.1 ± 6
^{235}U per Plate (g)	16.0 ± 0.48	12.25 ± 0.37
Alloy per Plate (Al) (g)	58.9	50.4

Table 6.4.3-16 Reactivity of Various Parameter Variations for 10-Plate McMaster Element

k_{eff}	σ	$k_{eff}+2\sigma$	Δk_{eff}	$\Delta k_{eff}/\sigma$	Description
1.11679	0.00083	1.11845	-	-	nominal fuel (0.153 cm plate, 0.051 cm meat, 0.8103 cm pitch)
1.11451	0.00077	1.11605	-0.00240	-3.1	decreased pitch -0.010 cm
1.11975	0.00078	1.12131	0.00286	3.7	increased pitch +0.010 cm
1.12042	0.00079	1.12200	0.00069	0.9	max pitch and decreased plate thickness - 0.008
1.12020	0.00080	1.12180	0.00049	0.6	max pitch and increased plate thickness +0.008
1.11680	0.00080	1.11840	-0.00291	-3.6	max pitch/min plate thickness and decreased fuel meat thick. (0.029 cm)
1.12154	0.00080	1.12314	0.00183	2.3	max pitch/min plate thickness and increased fuel meat thick. (0.061 cm)
1.12346	0.00081	1.12508	0.00377	4.7	max pitch/min plate thickness and increased fuel meat thick. (0.077 cm)
1.13520	0.00080	1.13680	0.01549	19.4	max pitch/min plate thickness and increased fuel meat thick. (0.145 cm)

Table 6.4.3-17 Reactivity of Various Parameter Variations for 18-Plate McMaster Element

k_{eff}	σ	$k_{eff}+2\sigma$	Δk_{eff}	$\Delta k_{eff}/\sigma$	Description
1.17730	0.00111	1.17952	-	-	nominal fuel (0.127 cm plate, 0.051 cm meat, 0.8103 cm pitch)
1.17068	0.00117	1.17302	-0.00650	-5.6	decreased pitch -0.010 cm
1.17810	0.00112	1.18034	0.00082	0.7	increased pitch +0.010 cm
1.17956	0.00119	1.18194	0.00160	1.3	max pitch and decreased plate thickness -0.008
1.17753	0.00117	1.17987	-0.00047	-0.4	max pitch and increased plate thickness +0.008
1.17646	0.00114	1.17874	-0.00160	-1.4	max pitch/min plate thickness and decreased fuel meat thick. (0.029 cm)
1.18002	0.00117	1.18236	0.00202	1.7	max pitch/min plate thickness and increased fuel meat thick. (0.061 cm)
1.19393	0.00116	1.19625	0.01591	13.7	max pitch/min plate thickness and increased fuel meat thick. (0.119 cm)
1.15124	0.00122	1.15368	-0.02584	-21.2	nominal case at minimum active fuel width (5.92 cm)

Table 6.4.3-18 MTR Limiting Fuel Configurations

Parameter	HEU/MEU	LEU
Min. side plate thickness (cm)	0.45	0.475
Min. side plate length (cm)	7.6	7.62
Min. plate thickness (cm)	0.122	0.127
Min. clad thickness (cm)	0.024	0.033
Maximum number of fuel plates	23	21
U^{235} content per plate (g)	19.5	21
Enrichment (wt % ^{235}U)	94	20
Max. Active Width (cm)	6.54(1)	6.0
Max. Active Fuel Height (cm)	62.5	60.0
Max. Uranium Wt %	50(2)	74

Notes:
1. A 7.3 cm active fuel width is modeled for reduced fissile material mass (^{235}U) and/or a reduced number of fuel plates.
2. Based on MEU fuel.

Table 6.4.3-19 Initial Fuel Configurations for MTR Bounding Evaluations

Variable	Value
Min. side plate thickness (cm)	0.40
Min. side plate length (cm)	7.5
Min. plate thickness (cm)	0.115
Min. clad thickness (cm)	0.020
Maximum number of fuel plates	23
U^{235} content per plate (g)	21
Enrichment (wt % ^{235}U)	94
Max. Active Width (cm)	6.6
Max. Active Fuel Height (cm)	65
Max. Uranium Wt %	50
Element/Plate Material Above/Below Active Fuel (cm)	0.7

Table 6.4.3-20 Reactivity Impact of Parameter Variations in the Finite Cask Model

Set	Number of Plates	^{235}U per Plate (g)	U wt%	^{235}U wt%	Fuel Width (cm)	Fuel Height (cm)	Additional Description of File Parameters	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
A	23	20	50%	94%	6.6	65.0	Plates at bottom	0.91822	0.00093	0.92008	0.93818	-0.01358	-14.6
	23	20	50%	94%	6.6	65.0	Axial shift to cask center	0.92549	0.00094	0.92737	0.94547	-0.00631	-6.7
	23	20	50%	94%	6.6	65.0	Axial shift alternating	0.93180	0.00091	0.93362	0.95172	--	--
B	23	20	50%	94%	6.6	56.0	Alternating shift (a.s.)	0.94724	0.00091	0.94906	0.96716	0.01544	17.0
	23	20	50%	94%	6.6	60.0	Alternating shift	0.94157	0.00092	0.94341	0.96151	0.00977	10.6
	23	20	50%	94%	6.6	71.752	Alternating shift	0.93015	0.00092	0.93199	0.95009	-0.00165	-1.8
C	23	30	50%	94%	6.6	56.0	Alternating shift	1.01772	0.00097	1.01966	1.03776	0.09128	94.1
	23	19	50%	94%	6.6	56.0	Alternating shift	0.93739	0.00091	0.93921	0.95731	0.01095	12.0
	23	18	50%	94%	6.6	56.0	Alternating shift	0.92644	0.00093	0.92830	0.94640	--	--
	23	17	50%	94%	6.6	56.0	Alternating shift	0.91468	0.00099	0.91666	0.93476	-0.01176	-11.9
	23	18	50%	50%	6.6	56.0	a.s.; MEU Core	0.90732	0.00092	0.90916	0.92726	-0.01912	-20.8
D	21	18	50%	94%	6.6	56.0	Alternating shift	0.91806	0.00092	0.91990	0.93800	-0.00838	-9.1
	19	18	50%	94%	6.6	56.0	Alternating shift	0.90657	0.00097	0.90851	0.92661	-0.01987	-20.5
E	23	18	75%	94%	6.6	56.0	Alternating shift	0.92567	0.00091	0.92749	0.94559	-0.00077	-0.8
	23	18	30%	94%	6.6	56.0	Alternating shift	0.92753	0.00097	0.92947	0.94757	0.00109	1.1
	23	18	50%	94%	6.6	56.0	a.s.; pitch -0.02 cm	0.91104	0.00096	0.91296	0.93106	-0.01540	-16.0
	23	18	50%	94%	6.6	56.0	a.s.; pitch -0.04 cm	0.89691	0.00095	0.89881	0.91691	-0.02953	-31.1
	23	18	50%	94%	6.6	56.0	a.s.; side plate lateral shift	0.92711	0.00094	0.92899	0.94709	0.00067	0.7
	23	18	50%	94%	6.6	56.0	a.s.; side plates 0.5 cm	0.92357	0.00093	0.92543	0.94353	-0.00287	-3.1
	23	18	50%	94%	6.6	56.0	a.s.; side plates 0.3 cm	0.92975	0.00093	0.93161	0.94971	0.00331	3.6
	23	18	50%	94%	6.6	56.0	a.s.; canister plates added	0.89768	0.00193	0.90154	0.91964	-0.02876	-14.9
	23	18	50%	94%	6.6	56.0	a.s.; clad width +1cm	0.92573	0.00097	0.92767	0.94577	-0.00071	-0.7
	23	18	50%	94%	6.6	56.0	a.s.; clad length +4cm	0.91304	0.00094	0.91492	0.93302	-0.01340	-14.3
	23	18	50%	94%	6.6	56.0	a.s.; plate 0.125, clad 0.025	0.91525	0.00094	0.91713	0.93523	-0.01119	-11.9
	23	18	50%	94%	6.6	56.0	a.s.; plate 0.115, clad 0.020	0.91405	0.00094	0.91593	0.93403	-0.01239	-13.2
F	19	20	50%	94%	6.6	56.0	Alternating shift	0.92822	0.00096	0.93014	0.94824	--	--
G	23	18	50%	94%	7.3	56.0	Alternating shift	0.94448	0.00090	0.94628	0.96438	--	--
	23	17	50%	94%	7.3	56.0	Alternating shift	0.93237	0.00092	0.93421	0.95231	--	--
	23	16.5	50%	94%	7.3	56.0	Alternating shift	0.92550	0.00094	0.92738	0.94548	--	--
H	23	22	75%	25%	7.3	56.0	Alternating shift; LEU Core	0.94090	0.00091	0.94272	0.96082	--	--
	23	22	75%	25%	6.6	56.0	Alternating shift; LEU Core	0.91993	0.00092	0.92177	0.93987	--	--
I	34	11	50%	94%	6.6	26.0	Alternating shift	0.87068	0.00094	0.87256	0.89066	--	--
	34	11	50%	94%	6.6	30.0	Alternating shift	0.87146	0.00095	0.87336	0.89146	--	--
	17	22	50%	94%	6.6	26.0	Fuel split by 2 cm spacer	0.92616	0.00091	0.92798	0.94608	--	--

Table 6.4.3-21 Baseline MTR Bounding Configurations

Parameter[1]	Generic	NISTR[2]
Plate thickness	≥ 0.115 cm	≥ 0.115 cm
Clad thickness	≥ 0.02 cm	≥ 0.02 cm
Number of fuel plates	≤ 23[3]	≤ 17
^{235}U content per plate	≤ 18 g[3,4,5]	≤ 22 g
Enrichment wt % ^{235}U	≤ 94[4]	≤ 94
Active width	≤ 6.6 cm[5]	≤ 6.6 cm
Active fuel height	≥ 56 cm	≥ 54 cm
Maximum reactivity (k_s)	0.9482	0.9461

Notes:
1. Loose fuel plates meeting the requirements in this table must be loaded into a MTR plate canister.
2. Fuel plates may be cut in half with each half limited to 11g ^{235}U and an active fuel length between 27 and 30 cm.
3. At a 19 fuel plate maximum, the plates are limited to 20g ^{235}U per plate.
4. LEU fuel plate with up to 22g ^{235}U may be loaded at a maximum enrichment of 25 wt % ^{235}U.
5. At a maximum active fuel width of 7.3 cm, the plates are limited to 16.5g ^{235}U.

Table 6.4.3-22 High Fissile Mass MTR Fuel – Bounding Parameter Analysis

Parameter	Variation From Baseline (Generic) MTR		
	Increased Plate Thickness and Fissile Mass [1]	Increased Plate Thickness and Fissile Mass and Decreased Number of Plates	Increased Fissile Mass and Decreased Number of Plates
Plate thickness [cm]	≥ 0.123	≥ 0.200	≥ 0.115
Clad thickness [cm]	≥ 0.02	≥ 0.02	≥ 0.02
Number of fuel plates	≤ 23	≤ 19	≤ 17
^{235}U content per plate [g]	≤ 20	≤ 21	≤ 21
Enrichment [wt % ^{235}U]	≤ 94	≤ 94	≤ 94
Active Width [cm]	≤ 6.6	≤ 6.6	≤ 6.6
Active Fuel Height [cm]	≥ 56	≥ 56	≥ 56
Maximum reactivity (k_s)	0.9488	0.8753	0.9451

1.) Requires a minimum 4 cm of fuel element hardware (or spacer material) separating the fuel segments axially.

Table 6.4.3-23 MTR High Fissile Content Loading Evaluation (460 g ^{235}U)

Number of Plates	^{235}U per Plate (g)	Fuel Width (cm)	Fuel Height (cm)	Plate Thickness (cm)	Offset (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk
23	20.0	6.6	56.0	0.115	0.7	0.94724	0.00091	0.94906	0.96716	--
23	20.0	6.6	56.0	0.115	1.7	0.94161	0.00093	0.94347	0.96157	-0.00563
23	20.0	6.6	56.0	0.115	2.0	0.93810	0.00094	0.93998	0.95808	-0.00914
23	20.0	6.6	56.0	0.115	3.0	0.93339	0.00112	0.93563	0.95373	-0.01385
23	20.0	6.6	56.0	0.115	4.0	0.92770	0.00107	0.92984	0.94794	-0.01954
23	20.0	6.6	56.0	0.123	0.7	0.93729	0.00095	0.93919	0.95729	-0.00995
23	20.0	6.6	56.0	0.123	1.7	0.93036	0.00093	0.93222	0.95032	-0.01688
23	20.0	6.6	56.0	0.123	2.0	0.92883	0.00093	0.93069	0.94879	-0.01841
19	21.0	6.6	56.0	0.200	0.7	0.85540	0.0093	0.85726	0.87526	--
17	21.0	6.6	56.0	0.115	0.7	0.92509	0.0095	0.92699	0.94509	--

Table 6.4.3-24 LEU MTR Active Fuel Width Increase Evaluation

Number of Plates	^{235}U per Plate (g)	U wt%	^{235}U wt%	Fuel Width (cm)	Fuel Height (cm)	Plate Thickness (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	k_s
23	22.0	75%	25%	6.6	56.0	0.115	0.91993	0.00092	0.92177	0.93987
23	22.0	75%	25%	7.0	56.0	0.115	0.93387	0.00093	0.93573	0.95383
23	22.0	75%	25%	7.0	56.0	0.119	0.92717	0.00090	0.92897	0.94707
23	21.5	75%	25%	7.0	56.0	0.115	0.92915	0.00087	0.93089	0.94899
23	22.0	75%	25%	7.0	63.0	0.115	0.92154	0.00087	0.92328	0.94138
17	22.0	75%	25%	7.1	56.0	0.115	0.90885	0.00093	0.91071	0.92881
23	22.0	75%	25%	7.1	56.0	0.200	0.81898	0.00089	0.82076	0.83886
23	22.0	75%	25%	7.15	56.0	0.119	0.93169	0.00086	0.93341	0.95151
22	22.0	75%	25%	7.15	56.0	0.119	0.92981	0.00092	0.93165	0.94975
23	21.5	75%	25%	7.15	56.0	0.119	0.92662	0.00090	0.92842	0.94652
23	22.0	75%	25%	7.15	61.0	0.119	0.92512	0.00091	0.92694	0.94504

Table 6.4.3-25 Summary of LEU MTR Bounding Configurations

Parameter	LEU Baseline	7.0 cm Active Width			7.1 cm Active Width		7.15 cm Active Width		
		Plate Thickness	^{235}U Content	Active Length	Plate Thickness	Number of Plates	Number of Plates	^{235}U Content	Active Length
Plate thickness [cm]	≥ 0.115	≥ 0.119	≥ 0.115	≥ 0.115	≥ 0.200	≥ 0.115	≥ 0.119	≥ 0.119	≥ 0.119
Clad thickness [cm]	≥ 0.02	≥ 0.02	≥ 0.02	≥ 0.02	≥ 0.02	≥ 0.02	≥ 0.02	≥ 0.02	≥ 0.02
Number of fuel plates	≤ 23	≤ 23	≤ 23	≤ 23	≤ 23	≤ 17	≤ 22	≤ 23	≤ 23
^{235}U content per plate [g]	≤ 22	≤ 22	≤ 21.5	≤ 22	≤ 22	≤ 22	≤ 22	≤ 21.5	≤ 22
Enrichment [wt % ^{235}U]	≤ 25	≤ 25	≤ 25	≤ 25	≤ 25	≤ 25	≤ 25	≤ 25	≤ 25
Active Width [cm]	≤ 6.6	≤ 7.0	≤ 7.0	≤ 7.0	≤ 7.1	≤ 7.1	≤ 7.15	≤ 7.15	≤ 7.15
Active Fuel Height [cm]	≥ 56	≥ 56	≥ 56	≥ 63	≥ 56	≥ 56	≥ 56	≥ 56	≥ 61
Maximum reactivity (k_s)	0.93987	0.94707	0.94899	0.94138	0.83886	0.92881	0.94975	0.94652	0.94504

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

Fuel ID	Plate thickness [cm]	Clad thickness [cm]	Number of fuel plates	^{235}U per plate [g]	Enrichment [wt % ^{235}U]	Active Width [cm]	Active Height [cm]	Fuel Offset [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
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 gram ^{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:

(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 6.4.3-28 LEU High Fissile Mass Bounding Configuration

Parameter	Value
Number of Elements per Basket	4
Plate thickness [cm]	≥ 0.115
Clad thickness [cm]	≥ 0.02
Number of fuel plates	≤ 23
^{235}U content per plate [g]	≤ 32
Enrichment [wt % ^{235}U]	≤ 25
Active Width [cm]	≤ 7.3
Active Fuel Height [cm]	≥ 56

Table 6.4.3-29 Cask Interior Moderator Density and Blocked Cell Study Results

Water Density	k_{eff} - No Block in Cells			k_{eff} - Cells Blocked		
(g/cc)	Top/Bottom	Middle	All	Top/Bottom	Middle	All
0.0001	0.27234	0.26713	0.23817	0.27245	0.26739	0.23954
0.05	0.40294	0.39430	0.35646	0.40162	0.39373	0.35399
0.1	0.48197	0.47202	0.42209	0.48063	0.47190	0.41877
0.15	0.53747	0.52908	0.46242	0.53688	0.52916	0.46267
0.2	0.58102	0.57382	0.49272	0.57990	0.57397	0.49199
0.25	0.61913	0.61263	0.51513	0.61741	0.61234	0.51569
0.3	0.64772	0.64313	0.53051	0.64984	0.64416	0.53452
0.35	0.67598	0.67399	0.54706	0.67618	0.67494	0.54860
0.4	0.70176	0.70168	0.56069	0.70205	0.70071	0.56383
0.45	0.72644	0.72472	0.57294	0.72649	0.72528	0.57630
0.5	0.74703	0.74779	0.58607	0.74782	0.74773	0.58752
0.55	0.76761	0.76773	0.59845	0.76797	0.77091	0.60062
0.6	0.78894	0.78853	0.60810	0.78536	0.78906	0.61363
0.65	0.80652	0.80700	0.61890	0.80456	0.80727	0.62501
0.7	0.82463	0.82581	0.63197	0.82236	0.82511	0.63753
0.75	0.83955	0.84342	0.64340	0.84073	0.84144	0.64965
0.8	0.85813	0.86053	0.65486	0.86006	0.86031	0.65927
0.85	0.87370	0.87748	0.66785	0.87507	0.87554	0.67184
0.875	0.88346	0.88416	0.67243	0.88172	0.88412	0.67783
0.9	0.89071	0.89426	0.67804	0.89148	0.89217	0.68348
0.925	0.89848	0.89942	0.68416	0.89951	0.90069	0.68737
0.95	0.90695	0.90763	0.69048	0.90568	0.90782	0.69599
0.975	0.91266	0.91418	0.69592	0.91351	0.91492	0.70057
0.9982	0.92071	0.92323	0.70202	0.91870	0.92264	0.70720

6.4.4 PWR and BWR Rods in a Rod Holder or Fuel Assembly Lattice

The NAC-LWT cask may transport up to 25 intact PWR or BWR fuel rods that are in a fuel rod holder or fuel assembly lattice. Up to 14 of 25 PWR or BWR fuel rods in a fuel rod holder may be classified as damaged.

6.4.4.1 Intact PWR and BWR Rods in a Rod Holder or Fuel Assembly Lattice

This section presents the criticality analysis for the NAC-LWT with up to 25 PWR or 25 BWR fuel rods of up to 5.0 w/o ^{235}U initial enrichment. No credit is taken for geometry control that is provided by the rod holder and no rod positions are specified for the rods in the lattice. Since various fuel rod arrangements may be shipped, the criticality of the PWR and BWR rods in the NAC-LWT cask cavity is studied to determine the optimum pitch and, therefore, the maximum k_{eff} for the cask. Both PWR and BWR studies evaluate rods unrestrained in the cavity. No credit is taken for any basket structure.

Cask k_{eff} versus rod fuel rod pitch is shown in Table 6.4.4-1 for the PWR analysis and Table 6.4.4-5 for the BWR study. The rod pitch, which corresponds to center-to-center spacing in a triangular and most reactive lattice formation, is varied from 1.128 cm to 5.997 cm. The limits 1.1278 cm and 5.997 cm correspond to the most compact and the most dispersed PWR rod formations in a triangular pitch, respectively. Due to the larger rod diameter, the BWR range is from 1.640 cm to 5.228 cm. These evaluations are based on an infinite array of casks with water at 1 gm/cc between the fuel rods and in the basket cavity. The neutron shield and cask exterior do not contain water and the results are reported for wet and dry clad gap configurations. Table 6.4.4-1 and Table 6.4.4-5 show that a broad peak in k_{eff} occurs in the rod pitch range from 2.5 to 3.5 cm for the PWR rods and 3.0 to 4.0 for the BWR rods, and that there is no statistically significant difference between wet gap and dry gap reactivities. Therefore, the most reactive configuration is chosen for the PWR rod system with a wet gap and a pitch of 2.922 cm and $k_{eff} = 0.6082 \pm 0.0035$. The BWR rod most reactive configuration occurs at a pitch of 3.691 cm and a dry gap $k_{eff} = 0.7045 \pm 0.0033$. These pitches will be used in the subsequent moderator studies.

25 PWR or BWR Rods Moderator Density Criticality Evaluations for Normal Conditions

With the fuel rods at optimum pitch (2.922 cm, PWR, or 3.691 cm, BWR), Table 6.4.4-2 and Table 6.4.4-6 present the cask k_{eff} as a function of moderator density inside and outside the cask.

An infinite array of casks on a square pitch is modeled at three cask pitches: touching (99.7 cm), 2-foot surface-to-surface (160.7 cm), and ISO-container spacing (242.84 cm). The water moderator density is varied from 1.0 gm/cc to 0.0 gm/cc, and for normal conditions it is assumed that the clad gap is dry and the neutron shield is filled with water. The results show an increase in reactivity with increasing internal moderator density. This indicates that moderator density changes due to increasing temperature have a negative reactivity effect. Low density moderation inside or outside of the cask does not produce abrupt increases in reactivity in comparison to other density values. There is no optimum at low density as expected from an undermoderated system. The calculations show that cask pitch has no significant impact on the reactivity of the cask array under normal conditions and that k_{eff} does not vary significantly when varying external moderator with constant full density internal moderator. For the PWR cases, the external moderator does not affect reactivity within statistical limits, and the most reactive case is chosen with both internal and external moderator density at 1.0 gm/cc. The k_{eff} in this case is 0.6070 ± 0.0033. Similarly, the most reactive BWR case is for a fully moderated interior, but a dry exterior, resulting in a k_{eff} of 0.7045 ± 0.0038. The external moderator does not affect reactivity since the fully moderated exterior case produces a slightly lower k_{eff} that is within statistics. For both the PWR and BWR analysis, the k_{eff} for the normal condition cask array with a dry cavity is very subcritical, i.e. ~ <0.1 and is insensitive to external moderator density variations.

Thus, up to 25 PWR or BWR rods with 5.0 w/o ^{235}U initial enrichment are acceptable in the NAC-LWT cask. An infinite array of casks with optimum interspersed moderation has been analyzed and the NAC-LWT cask with up to 25 PWR or BWR fuel rod of up to 5.0 w/o ^{235}U remains subcritical in all of the normal transport and accident conditions.

25 PWR or BWR Rods Moderator Density Criticality Evaluations for Accident Conditions

With the fuel rods at optimum pitch, Table 6.4.4-3 (PWR) and Table 6.4.4-7 (BWR) show the cask k_{eff} for the most reactive accident condition configuration as a function of moderator density variation in the cavity, neutron shield tank and outside the cask. Again, three cask spacings are presented: touching (99.7 cm), 2-foot surface-to-surface (160.7 cm), and the ISO-container spacing (242.84 cm). Moderator density is varied from 1.0 gm/cc to 0.0 gm/cc. For accident conditions it is assumed that the clad gap contains full density water and that the neutron shield tank is punctured and the moderator density in the tank is the same as the exterior moderator density. Again, the results show an increase in reactivity with increasing internal moderator density. Low density moderation inside or outside of the cask does not produce abrupt increases in reactivity in comparison to other density values. For both the PWR and BWR analyses, the calculations show that cask pitch does affect reactivity and that the k_{eff} for the accident condition cask array with a dry cavity, neutron shield and exterior is very subcritical, i.e. is less than 0.20. Reactivity is dominated by full density internal moderator. All other variations do not affect

reactivity significantly. Therefore, the most reactive PWR case is chosen with casks touching and the moderator density at 1.0 gm/cc in the cavity and at 0.0 gm/cc in the neutron shield tank as well as exterior. The k_{eff} in this case is 0.6077 ± 0.0030. Likewise, the most reactive BWR case is chosen with casks that are 242.82 cm apart (ISO case) and the moderator density at 1.0 gm/cc in the cavity and at 0.0 gm/cc in the neutron shield tank as well as exterior. The k_{eff} in this case is 0.7135 ± 0.0033.

Single Package Criticality Evaluation

To satisfy 10 CFR 71.55(b)(3), an analysis of the reflection of the containment system (inner shell) by water is performed on a single wet cask. Successive replacement of the cask radial shields with water reflection is also evaluated. The reactivity of the PWR system does not vary with statistical significance as each radial shield of the cask is replaced by water, from a k_{eff} = 0.6008 ± 0.0034 (k_s = 0.6215) for the full cask surrounded by water, to a k_{eff} = 0.6001 ± 0.0030 (k_s = 0.6200) for the inner shell surrounded by water. BWR results are k_{eff}s of 0.6932 and 0.6943 for a full cask reflected and the inner shell water reflected, respectively. The results from this evaluation can be seen in Table 6.4.4-4 (PWR) and Table 6.4.4-8 (BWR).

Conclusion

A calculation of k_s under normal and accident conditions can now be made based on the previous results and based on the KENO-Va validation statistics presented in Section 6.5.1 for low enriched uranium fuel. The value k_s is calculated based on the KENO-Va Monte Carlo average plus any biases and uncertainties associated with the methods and the modeling, i.e.:

$$k_s = k_{eff} + 2\sigma_{mc} + \Delta k_{Bias} + \Delta k_{BU}$$

In the validation presented in Section 6.5.1, a bias of 0.0052 (allowance for under prediction of k_{eff}) and a 95/95 method uncertainty of ± 0.0087 was determined. With this bias and uncertainty, the equation for k_s becomes:

$$k_s = k_{eff} + 2\sigma_{mc} + 0.0052 + 0.0087$$

Thus, k_s = 0.6275 under normal conditions for an infinite array of NAC-LWT casks loaded with 25 PWR design basis fuel rods and a flooded basket cavity and exterior. This is below the 0.95 regulatory limit. Under accident conditions, k_s = 0.6276 for an infinite array of NAC-LWT casks loaded with 25 PWR design basis fuel rods and with a flooded basket cavity and dry neutron shield and exterior.

Under normal conditions, k_s = 0.7251 for an infinite array of NAC-LWT casks loaded with 25 BWR design basis fuel rods and a flooded basket cavity and a dry exterior. This is below the 0.95 regulatory limit. Under accident conditions, k_s = 0.7340 for an infinite array of NAC-LWT casks loaded with 25 BWR design basis fuel rods and with a flooded basket cavity and dry neutron shield and exterior.

For both normal and accident conditions, the calculated k_{eff} values, after correction for biases and uncertainties, are below the 0.95 limit. The analyses demonstrate that, including all calculational and mechanical uncertainties, an infinite array of NAC-LWT casks with 25 PWR or BWR fuel rods remains subcritical under normal and accident conditions.

For both normal and accident conditions, the calculated k_{eff} values, after correction for biases and uncertainties, are below the 0.95 limit. The analyses demonstrate that, including all calculational and mechanical uncertainties, an infinite array of NAC-LWT casks with 25 PWR fuel remains subcritical under normal and accident conditions.

6.4.4.2 Damaged PWR and BWR Rods in a Rod Holder

This section presents the criticality analysis for the NAC-LWT with 25 PWR or BWR fuel rods of up to 5.0 w/o ^{235}U initial enrichment classified as damaged. Although the contents is limited to 14 damaged fuel rods in a 25-rod shipment, the analysis conservatively considers all 25 rods as failing during transport. No credit is taken for any parasitic absorption in the basket, fuel can or rod holder structure. Credit is taken for the rod holder weldment to contain the fissile material during water-fuel mixture studies. Criticality analyses are performed to satisfy the criticality safety requirements of 10 CFR Parts 71.55 and 71.59, as well as IAEA Transportation Safety Standards (TS-R-1). A single cask evaluation is also performed to comply with 10CFR71.55(b)(3). The analyses demonstrate that, including all calculational and mechanical uncertainties, the NAC-LWT is subcritical during normal and accident conditions with up to 25 damaged PWR or BWR rods.

Damaged Fuel Rod Evaluation – Heterogeneous (Rod) Configurations

Damaged fuel rods are evaluated in heterogeneous configurations by analyzing unclad fuel rods in a triangular pitch. Removing the cladding conservatively removes any potential parasitic absorbers while increasing the available volume for water moderator. Three rod arrays are considered: 25 rods, 37 rods, and 61 rods. The latter two arrays are complete hexagonal arrays. The limiting pitch is determined for each PWR and BWR array. The fuel region cross-sectional area is conserved in each of the configurations. The fuel rod radii for the various arrays are summarized in Table 6.4.4-19.

Water Exterior Evaluations

As shown in Tables 6.4.4-9 through 6.4.4-14 and Figures 6.4.4-1 and 6.4.4-2, the system reactivity increases as the number of rods is increased. As the number of rods increases, so does the cross-sectional area occupied by the rod array. Since the canister provides a limited cross-sectional area for the rod array, evaluations for arrays larger than 61 rods are not required.

Based on the can outer width of 5.5 inches (13.97 cm), the can cross-sectional area is 195.16 cm^2. Using the rod radius, rod pitch, and number of rods, the area of an enclosing hexagon is calculated for each of the three PWR and BWR arrays, shown in Table 6.4.4-19. This area is compared to the can area. For both BWR and PWR fuel, the 37-rod array results in an enclosing area that is larger than the can. A further increase in the cross-sectional lattice area, required for maximum reactivity, is seen in the 61-rod array. Therefore, the use of a 61-rod array is bounding for the NAC-LWT with no larger arrays requiring analysis.

Void Exterior/Preferential Flooding Evaluations

To increase the coupling of adjacent casks in the infinite array, system reactivity is evaluated for two additional scenarios: void exterior with fully flooded cask cavity and void exterior with preferentially flooded cask cavity. Preferential flooding removes the cask interior moderator outside the fuel rod lattice providing for increased neutronic interaction between casks in the infinite array. The 61-rod hexagonal array is employed.

As shown in Tables 6.4.4-15 and 6.4.4-16, the void exterior, completely flooded cask cavity, scenario produced slightly higher reactivities than the scenario containing a water cask exterior. This is the result of increased neutronic interaction between casks and indicates the need for preferential flooding evaluations.

The preferential flooding model encloses the 61-rod array in a fully flooded cylinder with the remaining cask cavity filled with the exterior moderator material. This allows the array to

remain flooded while voiding from the remaining cask cavity space, the neutron shield and cask exterior. A range of rod pitches is evaluated for both BWR and PWR fuel to determine the maximum reactivity pitch in this configuration. Given the increased neutronic interaction between casks, the most reactive rod pitch of the previously evaluated isolated cask changes. A check is also made to determine whether the modeled array remains conservative with respect to the envelope of the rod holder.

As shown in Tables 6.4.4-17 and 6.4.4-18, system reactivity is much higher given the preferential flooding scenario. As shown in Table 6.4.4-20, the 61-rod array remains conservative for BWR fuel under the preferential flooding scenario. A 61-rod array of PWR fuel at its most reactive pitch produces a cross sectional area slightly smaller than that produced by the rod holder exterior (186.9 cm^2 versus 195.2 cm^2 calculated for the canister). However, the area calculation takes no credit for the rod holder wall material and fuel rod tube insert, which reduce the available cross-sectional area significantly. A larger array of PWR fuel rods (with reduced diameter) is, therefore, not investigated.

Single Cask Evaluation

10CFR71.55(b)(3) requires an evaluation of the NAC-LWT with the containment system fully reflected by water. The containment for the NAC-LWT is the cask inner shell. While no operating condition results in a removal of the cask outer shell and lead gamma shield, the most reactive preferential flooding case for BWR fuel is reevaluated by removing the lead and outer shells (including neutron shield), and reflecting the system by water at full density on the X and Y faces (the Z boundary condition remains mirrored). The results of this analysis, a k_s = 0.60117, demonstrates that the system reactivity of the single cask, with containment fully reflected, is significantly below regulatory limits.

Homogenized Fuel/Water Evaluation

A homogenized mixture of UO_2 and water is analyzed in a finite axial model with an infinite array of casks. The width chosen for the fuel homogenization, 13.97 cm, is conservative in that the fuel material must be enclosed by the inner dimension of the rod holder.

Given the maximum fuel volume for 25 BWR fuel rods, 11588 cm^3, and a UO_2 volume fraction, the height of the homogenized mixture of UO_2 and water is calculated. For a UO_2 volume fraction of 0.16, the cross-sectional area of UO_2 is 31.23 cm^2 (195.16 cm^2 × 0.16) and the resultant axial extent is 371.11 cm. The fuel mixture is modeled at the top of the cask cavity.

The limiting UO_2 volume fraction is calculated using a void cask cavity (i.e., preferential flooding), cask exterior and neutron shield to maximize neutron interaction in the cask array. As

shown in Table 6.4.4-21 and Figure 6.4.4-3, the maximum reactivity is calculated with a UO_2 volume fraction of 16%.

Four sets of moderator density studies are performed, as shown in Tables 6.4.4-22 through 6.4.4-25. The studies all serve to demonstrate the maximum reactivity configuration of the voided cask cavity and cask exterior. All cases with a voided cask exterior also have a voided neutron shield; thus, the accident condition of loss of neutron shield is explicitly considered.

Single Cask Evaluation

10CFR71.55(b)(3) requires an evaluation of the NAC-LWT with the containment system fully reflected by water. The containment for the NAC-LWT is the cask inner shell. While no operating condition results in a removal of the cask outer shell and lead gamma shield, each of the partial flooding cases is reevaluated by removing the lead and outer shells (including neutron shield), and reflecting the system by full density water on the X and Y faces. The results of this analysis are shown in Table 6.4.4-26 and demonstrate that the system reactivity decreases with the removal of the lead, outer shell and neutron shield reflectors.

Code Bias and Code Bias Uncertainty Adjustments

A calculation of k_s under normal and accident conditions can now be made based on the results for the heterogeneous rod and the homogenized fuel/water evaluatons. Since the fuel rod (heterogeneous) configuration resulted in a significantly higher k_{eff} than the homogeneous configuration the KENO-Va validation statistics presented in Section 6.5.1 for low enriched uranium fuel are applied. The value k_s is calculated based on the KENO-Va Monte Carlo average plus any biases and uncertainties associated with the methods and the modeling, i.e.:

$$k_s = k_{eff} + 2\sigma_{mc} + \Delta k_{Bias} + \Delta k_{BU}$$

In the validation presented in Section 6.5.1, a bias of 0.0052 (allowance for under prediction of k_{eff}) and a 95/95 method uncertainty of ± 0.0087 were determined. With this bias and uncertainty, the equation for k_s becomes:

$$k_s = k_{eff} + 2\sigma_{mc} + 0.0052 + 0.0087$$

Each of the resulting tables for arrays of damaged fuel rods, Tables 6.4.4-19 through 6.4.4-26, includes the calculated k_s. Mixtures with significantly lower k_{eff} results are not limiting.

Under accident conditions (i.e., dry neutron shield) and preferential flooding, k_s = 0.89950 for an infinite array of NAC-LWT casks loaded with 25 BWR design basis damaged fuel rods. The calculated k_s for PWR fuel rods is 0.77156.

The calculated k_{eff} values, after correction for biases and uncertainties, are below the 0.95 limit. The analyses demonstrate that, including all calculational and mechanical uncertainties, an infinite array of NAC-LWT casks with 25 PWR or BWR damaged fuel rods remains subcritical under normal and accident conditions.

Figure 6.4.4-1 Maximum Reactivity Pitch Determination for Damaged BWR Rod Arrays – Water Exterior

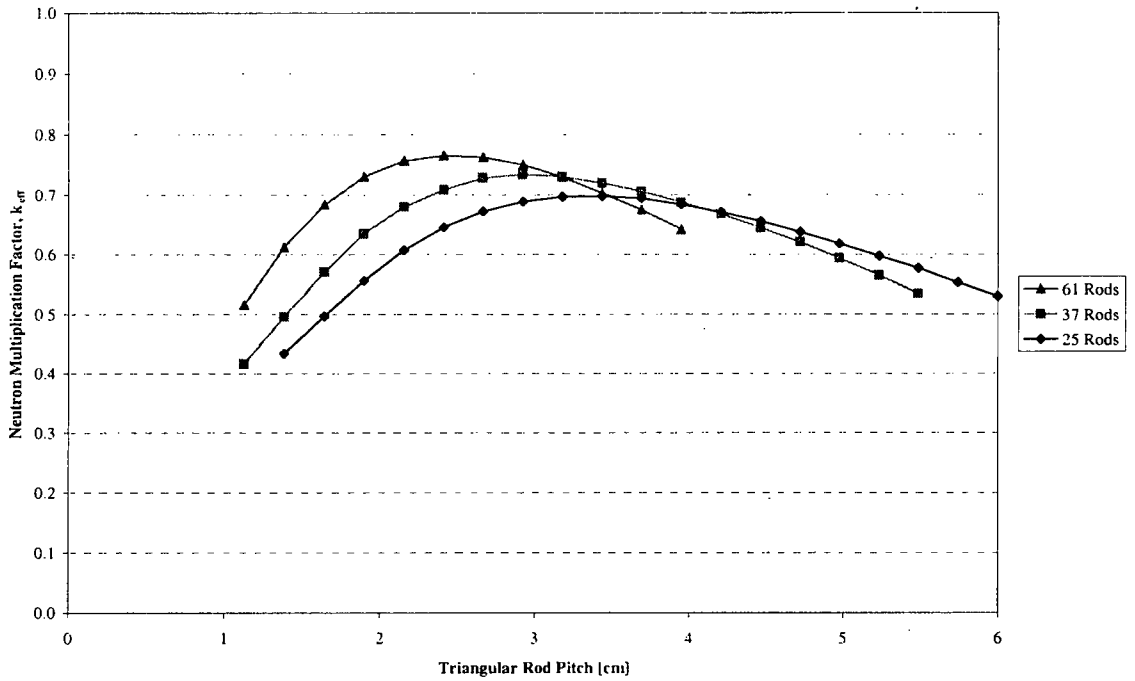

Figure 6.4.4-2 Maximum Reactivity Pitch Determination for Damaged PWR Rod Arrays – Water Exterior

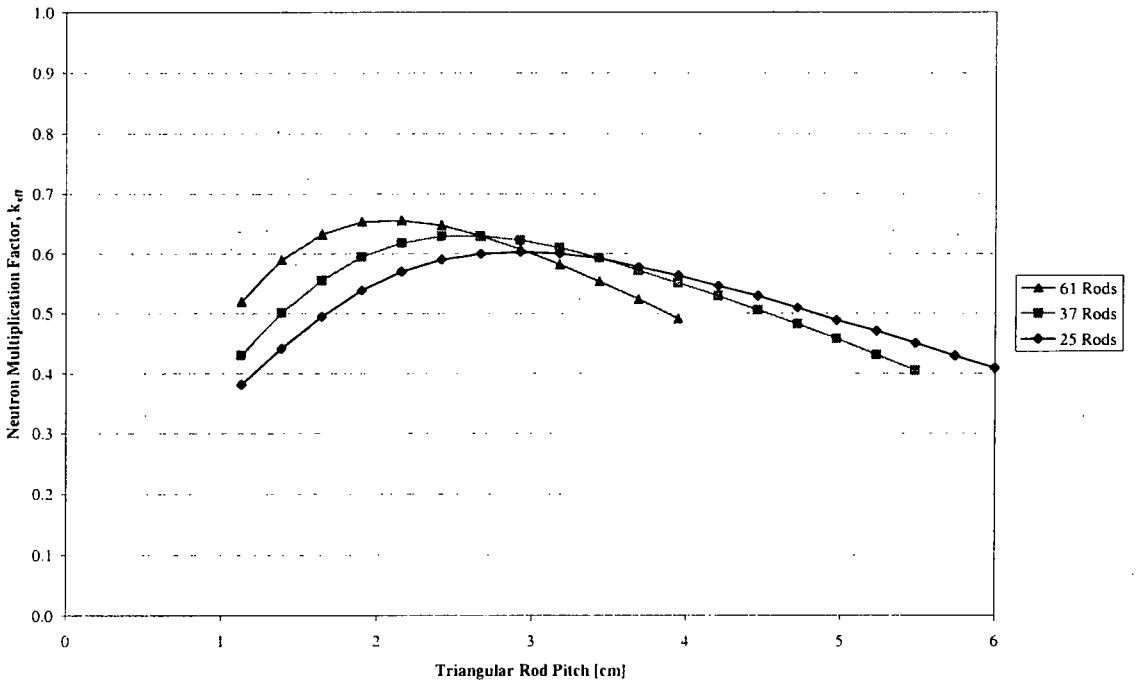

Figure 6.4.4-3 Maximum Reactivity Determination for Homogenized UO_2/Water Mixture

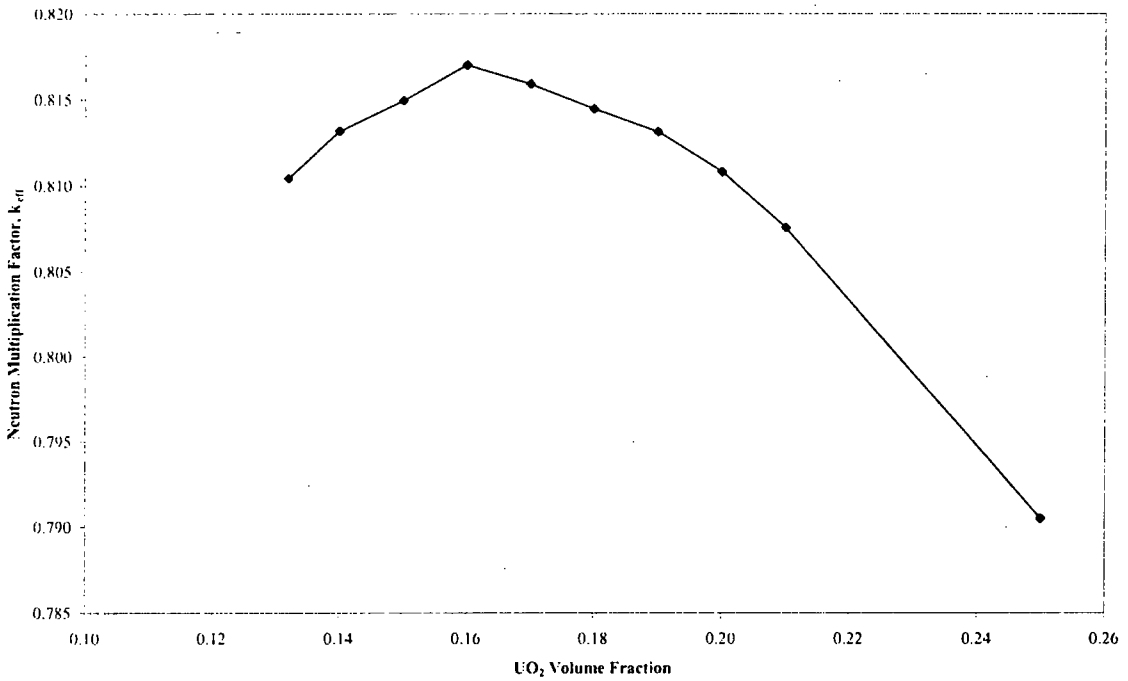

Table 6.4.4-1 NAC-LWT Cask with 25 PWR Rods, k_{eff} versus Fuel Rod Pitch, 5.0 w/o ^{235}U Initial Enrichment

Fuel Rod Pitch (cm)	Cask $k_{eff} \pm \sigma$ Wet Gap	Cask $k_{eff} \pm \sigma$ Dry Gap
1.12769	0.3581 ± 0.0027	0.3577 ± 0.0029
1.38399	0.4150 ± 0.0030	0.4167 ± 0.0033
1.64029	0.4757 ± 0.0032	0.4705 ± 0.0034
1.89659	0.5250 ± 0.0039	0.5268 ± 0.0032
2.15289	0.5578 ± 0.0035	0.5588 ± 0.0035
2.40919	0.5841 ± 0.0034	0.5801 ± 0.0035
2.66539	0.6018 ± 0.0033	0.6030 ± 0.0034
2.92169	0.6082 ± 0.0035	0.6037 ± 0.0035
3.17799	0.6037 ± 0.0034	0.6102 ± 0.0035
3.43429	0.5988 ± 0.0033	0.6002 ± 0.0033
3.69059	0.5838 ± 0.0034	0.5847 ± 0.0035
3.94689	0.5743 ± 0.0036	0.5725 ± 0.0033
4.20319	0.5610 ± 0.0032	0.5582 ± 0.0027
4.45949	0.5415 ± 0.0028	0.5464 ± 0.0036
4.71579	0.5217 ± 0.0027	0.5286 ± 0.0026
4.97209	0.5113 ± 0.0028	0.5109 ± 0.0028
5.22839	0.4858 ± 0.0026	0.4885 ± 0.0032
5.48459	0.4756 ± 0.0026	0.4763 ± 0.0030
5.74089	0.4562 ± 0.0029	0.4564 ± 0.0029
5.99719	0.4402 ± 0.0029	0.4385 ± 0.0028

Table 6.4.4-2 Reactivity with 25 PWR Rods vs. Basket Moderator Density, Normal Conditions, Infinite Array of Casks

Moderator Density	Casks Touching	2 Foot Surf.-to-Surf.	ISO Container 242.84 cm Pitch
Dry Exterior, Vary Internal Density			
0.0000	0.0413 ± 0.0004	0.0410 ± 0.0004	0.0410 ± 0.0005
0.0010	0.0414 ± 0.0005	0.0419 ± 0.0004	0.0421 ± 0.0004
0.0100	0.0483 ± 0.0005	0.0477 ± 0.0006	0.0488 ± 0.0005
0.0250	0.0652 ± 0.0008	0.0664 ± 0.0008	0.0645 ± 0.0008
0.0500	0.1026 ± 0.0014	0.1036 ± 0.0012	0.1051 ± 0.0012
0.0750	0.1429 ± 0.0017	0.1424 ± 0.0016	0.1453 ± 0.0015
0.1000	0.1845 ± 0.0021	0.1828 ± 0.0019	0.1860 ± 0.0022
0.2000	0.3075 ± 0.0029	0.3053 ± 0.0027	0.3070 ± 0.0026
0.4000	0.4296 ± 0.0033	0.4237 ± 0.0034	0.4265 ± 0.0036
0.6000	0.4959 ± 0.0036	0.4988 ± 0.0037	0.4931 ± 0.0030
0.8000	0.5615 ± 0.0035	0.5562 ± 0.0038	0.5560 ± 0.0034
0.9000	0.5823 ± 0.0035	0.5868 ± 0.0033	0.5866 ± 0.0036
1.0000	0.6056 ± 0.0036	0.6002 ± 0.0035	0.6030 ± 0.0030
Wet Interior, Vary External Density			
0.0000	0.5993 ± 0.0031	0.6027 ± 0.0036	0.6035 ± 0.0036
0.0010	0.5976 ± 0.0036	0.6021 ± 0.0034	0.6028 ± 0.0035
0.0100	0.6079 ± 0.0036	0.6052 ± 0.0037	0.6005 ± 0.0035
0.0250	0.6050 ± 0.0036	0.6034 ± 0.0033	0.6027 ± 0.0036
0.0500	0.6003 ± 0.0030	0.6005 ± 0.0034	0.6100 ± 0.0036
0.0750	0.6072 ± 0.0036	0.6009 ± 0.0033	0.5996 ± 0.0035
0.1000	0.6042 ± 0.0036	0.6038 ± 0.0036	0.5995 ± 0.0030
0.2000	0.6032 ± 0.0035	0.6034 ± 0.0035	0.6016 ± 0.0036
0.4000	0.6050 ± 0.0031	0.6032 ± 0.0031	0.5987 ± 0.0034
0.6000	0.6025 ± 0.0032	0.6071 ± 0.0037	0.6003 ± 0.0031
0.8000	0.5975 ± 0.0030	0.6045 ± 0.0034	0.6040 ± 0.0030
0.9000	0.5993 ± 0.0034	0.6033 ± 0.0039	0.6082 ± 0.0037
1.0000	0.6037 ± 0.0037	0.5970 ± 0.0033	0.6036 ± 0.0033
Vary Interior and Exterior Density Simultaneously			
0.0000	0.0407 ± 0.0005	0.0405 ± 0.0004	0.0409 ± 0.0004
0.0010	0.0418 ± 0.0004	0.0411 ± 0.0004	0.0418 ± 0.0005
0.0100	0.0480 ± 0.0005	0.0481 ± 0.0005	0.0488 ± 0.0005
0.0250	0.0669 ± 0.0008	0.0656 ± 0.0008	0.0649 ± 0.0007
0.0500	0.1051 ± 0.0012	0.1002 ± 0.0013	0.1034 ± 0.0012
0.0750	0.1415 ± 0.0016	0.1430 ± 0.0016	0.1464 ± 0.0018
0.1000	0.1850 ± 0.0020	0.1865 ± 0.0022	0.1826 ± 0.0019
0.2000	0.3014 ± 0.0025	0.3043 ± 0.0028	0.3011 ± 0.0027
0.4000	0.4245 ± 0.0030	0.4246 ± 0.0033	0.4193 ± 0.0032
0.6000	0.5022 ± 0.0037	0.4916 ± 0.0036	0.4998 ± 0.0031
0.8000	0.5567 ± 0.0034	0.5551 ± 0.0029	0.5550 ± 0.0034
0.9000	0.5865 ± 0.0035	0.5810 ± 0.0031	0.5725 ± 0.0033
1.0000	0.6070 ± 0.0033	0.6012 ± 0.0032	0.6012 ± 0.0034

Table 6.4.4-3 Reactivity with 25 PWR Rods vs. Basket Moderator Density, Accident Conditions, Infinite Array of Casks

Moderator Specific Gravity	Casks Touching	2 Foot Surface-to-Surface	ISO 242.84 cm Pitch
Dry Exterior, Vary Internal Density			
0.0000	0.1127 ± 0.0008	0.1135 ± 0.0008	0.1125 ± 0.0006
0.0010	0.1158 ± 0.0007	0.1161 ± 0.0007	0.1149 ± 0.0007
0.0100	0.1365 ± 0.0009	0.1377 ± 0.0009	0.1355 ± 0.0009
0.0250	0.1782 ± 0.0013	0.1778 ± 0.0012	0.1761 ± 0.0013
0.0500	0.2438 ± 0.0019	0.2392 ± 0.0018	0.2401 ± 0.0019
0.0750	0.2971 ± 0.0021	0.2974 ± 0.0021	0.2982 ± 0.0022
0.1000	0.3442 ± 0.0028	0.3404 ± 0.0027	0.3392 ± 0.0025
0.2000	0.4417 ± 0.0034	0.4417 ± 0.0030	0.4381 ± 0.0035
0.4000	0.4958 ± 0.0031	0.4941 ± 0.0032	0.4852 ± 0.0036
0.6000	0.5290 ± 0.0033	0.5228 ± 0.0034	0.5297 ± 0.0037
0.8000	0.5701 ± 0.0036	0.5689 ± 0.0034	0.5667 ± 0.0031
0.9000	0.5952 ± 0.0034	0.5842 ± 0.0030	0.5853 ± 0.0034
1.0000	0.6045 ± 0.0033	0.6040 ± 0.0032	0.6101 ± 0.0032
Wet Interior, Vary External Density			
0.0000	0.6008 ± 0.0033	0.6057 ± 0.0032	0.6047 ± 0.0034
0.0010	0.6053 ± 0.0033	0.6023 ± 0.0031	0.6046 ± 0.0036
0.0100	0.6010 ± 0.0033	0.6031 ± 0.0030	0.6036 ± 0.0032
0.0250	0.6058 ± 0.0035	0.6056 ± 0.0034	0.6002 ± 0.0029
0.0500	0.6052 ± 0.0035	0.5996 ± 0.0036	0.6028 ± 0.0037
0.0750	0.5991 ± 0.0035	0.6043 ± 0.0032	0.6017 ± 0.0034
0.1000	0.6022 ± 0.0037	0.6007 ± 0.0033	0.6081 ± 0.0036
0.2000	0.5975 ± 0.0033	0.6064 ± 0.0034	0.6016 ± 0.0032
0.4000	0.6063 ± 0.0038	0.6020 ± 0.0032	0.6090 ± 0.0035
0.6000	0.6063 ± 0.0032	0.6024 ± 0.0032	0.6014 ± 0.0035
0.8000	0.6044 ± 0.0035	0.6016 ± 0.0035	0.6018 ± 0.0034
0.9000	0.6010 ± 0.0033	0.6069 ± 0.0029	0.6041 ± 0.0035
1.0000	0.5986 ± 0.0031	0.6024 ± 0.0038	0.6060 ± 0.0034
Vary Interior and Exterior Density Simultaneously			
0.0000	0.1136 ± 0.0006	0.1110 ± 0.0006	0.1134 ± 0.0007
0.0010	0.1100 ± 0.0006	0.0985 ± 0.0007	0.0825 ± 0.0006
0.0100	0.0989 ± 0.0008	0.0696 ± 0.0007	0.0556 ± 0.0007
0.0250	0.1031 ± 0.0010	0.0769 ± 0.0010	0.0670 ± 0.0008
0.0500	0.1312 ± 0.0013	0.1090 ± 0.0013	0.1037 ± 0.0014
0.0750	0.1628 ± 0.0019	0.1483 ± 0.0018	0.1453 ± 0.0016
0.1000	0.1977 ± 0.0021	0.1854 ± 0.0020	0.1853 ± 0.0020
0.2000	0.3101 ± 0.0029	0.3018 ± 0.0025	0.3069 ± 0.0028
0.4000	0.4269 ± 0.0029	0.4287 ± 0.0032	0.4225 ± 0.0035
0.6000	0.4965 ± 0.0033	0.4952 ± 0.0035	0.4983 ± 0.0038
0.8000	0.5606 ± 0.0032	0.5614 ± 0.0035	0.5572 ± 0.0035
0.9000	0.5803 ± 0.0032	0.5782 ± 0.0037	0.5837 ± 0.0036
1.0000	0.6077 ± 0.0030	0.6011 ± 0.0037	0.5974 ± 0.0036

Table 6.4.4-4 PWR Rods, Single Package 10 CFR 71.55(b)(3) Evaluation k_{eff} Summary

Description	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$
Single Cask / Inner Shell Reflected with H_2O	0.6001 ± 0.0030	0.6061
Single Cask / Inner Shell and Lead Reflected with H_2O	0.6079 ± 0.0036	0.6151
Single Cask / Inner Shell, Lead & Outer Shell Reflected with H_2O	0.6020 ± 0.0031	0.6082
Single Intact Cask Reflected with H_2O	0.6008 ± 0.0034	0.6076

Table 6.4.4-5 NAC-LWT Cask with 25 BWR rods, k_{eff} versus Fuel Rod Pitch, 5.0 w/o ^{235}U Initial Enrichment

Fuel Rod Pitch (cm)	Cask $k_{eff} \pm \sigma$ Wet Gap			Cask $k_{eff} \pm \sigma$ Dry Gap		
1.64029	0.45706	±	0.00286	0.45873	±	0.00342
1.89659	0.52452	±	0.00385	0.52673	±	0.00355
2.15289	0.58707	±	0.00413	0.57828	±	0.00381
2.40919	0.62675	±	0.00393	0.62288	±	0.00333
2.66539	0.66556	±	0.00348	0.66648	±	0.00382
2.92169	0.68714	±	0.00383	0.68098	±	0.00317
3.17799	0.69181	±	0.00380	0.70311	±	0.00372
3.43429	0.69862	±	0.00368	0.70173	±	0.00300
3.69059	0.70297	±	0.00367	0.70447	±	0.00333
3.94689	0.69617	±	0.00347	0.69925	±	0.00329
4.20319	0.68521	±	0.00315	0.68556	±	0.00301
4.45949	0.67665	±	0.00369	0.6743	±	0.00337
4.71579	0.65473	±	0.00331	0.66008	±	0.00322
4.97209	0.64283	±	0.00344	0.64691	±	0.00330
5.22839	0.62652	±	0.00300	0.62668	±	0.00293

Table 6.4.4-6 Reactivity with 25 BWR Rods vs. Basket Moderator Density, Normal Conditions, Infinite Array of Casks

Moderator Specific Gravity	Casks Touching			2 Foot Surface-to-Surface			ISO 242.82 cm		
Dry Exterior, Vary Internal Density									
0.0000	0.05656	+ OR -	0.00055	0.05605	+ OR -	0.00059	0.05682	+ OR -	0.00057
0.0010	0.05819	+ OR -	0.00054	0.05788	+ OR -	0.00052	0.05871	+ OR -	0.00055
0.0100	0.06800	+ OR -	0.00062	0.06777	+ OR -	0.00073	0.06698	+ OR -	0.00065
0.0250	0.09072	+ OR -	0.00091	0.09067	+ OR -	0.00099	0.09127	+ OR -	0.00093
0.0500	0.13923	+ OR -	0.00146	0.13684	+ OR -	0.00140	0.13990	+ OR -	0.00125
0.0750	0.18606	+ OR -	0.00191	0.18738	+ OR -	0.00173	0.18799	+ OR -	0.00184
0.1000	0.23476	+ OR -	0.00216	0.23439	+ OR -	0.00210	0.23364	+ OR -	0.00212
0.2000	0.38517	+ OR -	0.00344	0.37607	+ OR -	0.00269	0.37838	+ OR -	0.00317
0.4000	0.53477	+ OR -	0.00344	0.53398	+ OR -	0.00357	0.53238	+ OR -	0.00399
0.6000	0.61570	+ OR -	0.00363	0.61111	+ OR -	0.00332	0.61508	+ OR -	0.00342
0.8000	0.66499	+ OR -	0.00388	0.66829	+ OR -	0.00360	0.66555	+ OR -	0.00367
0.9000	0.67966	+ OR -	0.00366	0.68529	+ OR -	0.00334	0.68097	+ OR -	0.00328
1.0000	0.69240	+ OR -	0.00386	0.70201	+ OR -	0.00364	0.69756	+ OR -	0.00346
Moderator Specific Gravity	**Casks Touching**			**2 Foot Surface-to-Surface**			**ISO 242.82 cm**		
Wet Interior, Vary External Density									
0.0000	0.69610	+ OR -	0.00339	0.69135	+ OR -	0.00338	0.69935	+ OR -	0.00329
0.0010	0.70161	+ OR -	0.00391	0.70301	+ OR -	0.00358	0.69066	+ OR -	0.00388
0.0100	0.69020	+ OR -	0.00397	0.69402	+ OR -	0.00352	0.70044	+ OR -	0.00329
0.0250	0.69884	+ OR -	0.00379	0.69871	+ OR -	0.00389	0.70458	+ OR -	0.00381
0.0500	0.69110	+ OR -	0.00349	0.69663	+ OR -	0.00384	0.69940	+ OR -	0.00326
0.0750	0.69634	+ OR -	0.00374	0.70282	+ OR -	0.00323	0.69400	+ OR -	0.00373
0.1000	0.69592	+ OR -	0.00367	0.69793	+ OR -	0.00317	0.69605	+ OR -	0.00352
0.2000	0.69566	+ OR -	0.00323	0.69491	+ OR -	0.00368	0.69803	+ OR -	0.00339
0.4000	0.69463	+ OR -	0.00382	0.69520	+ OR -	0.00331	0.70063	+ OR -	0.00348
0.6000	0.69541	+ OR -	0.00364	0.69413	+ OR -	0.00337	0.69327	+ OR -	0.00354
0.8000	0.69669	+ OR -	0.00329	0.69355	+ OR -	0.00380	0.69196	+ OR -	0.00365
0.9000	0.69587	+ OR -	0.00348	0.70373	+ OR -	0.00343	0.70134	+ OR -	0.00335
1.0000	0.70298	+ OR -	0.00377	0.70245	+ OR -	0.00365	0.69863	+ OR -	0.00333
Moderator Specific Gravity	**Casks Touching**			**2 Foot Surface-to-Surface**			**ISO 242.82 cm**		
Vary Interior and Exterior Density Simulataneously									
0.0000	0.05730	+ OR -	0.00053	0.05650	+ OR -	0.00052	0.05718	+ OR -	0.00049
0.0010	0.05797	+ OR -	0.00060	0.05815	+ OR -	0.00056	0.05839	+ OR -	0.00059
0.0100	0.06703	+ OR -	0.00062	0.06801	+ OR -	0.00070	0.06772	+ OR -	0.00074
0.0250	0.09224	+ OR -	0.00088	0.09213	+ OR -	0.00091	0.09063	+ OR -	0.00087
0.0500	0.14064	+ OR -	0.00150	0.13757	+ OR -	0.00153	0.13709	+ OR -	0.00145
0.0750	0.18790	+ OR -	0.00202	0.18714	+ OR -	0.00212	0.18650	+ OR -	0.00176
0.1000	0.23532	+ OR -	0.00225	0.23607	+ OR -	0.00229	0.23225	+ OR -	0.00256
0.2000	0.38056	+ OR -	0.00314	0.38750	+ OR -	0.00297	0.37600	+ OR -	0.00334
0.4000	0.53150	+ OR -	0.00323	0.53738	+ OR -	0.00338	0.53434	+ OR -	0.00372
0.6000	0.61988	+ OR -	0.00371	0.61154	+ OR -	0.00338	0.61457	+ OR -	0.00380
0.8000	0.66446	+ OR -	0.00377	0.66538	+ OR -	0.00334	0.66393	+ OR -	0.00362
0.9000	0.68590	+ OR -	0.00405	0.68149	+ OR -	0.00338	0.68109	+ OR -	0.00357
1.0000	0.70435	+ OR -	0.00312	0.69210	+ OR -	0.00383	0.69897	+ OR -	0.00348

Table 6.4.4-7 Reactivity with 25 BWR Rods vs. Basket Moderator Density, Accident Conditions, Infinite Array of Casks

Moderator Specific Gravity	Casks Touching			2 Foot Surface-to-Surface			ISO 242.82 cm		
Dry Exterior, Vary Internal Density									
0.0000	0.16678	+ OR -	0.00082	0.16532	+ OR -	0.00081	0.16417	+ OR -	0.00076
0.0010	0.16927	+ OR -	0.00092	0.16818	+ OR -	0.00076	0.16919	+ OR -	0.00083
0.0100	0.19533	+ OR -	0.00098	0.19554	+ OR -	0.00111	0.19714	+ OR -	0.00108
0.0250	0.24529	+ OR -	0.00150	0.24317	+ OR -	0.00136	0.24647	+ OR -	0.00156
0.0500	0.32172	+ OR -	0.00192	0.32000	+ OR -	0.00171	0.32349	+ OR -	0.00190
0.0750	0.38479	+ OR -	0.00267	0.38527	+ OR -	0.00234	0.38571	+ OR -	0.00253
0.1000	0.44132	+ OR -	0.00298	0.43394	+ OR -	0.00301	0.43722	+ OR -	0.00262
0.2000	0.56027	+ OR -	0.00330	0.56105	+ OR -	0.00321	0.55792	+ OR -	0.00334
0.4000	0.62723	+ OR -	0.00380	0.63534	+ OR -	0.00388	0.62068	+ OR -	0.00368
0.6000	0.65834	+ OR -	0.00371	0.65642	+ OR -	0.00342	0.65566	+ OR -	0.00399
0.8000	0.68180	+ OR -	0.00370	0.67879	+ OR -	0.00333	0.68134	+ OR -	0.00369
0.9000	0.69219	+ OR -	0.00333	0.69177	+ OR -	0.00348	0.69876	+ OR -	0.00338
1.0000	0.70574	+ OR -	0.00346	0.70062	+ OR -	0.00308	0.70613	+ OR -	0.00336
Moderator Specific Gravity	**Casks Touching**			**2 Foot Surface-to-Surface**			**ISO 242.82 cm**		
Wet Interior, Vary External Density									
0.0000	0.70485	+ OR -	0.00350	0.70537	+ OR -	0.00380	0.71353	+ OR -	0.00333
0.0010	0.70559	+ OR -	0.00330	0.70379	+ OR -	0.00376	0.70277	+ OR -	0.00317
0.0100	0.69932	+ OR -	0.00319	0.69971	+ OR -	0.00303	0.69208	+ OR -	0.00359
0.0250	0.69882	+ OR -	0.00378	0.69308	+ OR -	0.00346	0.69471	+ OR -	0.00343
0.0500	0.69939	+ OR -	0.00409	0.68428	+ OR -	0.00368	0.69751	+ OR -	0.00374
0.0750	0.69777	+ OR -	0.00369	0.69635	+ OR -	0.00352	0.69247	+ OR -	0.00358
0.1000	0.70068	+ OR -	0.00317	0.69051	+ OR -	0.00326	0.70317	+ OR -	0.00354
0.2000	0.69652	+ OR -	0.00304	0.69519	+ OR -	0.00337	0.69979	+ OR -	0.00329
0.4000	0.69578	+ OR -	0.00351	0.70041	+ OR -	0.00331	0.69308	+ OR -	0.00310
0.6000	0.69367	+ OR -	0.00362	0.69188	+ OR -	0.00404	0.69766	+ OR -	0.00327
0.8000	0.70330	+ OR -	0.00363	0.69912	+ OR -	0.00373	0.70236	+ OR -	0.00344
0.9000	0.69400	+ OR -	0.00340	0.69387	+ OR -	0.00385	0.69551	+ OR -	0.00386
1.0000	0.69902	+ OR -	0.00350	0.69844	+ OR -	0.00344	0.70029	+ OR -	0.00335
Moderator Specific Gravity	**Casks Touching**			**2 Foot Surface-to-Surface**			**ISO 242.82 cm**		
Vary Interior and Exterior Density Simulataneously									
0.0000	0.16499	+ OR -	0.00076	0.16534	+ OR -	0.00084	0.16534	+ OR -	0.00084
0.0010	0.15978	+ OR -	0.00082	0.11798	+ OR -	0.00081	0.11798	+ OR -	0.00081
0.0100	0.14066	+ OR -	0.00100	0.07981	+ OR -	0.00085	0.07981	+ OR -	0.00085
0.0250	0.14370	+ OR -	0.00128	0.09501	+ OR -	0.00100	0.09501	+ OR -	0.00100
0.0500	0.17380	+ OR -	0.00174	0.13825	+ OR -	0.00129	0.13825	+ OR -	0.00129
0.0750	0.21261	+ OR -	0.00179	0.19305	+ OR -	0.00197	0.19305	+ OR -	0.00197
0.1000	0.25648	+ OR -	0.00229	0.23437	+ OR -	0.00233	0.23437	+ OR -	0.00233
0.2000	0.38917	+ OR -	0.00323	0.37995	+ OR -	0.00299	0.37995	+ OR -	0.00299
0.4000	0.53569	+ OR -	0.00371	0.52997	+ OR -	0.00334	0.52997	+ OR -	0.00334
0.6000	0.61450	+ OR -	0.00367	0.61391	+ OR -	0.00352	0.61391	+ OR -	0.00352
0.8000	0.66387	+ OR -	0.00329	0.66631	+ OR -	0.00384	0.66631	+ OR -	0.00384
0.9000	0.68209	+ OR -	0.00360	0.68136	+ OR -	0.00384	0.68136	+ OR -	0.00384
1.0000	0.69742	+ OR -	0.00378	0.68992	+ OR -	0.00387	0.68992	+ OR -	0.00387

Table 6.4.4-8 BWR Rods, Single Package 10 CFR 71.55(b)(3) Evaluation k_{eff} Summary

Description	$k_{eff} \pm \sigma$			$k_{eff} + 2\sigma$
Single Cask/ Inner Shell H_2O Reflected	0.69428	±	0.00368	0.70164
Single Cask/ Inner Shell & Lead H_2O Reflected	0.69355	±	0.00397	0.70149
Single Cask/ Inner Shell, Lead, & Outer Shell H_2O Reflected	0.69532	±	0.00373	0.70278
Single Cask H_2O Reflected	0.69322	±	0.00381	0.70084

Table 6.4.4-9 Maximum Reactivity Pitch Determination for 25 BWR Rods – Water Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	1	1.3840	0.43688	0.00070	0.45218	0.43828	-0.26228	-374.7
1	1	1.6403	0.49775	0.00076	0.51317	0.49927	-0.20129	-264.9
1	1	1.8966	0.55826	0.00078	0.57372	0.55982	-0.14074	-180.4
1	1	2.1529	0.60670	0.00083	0.62226	0.60836	-0.09220	-111.1
1	1	2.4092	0.64459	0.00080	0.66009	0.64619	-0.05437	-68.0
1	1	2.6654	0.67337	0.00081	0.68889	0.67499	-0.02557	-31.6
1	1	2.9217	0.68893	0.00084	0.70451	0.69061	-0.00995	-11.8
1	1	3.1780	0.69768	0.00080	0.71318	0.69928	-0.00128	-1.6
1	1	3.4343	0.69896	0.00080	0.71446	0.70056	--	--
1	1	3.6906	0.69337	0.00077	0.70881	0.69491	-0.00565	-7.3
1	1	3.9469	0.68509	0.00075	0.70049	0.68659	-0.01397	-18.6
1	1	4.2032	0.66997	0.00075	0.68537	0.67147	-0.02909	-38.8
1	1	4.4595	0.65593	0.00074	0.67131	0.65741	-0.04315	-58.3
1	1	4.7158	0.63801	0.00076	0.65343	0.63953	-0.06103	-80.3
1	1	4.9721	0.61716	0.00072	0.63250	0.61860	-0.08196	-113.8
1	1	5.2284	0.59692	0.00070	0.61222	0.59832	-0.10224	-146.1
1	1	5.4846	0.57611	0.00073	0.59147	0.57757	-0.12299	-168.5
1	1	5.7409	0.55318	0.00068	0.56844	0.55454	-0.14602	-214.7
1	1	5.9972	0.53013	0.00070	0.54543	0.53153	-0.16903	-241.5

Table 6.4.4-10 Maximum Reactivity Pitch Determination for 25 PWR Rods – Water Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	1	1.1277	0.38430	0.00070	0.39960	0.38570	-0.21964	-313.8
1	1	1.3840	0.44279	0.00072	0.45813	0.44423	-0.16111	-223.8
1	1	1.6403	0.49656	0.00077	0.51200	0.49810	-0.10724	-139.3
1	1	1.8966	0.53980	0.00073	0.55516	0.54126	-0.06408	-87.8
1	1	2.1529	0.56950	0.00075	0.58490	0.57100	-0.03434	-45.8
1	1	2.4092	0.59041	0.00078	0.60587	0.59197	-0.01337	-17.1
1	1	2.6654	0.60073	0.00077	0.61617	0.60227	-0.00307	-4.0
1	1	2.9217	0.60380	0.00077	0.61924	0.60534	--	--
1	1	3.1780	0.59904	0.00074	0.61442	0.60052	-0.00482	-6.5
1	1	3.4343	0.59206	0.00078	0.60752	0.59362	-0.01172	-15.0
1	1	3.6906	0.57836	0.00069	0.59364	0.57974	-0.02560	-37.1
1	1	3.9469	0.56256	0.00068	0.57782	0.56392	-0.04142	-60.9
1	1	4.2032	0.54640	0.00070	0.56170	0.54780	-0.05754	-82.2
1	1	4.4595	0.52823	0.00069	0.54351	0.52961	-0.07573	-109.8
1	1	4.7158	0.51025	0.00067	0.52549	0.51159	-0.09375	-139.9
1	1	4.9721	0.49011	0.00068	0.50537	0.49147	-0.11387	-167.5
1	1	5.2284	0.47064	0.00066	0.48586	0.47196	-0.13338	-202.1
1	1	5.4846	0.45036	0.00063	0.46552	0.45162	-0.15372	-244.0
1	1	5.7409	0.42865	0.00062	0.44379	0.42989	-0.17545	-283.0
1	1	5.9972	0.40918	0.00059	0.42426	0.41036	-0.19498	-330.5

Table 6.4.4-11 Maximum Reactivity Pitch Determination for 37 BWR Rods – Water Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	1	1.1277	0.41793	0.00067	0.43317	0.41927	-0.31608	-471.8
1	1	1.3840	0.49679	0.00073	0.51215	0.49825	-0.23710	-324.8
1	1	1.6403	0.57355	0.00077	0.58899	0.57509	-0.16026	-208.1
1	1	1.8966	0.63372	0.00081	0.64924	0.63534	-0.10001	-123.5
1	1	2.1529	0.67993	0.00087	0.69557	0.68167	-0.05368	-61.7
1	1	2.4092	0.71022	0.00085	0.72582	0.71192	-0.02343	-27.6
1	1	2.6654	0.72818	0.00082	0.74372	0.72982	-0.00553	-6.7
1	1	2.9217	0.73371	0.00082	0.74925	0.73535	--	--
1	1	3.1780	0.73076	0.00082	0.74630	0.73240	-0.00295	-3.6
1	1	3.4343	0.72100	0.00078	0.73646	0.72256	-0.01279	-16.4
1	1	3.6906	0.70690	0.00076	0.72232	0.70842	-0.02693	-35.4
1	1	3.9469	0.68847	0.00081	0.70399	0.69009	-0.04526	-55.9
1	1	4.2032	0.66618	0.00075	0.68158	0.66768	-0.06767	-90.2
1	1	4.4595	0.64430	0.00073	0.65966	0.64576	-0.08959	-122.7
1	1	4.7158	0.61821	0.00071	0.63353	0.61963	-0.11572	-163.0
1	1	4.9721	0.59337	0.00073	0.60873	0.59483	-0.14052	-192.5
1	1	5.2284	0.56602	0.00068	0.58128	0.56738	-0.16797	-247.0
1	1	5.4846	0.53531	0.00068	0.55057	0.53667	-0.19868	-292.2

Table 6.4.4-12 Maximum Reactivity Pitch Determination for 37 PWR Rods – Water Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	1	1.1277	0.43247	0.00068	0.44773	0.43383	-0.19855	-292.0
1	1	1.3840	0.50187	0.00077	0.51731	0.50341	-0.12897	-167.5
1	1	1.6403	0.55749	0.00078	0.57295	0.55905	-0.07333	-94.0
1	1	1.8966	0.59561	0.00081	0.61113	0.59723	-0.03515	-43.4
1	1	2.1529	0.61842	0.00078	0.63388	0.61998	-0.01240	-15.9
1	1	2.4092	0.62864	0.00079	0.64412	0.63022	-0.00216	-2.7
1	1	2.6654	0.63084	0.00077	0.64628	0.63238	--	--
1	1	2.9217	0.62153	0.00072	0.63687	0.62297	-0.00941	-13.1
1	1	3.1780	0.60939	0.00072	0.62473	0.61083	-0.02155	-29.9
1	1	3.4343	0.59297	0.00070	0.60827	0.59437	-0.03801	-54.3
1	1	3.6906	0.57112	0.00067	0.58636	0.57246	-0.05992	-89.4
1	1	3.9469	0.54994	0.00067	0.56518	0.55128	-0.08110	-121.0
1	1	4.2032	0.52793	0.00069	0.54321	0.52931	-0.10307	-149.4
1	1	4.4595	0.50588	0.00065	0.52108	0.50718	-0.12520	-192.6
1	1	4.7158	0.48106	0.00066	0.49628	0.48238	-0.15000	-227.3
1	1	4.9721	0.45664	0.00063	0.47180	0.45790	-0.17448	-277.0
1	1	5.2284	0.43149	0.00061	0.44661	0.43271	-0.19967	-327.3
1	1	5.4846	0.40582	0.00062	0.42096	0.40706	-0.22532	-363.4

Table 6.4.4-13 Maximum Reactivity Pitch Determination for 61 BWR Rods – Water Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	1	1.1277	0.52008	0.00072	0.53542	0.52152	-0.24512	-340.4
1	1	1.3840	0.61379	0.00081	0.62931	0.61541	-0.15123	-186.7
1	1	1.6403	0.68471	0.00083	0.70027	0.68637	-0.08027	-96.7
1	1	1.8966	0.73218	0.00083	0.74774	0.73384	-0.03280	-39.5
1	1	2.1529	0.75701	0.00082	0.77255	0.75865	-0.00799	-9.7
1	1	2.4092	0.76498	0.00083	0.78054	0.76664	--	--
1	1	2.6654	0.76171	0.00078	0.77717	0.76327	-0.00337	-4.3
1	1	2.9217	0.74933	0.00075	0.76473	0.75083	-0.01581	-21.1
1	1	3.1780	0.72877	0.00074	0.74415	0.73025	-0.03639	-49.2
1	1	3.4343	0.70376	0.00073	0.71912	0.70522	-0.06142	-84.1
1	1	3.6906	0.67540	0.00072	0.69074	0.67684	-0.08980	-124.7
1	1	3.9469	0.64190	0.00069	0.65718	0.64328	-0.12336	-178.8

Table 6.4.4-14 Maximum Reactivity Pitch Determination for 61 PWR Rods – Water Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	1	1.1277	0.52230	0.00075	0.53770	0.52380	-0.13379	-178.4
1	1	1.3840	0.58974	0.00078	0.60520	0.59130	-0.06629	-85.0
1	1	1.6403	0.63319	0.00083	0.64875	0.63485	-0.02274	-27.4
1	1	1.8966	0.65233	0.00077	0.66777	0.65387	-0.00372	-4.8
1	1	2.1529	0.65607	0.00076	0.67149	0.65759	--	--
1	1	2.4092	0.64753	0.00076	0.66295	0.64905	-0.00854	-11.2
1	1	2.6654	0.63012	0.00072	0.64546	0.63156	-0.02603	-36.2
1	1	2.9217	0.60859	0.00073	0.62395	0.61005	-0.04754	-65.1
1	1	3.1780	0.58257	0.00070	0.59787	0.58397	-0.07362	-105.2
1	1	3.4343	0.55274	0.00066	0.56796	0.55406	-0.10353	-156.9
1	1	3.6906	0.52407	0.00066	0.53929	0.52539	-0.13220	-200.3
1	1	3.9469	0.49246	0.00062	0.50760	0.49370	-0.16389	-264.3

Table 6.4.4-15 Maximum Reactivity Pitch Determination for 61 BWR Rods – Void Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	0	1.1277	0.52156	0.00075	0.53696	0.52306	-0.25209	-336.1
1	0	1.3840	0.61695	0.00083	0.63251	0.61861	-0.15654	-188.6
1	0	1.6403	0.68835	0.00083	0.70391	0.69001	-0.08514	-102.6
1	0	1.8966	0.73509	0.00085	0.75069	0.73679	-0.03836	-45.1
1	0	2.1529	0.76248	0.00083	0.77804	0.76414	-0.01101	-13.3
1	0	2.4092	0.77355	0.00080	0.78905	0.77515	--	--
1	0	2.6654	0.77146	0.00079	0.78694	0.77304	-0.00211	-2.7
1	0	2.9217	0.76267	0.00075	0.77807	0.76417	-0.01098	-14.6
1	0	3.1780	0.74480	0.00072	0.76014	0.74624	-0.02891	-40.2
1	0	3.4343	0.72517	0.00073	0.74053	0.72663	-0.04852	-66.5
1	0	3.6906	0.70227	0.00069	0.71755	0.70365	-0.07150	-103.6
1	0	3.9469	0.67451	0.00071	0.68983	0.67593	-0.09922	-139.7

Table 6.4.4-16 Maximum Reactivity Pitch Determination for 61 PWR Rods – Void Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	0	1.1277	0.52341	0.00079	0.53889	0.52499	-0.13907	-176.0
1	0	1.3840	0.59319	0.00077	0.60863	0.59473	-0.06933	-90.0
1	0	1.6403	0.63388	0.00079	0.64936	0.63546	-0.02860	-36.2
1	0	1.8966	0.65655	0.00078	0.67201	0.65811	-0.00595	-7.6
1	0	2.1529	0.66256	0.00075	0.67796	0.66406	--	--
1	0	2.4092	0.65394	0.00072	0.66928	0.65538	-0.00868	-12.1
1	0	2.6654	0.63865	0.00070	0.65395	0.64005	-0.02401	-34.3
1	0	2.9217	0.61660	0.00069	0.63188	0.61798	-0.04608	-66.8
1	0	3.1780	0.59274	0.00066	0.60796	0.59406	-0.07000	-106.1
1	0	3.4343	0.56934	0.00065	0.58454	0.57064	-0.09342	-143.7
1	0	3.6906	0.54287	0.00064	0.55805	0.54415	-0.11991	-187.4
1	0	3.9469	0.51595	0.00063	0.53111	0.51721	-0.14685	-233.1

Table 6.4.4-17 Maximum Reactivity Pitch Determination for 61 BWR Rods – Void Exterior and Preferential Flooding of Cask Cavity

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0	0	1.1277	0.53776	0.00070	0.55306	0.53916	-0.34644	-494.9
0	0	1.3840	0.70636	0.00077	0.72180	0.70790	-0.17770	-230.8
0	0	1.6403	0.81018	0.00082	0.82572	0.81182	-0.07378	-90.0
0	0	1.8966	0.86442	0.00079	0.87990	0.86600	-0.01960	-24.8
0	0	2.1529	0.88400	0.00080	0.89950	0.88560	--	--
0	0	2.4092	0.87897	0.00077	0.89441	0.88051	-0.00509	-6.6
0	0	2.6654	0.86184	0.00079	0.87732	0.86342	-0.02218	-28.1
0	0	2.9217	0.83244	0.00073	0.84780	0.83390	-0.05170	-70.8
0	0	3.1780	0.79468	0.00071	0.81000	0.79610	-0.08950	-126.1
0	0	3.4343	0.75931	0.00070	0.77461	0.76071	-0.12489	-178.4
0	0	3.6906	0.71973	0.00073	0.73509	0.72119	-0.16441	-225.2

Table 6.4.4-18 Maximum Reactivity Pitch Determination for 61 PWR Rods – Void Exterior and Preferential Flooding of Cask Cavity

Cask Cavity (g/cc)	Exterior (g/cc)	Pitch (cm)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0	0	1.1277	0.55291	0.00071	0.56823	0.55433	-0.20333	-286.4
0	0	1.3840	0.67194	0.00076	0.68736	0.67346	-0.08420	-110.8
0	0	1.6403	0.73270	0.00078	0.74816	0.73426	-0.02340	-30.0
0	0	1.8966	0.75614	0.00076	0.77156	0.75766	--	--
0	0	2.1529	0.75121	0.00076	0.76663	0.75273	-0.00493	-6.5
0	0	2.4092	0.73087	0.00076	0.74629	0.73239	-0.02527	-33.3
0	0	2.6654	0.70242	0.00072	0.71776	0.70386	-0.05380	-74.7
0	0	2.9217	0.66618	0.00068	0.68144	0.66754	-0.09012	-132.5
0	0	3.1780	0.62965	0.00067	0.64489	0.63099	-0.12667	-189.1
0	0	3.4343	0.59036	0.00065	0.60556	0.59166	-0.16600	-255.4
0	0	3.6906	0.55310	0.00063	0.56826	0.55436	-0.20330	-322.7

Table 6.4.4-19 Damaged Rod Array Area Calculation – Flooded Cask Cavity

Moderation	Number of Rods	Fuel Type	Pitch [cm]	Rod Radius [cm]	# Rods Max	Diameter [cm]	$Area_{Hex}$ [cm^2]
Water Cavity	25	BWR	3.434	0.622	5	14.98	168.3
Water Exterior		PWR	2.922	0.478	5	12.64	119.9
Water Cavity	37	BWR	2.922	0.512	7	18.55	258.2
Water Exterior		PWR	2.665	0.393	7	16.78	211.1
Water Cavity	61	BWR	2.409	0.398	9	20.07	302.1
Water Exterior		PWR	2.153	0.306	9	17.84	238.6

Table 6.4.4-20 Damaged Rod Array Area Calculation – Preferential Flooding

Moderation	Number of Rods	Fuel Type	Pitch [cm]	Rod Radius [cm]	# Rods Max	Diameter [cm]	$Area_{Hex}$ [cm^2]
Partially Flooded Cavity	61	BWR	2.153	0.398	9	18.02	243.5
Void Exterior		PWR	1.897	0.306	9	15.78	186.9

Table 6.4.4-21 Maximum Reactivity Determination for Homogenized UO_2/Water Mixture

Cask Cavity (g/cc)	Exterior (g/cc)	UO_2 Vol Frac	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0	0	0.132	0.81043	0.00075	0.81193	-0.00665	-8.9
0	0	0.14	0.81319	0.00075	0.81469	-0.00389	-5.2
0	0	0.15	0.81495	0.00071	0.81637	-0.00221	-3.1
0	0	0.16	0.81702	0.00078	0.81858	--	--
0	0	0.17	0.81592	0.00076	0.81744	-0.00114	-1.5
0	0	0.18	0.81448	0.00078	0.81604	-0.00254	-3.3
0	0	0.19	0.81315	0.00079	0.81473	-0.00385	-4.9
0	0	0.20	0.81080	0.00080	0.81240	-0.00618	-7.7

Table 6.4.4-22 Homogenized UO_2/Water Cask Cavity Moderator Density Study Results - Void Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	UO_2 Vol Frac	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0.0	0	0.16	0.81702	0.00078	0.81858	--	--
0.1	0	0.16	0.80234	0.00078	0.80390	-0.01468	-18.8
0.2	0	0.16	0.79078	0.00083	0.79244	-0.02614	-31.5
0.3	0	0.16	0.77986	0.00082	0.78150	-0.03708	-45.2
0.4	0	0.16	0.77082	0.00084	0.77250	-0.04608	-54.9
0.5	0	0.16	0.76440	0.00086	0.76612	-0.05246	-61.0
0.6	0	0.16	0.75856	0.00081	0.76018	-0.05840	-72.1
0.7	0	0.16	0.75823	0.00079	0.75981	-0.05877	-74.4
0.8	0	0.16	0.75812	0.00079	0.75970	-0.05888	-74.5
0.9	0	0.16	0.75836	0.00080	0.75996	-0.05862	-73.3
1.0	0	0.16	0.76077	0.00085	0.76247	-0.05611	-66.0

Table 6.4.4-23 Homogenized UO_2/Water Cask Cavity Moderator Density Study Results - Water Exterior

Cask Cavity (g/cc)	Exterior (g/cc)	UO_2 Vol Frac	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0.0	1	0.16	0.65512	0.00078	0.65668	-0.10233	-131.2
0.1	1	0.16	0.68935	0.00083	0.69101	-0.06800	-81.9
0.2	1	0.16	0.70977	0.00084	0.71145	-0.04756	-56.6
0.3	1	0.16	0.72173	0.00084	0.72341	-0.03560	-42.4
0.4	1	0.16	0.72868	0.00079	0.73026	-0.02875	-36.4
0.5	1	0.16	0.73455	0.00083	0.73621	-0.02280	-27.5
0.6	1	0.16	0.73958	0.00081	0.74120	-0.01781	-22.0
0.7	1	0.16	0.74478	0.00082	0.74642	-0.01259	-15.4
0.8	1	0.16	0.74887	0.00084	0.75055	-0.00846	-10.1
0.9	1	0.16	0.75191	0.00082	0.75355	-0.00546	-6.7
1.0	1	0.16	0.75743	0.00079	0.75901	--	--

Table 6.4.4-24 Homogenized UO_2/Water Exterior Moderator Density Study Results – Void Cask Cavity

Cask Cavity (g/cc)	Exterior (g/cc)	UO_2 Vol Frac	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0	0.0	0.16	0.81702	0.00078	0.81858	--	--
0	0.1	0.16	0.66923	0.00081	0.67085	-0.14773	-182.4
0	0.2	0.16	0.65897	0.00080	0.66057	-0.15801	-197.5
0	0.3	0.16	0.65619	0.00078	0.65775	-0.16083	-206.2
0	0.4	0.16	0.65607	0.00078	0.65763	-0.16095	-206.3
0	0.5	0.16	0.65449	0.00079	0.65607	-0.16251	-205.7
0	0.6	0.16	0.65513	0.00081	0.65675	-0.16183	-199.8
0	0.7	0.16	0.65479	0.00077	0.65633	-0.16225	-210.7
0	0.8	0.16	0.65445	0.00077	0.65599	-0.16259	-211.2
0	0.9	0.16	0.65591	0.00081	0.65753	-0.16105	-198.8
0	1.0	0.16	0.65512	0.00078	0.65668	-0.16190	-207.6

Table 6.4.4-25 Homogenized UO_2/Water Exterior Moderator Density Study Results – Water Cask Cavity

Cask Cavity (g/cc)	Exterior (g/cc)	UO_2 Vol Frac	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	0.0	0.16	0.76077	0.00085	0.76247	--	--
1	0.1	0.16	0.75700	0.00085	0.75870	-0.00377	-4.4
1	0.2	0.16	0.75719	0.00080	0.75879	-0.00368	-4.6
1	0.3	0.16	0.75696	0.00081	0.75858	-0.00389	-4.8
1	0.4	0.16	0.75430	0.00083	0.75596	-0.00651	-7.8
1	0.5	0.16	0.75574	0.00081	0.75736	-0.00511	-6.3
1	0.6	0.16	0.75516	0.00080	0.75676	-0.00571	-7.1
1	0.7	0.16	0.75480	0.00085	0.75650	-0.00597	-7.0
1	0.8	0.16	0.75601	0.00084	0.75769	-0.00478	-5.7
1	0.9	0.16	0.75542	0.00081	0.75704	-0.00543	-6.7
1	1.0	0.16	0.75743	0.00079	0.75901	-0.00346	-4.4

Table 6.4.4-26 Single Cask Containment Reflected Results Comparison for Homogenized UO_2/Water Model

Cask Configuration	Cask Cavity (g/cc)	Exterior (g/cc)	UO_2 Vol Frac	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
Array	0	0	0.16	0.81702	0.00078	0.81858	--	--
Single	0	0	0.16	0.50369	0.00076	0.50521	-0.31337	-412.3
Array	1	0	0.16	0.76077	0.00085	0.76247	--	--
Single	1	0	0.16	0.74882	0.00085	0.75052	-0.01195	-14.1
Array	1	1	0.16	0.75743	0.00079	0.75901	--	--
Single	1	1	0.16	0.75043	0.00080	0.75203	-0.00698	-8.7
Array	0	1	0.16	0.65512	0.00078	0.65668	--	--
Single	0	1	0.16	0.54351	0.00078	0.54507	-0.11161	-143.1

6.4.5 TRIGA Fuel Elements

This section presents the criticality evaluation for TRIGA fuel elements in the NAC-LWT with nonpoisoned and poisoned basket modules for intact and failed fuel. In the nonpoisoned configuration, up to 120 intact TRIGA fuel elements can be transported in the NAC-LWT cask. In the poisoned configuration, up to 140 intact TRIGA elements can be transported in the NAC-LWT cask. Up to four TRIGA fuel elements can be contained in screened canisters. Up to two failed TRIGA fuel elements can be contained in sealed canisters. The analyses are performed to satisfy the requirements of 10 CFR Parts 71.55 and 71.59 as well as IAEA Transportation Safety Standards (TS-R-1).

The most reactive TRIGA fuel element type in the NAC-LWT TRIGA basket is evaluated in Section 6.4.5.1. The most reactive basket and intact fuel configurations, including both geometric perturbations and manufacturing tolerances, under wet and dry conditions are evaluated in Section 6.4.5.2. The most reactive cask configuration with three baskets of intact design-basis TRIGA fuel and two baskets of fuel, either in screened cans or in sealed cans, is evaluated under normal and accident conditions in Section 6.4.5.3. Preferential flooding of the screened and sealed failed fuel cans is also evaluated. The maximum k_{eff} of the NAC-LWT cask loaded with design-basis TRIGA fuel is evaluated under normal and accident conditions in Section 6.4.5.4. A single package evaluation, in accordance with 10 CFR 71.55(b)(3), is performed in Section 6.4.5.5. The analyses demonstrates that, including all calculational and mechanical uncertainties, the NAC-LWT cask remains subcritical ($k_s < 0.95$) under normal and accident conditions.

Any combination of TRIGA fuel element types can be placed in the NAC-LWT TRIGA baskets. TRIGA fuel cluster rods are analyzed as separate loadings in Section 6.4.6 and will not be shipped with TRIGA fuel elements.

6.4.5.1 Most Reactive TRIGA Fuel Element

Of the four main types of TRIGA fuel elements (Table 6.2.5-1), three (aluminum clad, stainless steel clad, and FFCR) are explicitly analyzed to determine which element is bounding in terms of criticality. The ACPR fuel element and fuel follower control rod types are eliminated from consideration due to their low ^{235}U loading. For steel clad fuel, the standard, and FLIP LEU-I compositions (Table 6.2.5-2) are also eliminated from further consideration due to their low ^{235}U loading. These element types are bounded by this analysis. The two types of Al clad fuel

elements, each with 20 wt% ^{235}U loading are analyzed, and the two types of stainless steel clad elements (standard streamlined and standard plain) both enriched to either 20 wt% or 70 wt% in ^{235}U are analyzed. The FFCR element is analyzed with FLIP LEU-I composition enriched to 20 wt% ^{235}U.

6.4.5.1.1 Nonpoisoned Basket Most Reactive TRIGA Fuel Element Evaluation

The parametric evaluation of the TRIGA fuel element types for the nonpoisoned basket is performed with the fuel/basket unit cell infinite array model. The reactivities of the seven candidate fuel types are presented in Table 6.4.5-1. The results show that the stainless steel clad, standard plain, TRIGA fuel element with FLIP composition at 70 wt% ^{235}U is the most reactive of all TRIGA fuel element types. Table 6.4.5-1 also includes the results for several combinations of steel FLIP LEU (20 wt% ^{235}U) and FLIP HEU (70 wt% ^{235}U) which are bounded by the results for four 70 wt% ^{235}U elements per basket cell.

6.4.5.1.2 Poisoned Basket Most Reactive TRIGA Fuel Element Evaluation

The parametric evaluation of TRIGA fuel element types for the poisoned basket is performed with an infinite cask array model. The reactivity of the candidate fuel types is presented in Table 6.4.5-2. Again, the results show that the stainless steel clad, standard plain, TRIGA fuel element with FLIP composition at 70 wt% ^{235}U is the most reactive of all TRIGA fuel element types, and combinations of steel FLIP LEU (20 wt% ^{235}U) and FLIP HEU (70 wt% ^{235}U) are bounded by the results for four 70 wt% ^{235}U elements per basket cell. Because of the low relative reactivity of the 14-inch aluminum clad and FFCR (Table 6.4.5-1) elements, it is not necessary to re-analyze these elements.

6.4.5.1.3 Summary of Most Reactive TRIGA Fuel Element Evaluation

The stainless steel clad, standard plain, TRIGA fuel element with FLIP composition at 70 wt% ^{235}U is the most reactive of all TRIGA fuel element types in the poisoned and nonpoisoned baskets. Four of these elements in basket openings bound the other element types and any combination with other such elements. This TRIGA fuel element type and the TRIGA fuel cluster rods will be utilized in subsequent evaluations of the NAC-LWT cask with poisoned and nonpoisoned baskets.

6.4.5.2 Most Reactive Fuel Element and Basket Configurations

The primary basket tolerances affecting system reactivity are geometric tolerances, including the positioning of the fuel elements in the cell opening, the size of the cell opening; and manufacturing tolerances, including the thickness of the steel plate dividing the basket openings. The effect of these tolerances is evaluated sequentially in this section.

6.4.5.2.1 Geometric Perturbations

The TRIGA fuel elements are held in place by basket modules. Each cell opening in the basket module can contain up to four TRIGA fuel elements. The TRIGA fuel elements are not constrained in the opening and, therefore, may shift to any location in the opening. Wet and dry conditions of the TRIGA fuel are evaluated to determine the most reactive fuel element and basket configuration.

Table 6.4.5-3 and Table 6.4.5-4 show the non-poisoned and poisoned axially infinite basket cask k_{eff} with design-basis TRIGA fuel elements. The effects evaluated in the tables include fuel element movement and partial loading in wet and dry basket openings.

For each basket configuration, the most reactive wet configuration contains four design-basis TRIGA fuel elements moved outward to the corners of each cell opening, with k_{eff} = 0.83468 ± 0.00101 and 0.87874 ± 0.00123 for non-poisoned and poisoned basket configurations, respectively. Although the reactivity of the non-poisoned basket configurations with three fuel elements in a cell are similar to that with four rods, the four rod configuration is selected as the most reactive because it contains the greatest amount of ^{235}U. The wet configuration maximizes the moderation between TRIGA fuel elements within the wet cavity and is referred to as the wet configuration for TRIGA fuel elements.

The most reactive dry configuration, with no water in the neutron shield, contains four design-basis TRIGA fuel elements touching in each opening and moved inward to the basket center with k_{eff} = 0.93434 ± 0.00115 and 0.88969 ± 0.00122 for non-poisoned and poisoned basket configurations, respectively. This dry configuration minimizes the neutron leakage of TRIGA fuel elements within the dry basket and is referred to as the dry configuration for TRIGA fuel elements. The partial loading evaluations show a general decrease in reactivity with a decreasing number of fuel elements.

6.4.5.2.2 Manufacturing Tolerance Perturbations

In addition to geometric tolerances, the wet and dry configurations were evaluated to determine the effect of manufacturing tolerances. The dimensional ranges of the plate materials used to construct the basket openings are 0.28 inch minimum/0.3125 inch maximum for the center plate, 0.24 inch minimum/0.295 inch maximum for the outside divider plate, and 0.12 inch minimum/0.13 inch maximum for the outside plate. The cell opening is checked during fabrication to ensure a minimum cell opening of 3.38 inches square, and a maximum cell opening size of 3.48 inches square. The most reactive configurations based on geometric tolerances are utilized in this analysis.

Table 6.4.5-5 and Table 6.4.5-6 show the nonpoisoned and poisoned basket, cask k_{eff} with design-basis TRIGA fuel elements. The effects evaluated in the tables include perturbations on basket plate thickness and basket opening size. For the nonpoisoned basket, within statistical limits, the most reactive wet and dry configurations contain baskets with the minimum stainless steel thickness divider plates. The reactivity of these wet and dry configurations are k_{eff} = 0.86861 ± 0.00094 and k_{eff} = 0.90501 ± 0.00109, respectively. Furthermore, the most reactive dry configuration for manufacturing tolerances contains the minimum basket opening, k_{eff} = 0.90817 ± 0.00105. For the poisoned basket configuration, the perturbations do not significantly increase reactivity.

6.4.5.3 Sealed and Screened Cans Criticality Evaluation

Criticality calculations were performed in screened and sealed failed fuel cans in the top and base basket modules of the cask. Three cases are examined for each basket combination, an all dry system, a full wet system, and a preferentially wet system with water only in the screened or sealed failed fuel can. Fuel in sealed cans is modeled both homogeneously, heterogeneously, and with partial loadings. The three central modules contain intact fuel in the most reactive wet or dry configurations, as appropriate, as determined in Section 6.4.5.2. The reactivities of the failed fuel combinations are compared to the reactivities of respective intact fuel configurations, and moderator density studies are performed on the most reactive configurations in Section 6.4.5.4.

6.4.5.3.1 Screened Failed Fuel Can Evaluations

Table 6.4.5-7 shows the results of the preferential flooding and partial loading studies of the screened failed fuel can configurations with design-basis TRIGA fuel elements in nonpoisoned and poisoned baskets. As seen in the table, the most reactive configurations for the NAC-LWT

cask containing screened cans with TRIGA fuel elements is an infinite array of casks with dry cavities, loaded with preferentially flooded screened cans, with each can containing four fuel elements in the corners of the cans. The most reactive poisoned configuration also contains the maximum can opening size.

The reactivity, k_{eff}, for the nonpoisoned and poisoned configurations is 0.90926 ± 0.00126 and 0.90224 ± 0.00128, respectively. The reactivity of the screened cans in the nonpoisoned basket configuration is bounded by the sealed can evaluations presented in Section 6.4.5.3.2.

6.4.5.3.2 Sealed Failed Fuel Can Evaluations

Table 6.4.5-8 shows the results of the preferential flooding and partial loading studies of the sealed failed fuel can configurations with TRIGA fuel elements in nonpoisoned and poisoned baskets. Included in the sealed can evaluations are homogenous fuel/moderator mixture cases, representing fuel debris, with the mixture either being solid (no water), filling one half of the can or filling the whole can. Cases are evaluated for the solid in the mixture both with and without graphite.

As seen in the table, the most reactive configuration for the NAC-LWT cask with the non-poisoned basket containing sealed cans is for an infinite array of casks with dry cavities loaded with preferentially flooded, maximum diameter, sealed cans, each can containing a homogeneous mixture of water and the fissile material equivalent to two TRIGA fuel elements. The most reactive nonpoisoned configuration is k_{eff} = 0.91355 ± 0.00119. The "Wet Cask/Wet Can, Elements Out" case for the non-poisoned basket was not analyzed because the reactivity of the element configurations is significantly lower than the homogenized mixture configurations.

The most reactive poisoned basket configuration is selected as the case containing flooded cask and cans with elements touching the can wall. The reactivity, k_{eff}, for this configuration is 0.88574 ± 0.00130. Since the screened can reactivity presented in Section 6.4.5.3.1 is higher, this configuration is bounded.

6.4.5.4 Moderator Density Criticality Evaluations for Intact TRIGA Fuel Elements

The evaluations for normal and accident conditions include moderator density variations in the cask cavity and external environment to the cask. One evaluation is performed for each basket (nonpoisoned / poisoned) combination. Table 6.4.5-9 and Table 6.4.5-10 show the most reactive

configurations for these combinations as determined in Section 6.4.5.3. The tables contain results for infinite axial length models for the intact fuel and finite axial length models with cask end caps for failed fuel. Comparing the reactivity of the more conservative infinite models with finite models is acceptable, provided the result with the highest k_{eff} is always selected. Alternately, converting conservative infinite axial length models to finite axial length models is equally acceptable.

As seen in Table 6.4.5-9, $k_{eff} = 0.93434 \pm 0.00115$ for the most reactive dry configuration with intact, TRIGA fuel elements in the nonpoisoned basket. When reevaluated as a finite axial length cask model with end caps, the resulting $k_{eff} = 0.89731 \pm 0.00117$. As a result, the most reactive configuration of TRIGA fuel elements in the nonpoisoned basket becomes the configuration with two baskets with sealed cans preferentially flooded with a dry cask, $k_{eff} = 0.91355 \pm 0.00119$. This configuration is chosen for further moderator density variation evaluations.

As seen in Table 6.4.5-10, the most reactive configuration of TRIGA fuel elements in the poisoned basket contains two screened cans preferentially flooded with a dry cask. This configuration is chosen for moderator density variations.

Results of the moderator density variation cases for normal and accident conditions for the two basket configurations are presented in Table 6.4.5-11 through Table 6.4.5-14.

As seen in Table 6.4.5-12, the most reactive configuration for the TRIGA fuel elements in the nonpoisoned basket contains two baskets with sealed cans, preferentially flooded, under accident conditions with no water in the cask interior, neutron shield, or exterior, $k_{eff} = 0.9136 \pm 0.0012$. Per Section 6.5.3, this corresponds to $k_s = 0.9328$.

As seen in Table 6.4.5-14, the most reactive configuration for the TRIGA fuel elements in the poisoned basket, contains two baskets with sealed cans, preferentially flooded, under accident conditions with no water in the cask interior, neutron shield, or exterior, $k_{eff} = 0.9022 \pm 0.0015$. Per Section 6.5.3, this corresponds to $k_s = 0.9220$.

6.4.5.5 Single Package Criticality Evaluation

To satisfy 10 CFR 71.55(b)(3), an analysis of the reflection of the containment system (inner shell) by water is performed on a single wet cask. Successive replacement of the cask radial

shields with water reflection is also evaluated for each basket (nonpoisoned/poisoned) combination. As seen in Table 6.4.5-15 and Table 6.4.5-16, the reactivity of the system drops as each radial shield of the cask is replaced by water from the full cask surrounded by water, to the inner shell surrounded by water.

6.4.5.6 Conclusion

Thus, including all calculational and mechanical uncertainties, an infinite array of NAC-LWT casks remains sub-critical, and is below the 0.95 limit, corrected for bias and uncertainty, under normal and accident conditions with:

Nonpoisoned Baskets:

1. 120 TRIGA fuel elements,
2. Screened cans each with four TRIGA fuel elements (top and bottom baskets only),
3. Sealed cans (top and bottom baskets only) with two TRIGA fuel elements.

Poisoned Baskets:

1. 140 TRIGA fuel elements,
2. Screened cans each with four TRIGA fuel elements (top and bottom baskets only),
3. Sealed cans (top and bottom baskets only) with two TRIGA fuel elements.

Table 6.4.5-1 Parametric Study – Fuel / Basket k-infinity versus TRIGA Fuel Element Type, Nonpoisoned Basket

(Infinite Array of Nonpoisoned TRIGA Basket Cells with Four (4) Elements)

Fuel Element Type	Initial U Content wt%	Total U grams	^{235}U wt%	Wet Case Results K(infinity) ± σ	Dry Case Results k(infinity) ± σ
Original Al Clad 14 inch Active Fuel	8-8.5	205	20.0	1.01740 ± 0.00081	1.04129 ± 0.00066
Original Al Clad 15 inch Active Fuel	8-8.5	205	20.0	1.00636 ± 0.00081	1.02634 ± 0.00065
Stand. Streamlined Steel Clad 15 inch Active Fuel (FLIP)	8.5	196	70.0	1.33900 ± 0.00094	1.43012 ± 0.00078
Stand. Plain Steel Clad 15 Active Fuel (FLIP)	8.5	196	70.0	1.33969 ± 0.00097	1.43009 ± 0.00077
Stand. Streamlined Steel Clad FLIP-LEU-II	30.6	845	20.0	1.28517 ± 0.00087	1.31180 ± 0.00073
Stand. Plain Steel Clad FLIP-LEU-II	30.6	845	20.0	1.28512 ± 0.00088	1.31198 ± 0.00072
FFCR Element FLIP-LEU-I	20.0	484	20.0	1.16407 ± 0.00086	1.23186 ± 0.00071
1-70 wt% ^{235}U + 3-20 wt% ^{235}U	--	--	--	1.30429 ± 0.00091	1.34060 ± 0.00071
3-70 wt% ^{235}U + 1-20 wt% ^{235}U	--	--	--	1.32896 ± 0.00092	1.40083 ± 0.00077
2-70 wt% ^{235}U + 2-20 wt% ^{235}U	--	--	--	1.31601 ± 0.00094	1.37156 ± 0.00076

LEU Low Enriched Uranium

FLIP Fuel Life Improvement Program

FFCR Fuel Follower Control Rod

* Resonance treatment for two different fuel types is included.

Table 6.4.5-2 Parametric Study – Cask k_{eff} versus TRIGA Fuel Element Type, Poisoned Basket

Fuel Element Type	Initial U Content wt%	Total U grams	^{235}U wt%	Wet Case Results $k_{eff} \pm \sigma$	Dry Case Results $K_{eff} \pm \sigma$
Original Al Clad 15 inch Active Fuel	8-8.5	205	20.0	0.58906 ± 0.00097	0.47118 ± 0.00076
Stand. Streamlined Steel Clad 15 inch Active Fuel (FLIP)	8.5	196	70.0	0.86504 ± 0.00134	0.85705 ± 0.00112
Stand. Plain Steel Clad 15 Active Fuel (FLIP)	8.5	196	70.0	0.86647 ± 0.00137	0.86610 ± 0.00115
Stand. Streamlined Steel Clad FLIP-LEU-II	30.6	845	20.0	0.83413 ± 0.00130	0.80073 ± 0.00103
Stand. Plain Steel Clad FLIP-LEU-II	30.6	845	20.0	0.83604 ± 0.00127	0.80492 ± 0.00099
1-70 wt% ^{235}U + 3-20 wt% ^{235}U	--	--	--	0.84391 ± 0.00133	0.81589 ± 0.00101
3-70 wt% ^{235}U + 1-20 wt% ^{235}U	--	--	--	0.85826 ± 0.00131	0.84917 ± 0.00108
2-70 wt% ^{235}U + 2-20 wt% ^{235}U	--	--	--	0.85162 ± 0.00129	0.83177 ± 0.00103

Table 6.4.5-3 Axially Infinite Cask k_{eff} with TRIGA Fuel Elements – Fuel Element Placement Perturbations, Nonpoisoned Basket

Basket Configuration	Wet Case Results $k_{eff} \pm \sigma$	Dry Case Results $k_{eff} \pm \sigma$
Elements Touching, Moved In	-	0.93434 ± 0.00115
Elements Touching, Centered	0.77382 ± 0.00109	0.92672 ± 0.00185
Elements Out	0.83468 ± 0.00101	0.90817 ± 0.00105
Elements Centered, Quadrants	0.81340 ± 0.00107	-
Three - 70 wt% ^{235}U Elements (Equilateral)	0.83646 ± 0.00112	-
Three - 70 wt% ^{235}U Elements (in corner)	0.83579 ± 0.00101	0.80629 ± 0.00110
Three - 70 wt% ^{235}U Elements (Isosceles)	0.83468 ± 0.00101	-
Two - 70 wt% ^{235}U Elements (Center)	0.67480 ± 0.00097	0.63503 ± 0.00108
One - 70 wt% ^{235}U Elements (Center)	0.44428 ± 0.00091	-

Table 6.4.5-4 Axially Infinite Cask k_{eff} with TRIGA Fuel Elements – Fuel Element Placement Perturbations, Poisoned Basket

Basket Configuration	Wet Case Results $k_{eff} \pm \sigma$	Dry Case Results $k_{eff} \pm \sigma$
Elements Touching, Moved In	-	0.88969 ± 0.00122
Elements Touching, Centered	0.82705 ± 0.00136	0.87833 ± 0.00122
Elements Touching, Moved Out	-	0.87871 ± 0.00112
Elements Centered, Quadrants	0.86647 ± 0.00134	0.86610 ± 0.00115
Elements Out	0.87874 ± 0.00123	0.85348 ± 0.00114
27 Elements, Touching	0.85014 ± 0.00131	0.66829 ± 0.00114
27 Elements, Corners	0.84686 ± 0.00124	-
26 Elements, Touching	0.82959 ± 0.00124	0.64354 ± 0.00117
26 Elements, Corners	0.81959 ± 0.00126	-
21 Elements, Touching	0.70693 ± 0.00127	0.55021 ± 0.00110
21 Elements, Corners	0.73134 ± 0.00133	-
14 Elements, Touching	0.58154 ± 0.00136	0.39354 ± 0.00097
14 Elements, Corners	0.55112 ± 0.00117	-

Table 6.4.5-5 Axially Infinite Cask k_{eff} with TRIGA Fuel Elements – Basket Manufacturing Tolerance Perturbations, Nonpoisoned Basket

Basket Configuration	Wet Case Results w/ Dry Neutron Shield $k_{eff} \pm \sigma$	Dry Case Results $k_{eff} \pm \sigma$
Base Case[1]	0.86190 ± 0.00089[3]	0.90053 ± 0.00115[4]
Thin SS Plates	0.86861 ± 0.00094	0.90501 ± 0.00109
Maximum Basket Opening[2]	0.86864 ± 0.00097	0.90023 ± 0.00107
Minimum Basket Opening[2]	0.86489 ± 0.00091	0.90817 ± 0.00105

Notes:

1. Both wet and dry base case configurations include elements out to corners of basket openings.
2. Incorporates minimum thickness stainless steel, basket divider plates.
3. Comparable to the "elements out," k_{eff} = 0.83468 ± 0.00101, configuration of Table 6.4.5-3 except the neutron shield is dry.
4. Incorporates the "elements out" configuration.

Table 6.4.5-6 Axially Infinite Cask k_{eff} with TRIGA Fuel Elements – Basket Manufacturing Tolerance Perturbations, Poisoned Basket

Basket Configuration	Wet Case Results $k_{eff} \pm \sigma$	Dry Case Results $k_{eff} \pm \sigma$
Base Case[1]	0.87874 ± 0.00123	0.88969 ± 0.00122
Minimum Opening[2]	0.87832 ± 0.00127	0.89054 ± 0.00107
Increased Central Opening[2]	0.87981 ± 0.00133	0.88722 ± 0.00118
Increased Exterior Openings[2]	0.87875 ± 0.00134	0.88998 ± 0.00120
Increased Central Opening, Decreased Exterior Openings[2]	0.87475 ± 0.00134	0.88724 ± 0.00116

Notes:

1. Most reactive configurations from Table 6.4.5-4.
2. Incorporates minimum thickness stainless steel, basket divider plates.

Table 6.4.5-7 Screened Can Preferential Flooding and Partial Loading Reactivity Evaluations for TRIGA Fuel Elements, Nonpoisoned and Poisoned Baskets

Description	$k_{eff} \pm \sigma$ Nonpoisoned Basket	$k_{eff} \pm \sigma$ Poisoned Basket
Wet Cask / Wet Can	0.84040 ± 0.00132	0.88010 ± 0.00139
Dry Cask / Dry Can	0.89383 ± 0.00120	0.86228 ± 0.00128
Dry Cask / Wet Can – Elements To Center of Cask	0.89778 ± 0.00124	0.88272 ± 0.00124
Dry Cask / Wet Can – Elements To Center of Can	0.89435 ± 0.00124	0.87727 ± 0.00124
Dry Cask / Wet Can – Elements Quadrant Centered	0.89821 ± 0.00129	0.88737 ± 0.00123
Dry Cask / Wet Can – Elements in Corners	0.90926 ± 0.00126	0.89957 ± 0.00118
Dry Cask / Wet Can – Elements in Corners, Max. Can	0.90673 ± 0.00123	0.90224 ± 0.00128
18 Elements per Basket Module	0.84896 ± 0.00121	0.82527 ± 0.00114
12 Elements per Basket Module	0.82532 ± 0.00125	0.80281 ± 0.00119

Table 6.4.5-8 Sealed Can Preferential Flooding and Partial Loading Reactivity Evaluations for TRIGA Fuel Elements, Nonpoisoned and Poisoned Baskets

Description	$k_{eff} \pm \sigma$ Nonpoisoned Basket	$k_{eff} \pm \sigma$ Poisoned Basket
Wet Cask / Wet Can, Elements Out	-	0.88574 ± 0.00130
Wet Cask / Wet Can	0.84331 ± 0.00129	0.88036 ± 0.00125
Dry Cask / Dry Can	0.85693 ± 0.00121	0.83021 ± 0.00118
Dry Cask / Wet Can	0.84376 ± 0.00129	0.78084 ± 0.00114
2 Rods per Can - 3 Five Inch Fuel Pellets	0.84346 ± 0.00128	0.88212 ± 0.00133
Mixture Solid (No Moderator)- 2 Rods Per Can	0.87512 ± 0.00122	0.88371 ± 0.00125
Mixture Half Can Height - 2 Rods Per Can	0.90691 ± 0.00212	0.88564 ± 0.00146
Mixture Full Can Height - 2 Rods Per Can	0.91088 ± 0.00106	0.88411 ± 0.00129
Mixture - Solid (No Moderator) - 1 Rods Per Can	0.85868 ± 0.00132	0.88472 ± 0.00131
Mixture - Half Can Height - 1 Rods Per Can	0.87411 ± 0.00117	0.88204 ± 0.00130
Mixture - Full Can Height - 1 Rods Per Can	0.85913 ± 0.00117	0.88477 ± 0.00142
2 Rods Per Can + Graphite – Solid	0.87208 ± 0.00117	0.88616 ± 0.00138
2 Rods Per Can + Graphite – Full Can Height	0.89867 ± 0.00118	0.88431 ± 0.00129
Increased Can Diameter (+0.02 inch)[1]	0.91355 ± 0.00119	0.88436 ± 0.00138

Notes:

1. The increased can diameter cases were analyzed using the most reactive cases for each basket configuration (nonpoisoned/poisoned). The "Wet Cask/Wet Can, Elements Out" case was selected for the poisoned basket configuration due to the lack of statistically significant differences in the above reported results.

Table 6.4.5-9 Summary of Most Reactive Configurations, TRIGA Fuel Elements, Nonpoisoned Basket

	Wet	Dry	Preferential
Intact Fuel	0.86861 ± 0.00094	0.93434 ± 0.00115 [1]	-
Screened Fuel Cans	0.84040 ± 0.00132	0.89383 ± 0.00120	0.90926 ± 0.00126
Sealed Fuel Cans	0.84331 ± 0.00129	0.85693 ± 0.00121	0.91355 ± 0.00199

Notes:

1. As reported in Section 6.4.5.4, this case is reevaluated with a finite axial length model, making the preferentially flooded, sealed can case the most reactive.

Table 6.4.5-10 Summary of Most Reactive Configurations, TRIGA Fuel Elements, Poisoned Basket

	Wet	Dry	Preferential
Intact Fuel	0.87874 ± 0.00123	0.88969 ± 0.00122	-
Screened Fuel Cans	0.88010 ± 0.00139	0.86228 ± 0.00128	0.90224 ± 0.00128
Sealed Fuel Cans	0.88574 ± 0.00130	0.83021 ± 0.00118	0.88564 ± 0.00146

Table 6.4.5-11 Reactivity Results for TRIGA Fuel Elements, Sealed Cans, Normal Conditions, Nonpoisoned Basket

Moderator SG	Casks Touching ($k_{eff} \pm \sigma$)	8 Foot Center-To-Center ($k_{eff} \pm \sigma$)
Dry Exterior, Vary Internal Density		
0.00000	0.7239 ± 0.0012	0.7203 ± 0.0012
0.00100	0.7205 ± 0.0012	0.7212 ± 0.0012
0.00178	0.7231 ± 0.0013	0.7201 ± 0.0012
0.00316	0.7216 ± 0.0012	0.7202 ± 0.0012
0.00562	0.7227 ± 0.0012	0.7181 ± 0.0012
0.01000	0.7234 ± 0.0012	0.7224 ± 0.0012
0.01780	0.7205 ± 0.0012	0.7223 ± 0.0013
0.03160	0.7249 ± 0.0012	0.7242 ± 0.0012
0.05620	0.7263 ± 0.0012	0.7285 ± 0.0012
0.10000	0.7295 ± 0.0012	0.7303 ± 0.0012
0.17800	0.7446 ± 0.0012	0.7415 ± 0.0012
0.31600	0.7674 ± 0.0012	0.7647 ± 0.0013
0.56200	0.7887 ± 0.0013	0.7884 ± 0.0013
0.70000	0.7977 ± 0.0014	0.7961 ± 0.0014
0.80000	0.8009 ± 0.0013	0.7974 ± 0.0013
0.90000	0.8000 ± 0.0013	0.8008 ± 0.0012
1.00000	0.8020 ± 0.0013	0.8022 ± 0.0014
Optimally Moderated Cask Interior (SG = 1.0), Vary External Density		
0.00000	0.8020 ± 0.0013	0.8022 ± 0.0013
0.00100	0.8013 ± 0.0014	0.8010 ± 0.0013
0.00178	0.7993 ± 0.0014	0.8003 ± 0.0013
0.00316	0.8017 ± 0.0014	0.8024 ± 0.0013
0.00562	0.8041 ± 0.0014	0.8002 ± 0.0013
0.01000	0.8018 ± 0.0013	0.8032 ± 0.0013
0.01780	0.8025 ± 0.0013	0.8018 ± 0.0013
0.03160	0.8001 ± 0.0013	0.8023 ± 0.0013
0.05620	0.8004 ± 0.0014	0.7993 ± 0.0013
0.10000	0.8008 ± 0.0012	0.8000 ± 0.0013
0.17800	0.8018 ± 0.0014	0.8019 ± 0.0013
0.31600	0.8034 ± 0.0014	0.8019 ± 0.0013
0.56200	0.7996 ± 0.0013	0.8025 ± 0.0013
0.70000	0.8018 ± 0.0014	0.8026 ± 0.0014
0.80000	0.8013 ± 0.0013	0.8009 ± 0.0013
0.90000	0.7998 ± 0.0013	0.8009 ± 0.0012
1.00000	0.8019 ± 0.0015	0.8003 ± 0.0013
Vary Internal and External Density Simultaneously		
0.00000	0.7239 ± 0.0012	0.7203 ± 0.0013
0.00100	0.7212 ± 0.0012	0.7192 ± 0.0012
0.00178	0.7210 ± 0.0011	0.7236 ± 0.0012
0.00316	0.7202 ± 0.0012	0.7217 ± 0.0012
0.00562	0.7225 ± 0.0012	0.7218 ± 0.0012
0.01000	0.7229 ± 0.0012	0.7236 ± 0.0012
0.01780	0.7230 ± 0.0012	0.7239 ± 0.0012
0.03160	0.7253 ± 0.0013	0.7236 ± 0.0012
0.05620	0.7273 ± 0.0012	0.7261 ± 0.0013
0.10000	0.7311 ± 0.0012	0.7296 ± 0.0013
0.17800	0.7439 ± 0.0013	0.7429 ± 0.0012
0.31600	0.7634 ± 0.0013	0.7650 ± 0.0013
0.56200	0.7882 ± 0.0014	0.7898 ± 0.0013
0.70000	0.7950 ± 0.0014	0.7941 ± 0.0012
0.80000	0.7950 ± 0.0013	0.7973 ± 0.0013
0.90000	0.7984 ± 0.0012	0.8002 ± 0.0012
1.00000	0.8000 ± 0.0013	0.8029 ± 0.0014

Table 6.4.5-12 Reactivity Results for TRIGA Fuel Elements, Sealed Cans, Accident Conditions, Nonpoisoned Basket

Moderator SG	Casks Touching ($k_{eff} \pm \sigma$)	8 Foot Center-To-Center ($k_{eff} \pm \sigma$)
Dry Exterior and Neutron Shield, Vary Internal Moderator		
0.00000	0.9136 ± 0.0012	0.9057 ± 0.0011
0.00100	0.9119 ± 0.0012	0.9054 ± 0.0011
0.00178	0.9101 ± 0.0012	0.9041 ± 0.0011
0.00316	0.9110 ± 0.0011	0.9040 ± 0.0011
0.00562	0.9095 ± 0.0012	0.9046 ± 0.0011
0.01000	0.9059 ± 0.0012	0.8999 ± 0.0012
0.01780	0.9021 ± 0.0012	0.8979 ± 0.0012
0.03160	0.8965 ± 0.0012	0.8908 ± 0.0011
0.05620	0.8842 ± 0.0013	0.8793 ± 0.0012
0.10000	0.8660 ± 0.0012	0.8622 ± 0.0012
0.17800	0.8432 ± 0.0012	0.8419 ± 0.0012
0.31600	0.8275 ± 0.0013	0.8222 ± 0.0012
0.56200	0.8185 ± 0.0013	0.8153 ± 0.0014
0.70000	0.8144 ± 0.0013	0.8124 ± 0.0013
0.80000	0.8140 ± 0.0013	0.8091 ± 0.0013
0.90000	0.8154 ± 0.0012	0.8082 ± 0.0013
1.00000	0.8117 ± 0.0013	0.8081 ± 0.0013
Optimally Moderated Internal (SG = 0.0), Vary Neutron Shield and Exterior		
0.00000	0.9136 ± 0.0012	0.9057 ± 0.0011
0.00100	0.8950 ± 0.0011	0.8208 ± 0.0012
0.00178	0.8887 ± 0.0011	0.7931 ± 0.0012
0.00316	0.8732 ± 0.0012	0.7651 ± 0.0012
0.00562	0.8505 ± 0.0012	0.7454 ± 0.0011
0.01000	0.8210 ± 0.0011	0.7311 ± 0.0012
0.01780	0.7957 ± 0.0012	0.7233 ± 0.0012
0.03160	0.7655 ± 0.0012	0.7192 ± 0.0011
0.05620	0.7432 ± 0.0012	0.7195 ± 0.0013
0.10000	0.7325 ± 0.0013	0.7177 ± 0.0012
0.17800	0.7252 ± 0.0011	0.7206 ± 0.0012
0.31600	0.7216 ± 0.0012	0.7213 ± 0.0012
0.56200	0.7211 ± 0.0012	0.7211 ± 0.0012
0.70000	0.7199 ± 0.0012	0.7190 ± 0.0012
0.80000	0.7213 ± 0.0012	0.7184 ± 0.0012
0.90000	0.7183 ± 0.0013	0.7196 ± 0.0012
1.00000	0.7189 ± 0.0011	0.7194 ± 0.0013
Vary Interior, Exterior and Neutron Shield Simultaneously		
0.00000	0.9136 ± 0.0012	0.9057 ± 0.0011
0.00100	0.8964 ± 0.0012	0.8189 ± 0.0012
0.00178	0.8879 ± 0.0011	0.7913 ± 0.0013
0.00316	0.8726 ± 0.0012	0.7673 ± 0.0013
0.00562	0.8496 ± 0.0011	0.7459 ± 0.0012
0.01000	0.8223 ± 0.0012	0.7345 ± 0.0012
0.01780	0.7903 ± 0.0012	0.7237 ± 0.0012
0.03160	0.7685 ± 0.0012	0.7223 ± 0.0011
0.05620	0.7504 ± 0.0012	0.7242 ± 0.0012
0.10000	0.7415 ± 0.0013	0.7296 ± 0.0012
0.17800	0.7445 ± 0.0013	0.7404 ± 0.0013
0.31600	0.7674 ± 0.0013	0.7658 ± 0.0013
0.56200	0.7904 ± 0.0013	0.7898 ± 0.0013
0.70000	0.7972 ± 0.0014	0.7936 ± 0.0014
0.80000	0.7969 ± 0.0013	0.7956 ± 0.0014
0.90000	0.8003 ± 0.0013	0.8007 ± 0.0013
1.00000	0.8000 ± 0.0013	0.8013 ± 0.0013

Table 6.4.5-13 Reactivity Results for TRIGA Fuel Elements, Screened Cans, Normal Conditions, Poisoned Basket

Moderator SG	Casks Touching ($k_{eff} \pm \sigma$)	8 Foot Center-To-Center ($k_{eff} \pm \sigma$)
Dry Exterior, Vary Internal Density		
0.00000	0.8376 ± 0.0018	0.8381 ± 0.0017
0.00100	0.8408 ± 0.0017	0.8418 ± 0.0016
0.00178	0.8408 ± 0.0018	0.8412 ± 0.0018
0.00316	0.8390 ± 0.0017	0.8432 ± 0.0016
0.00562	0.8371 ± 0.0017	0.8399 ± 0.0017
0.01000	0.8420 ± 0.0017	0.8397 ± 0.0018
0.01780	0.8383 ± 0.0017	0.8419 ± 0.0017
0.03160	0.8413 ± 0.0017	0.8427 ± 0.0017
0.05620	0.8466 ± 0.0017	0.8448 ± 0.0017
0.10000	0.8433 ± 0.0016	0.8479 ± 0.0017
0.17800	0.8510 ± 0.0017	0.8502 ± 0.0017
0.31600	0.8497 ± 0.0016	0.8505 ± 0.0016
0.56200	0.8453 ± 0.0017	0.8484 ± 0.0017
0.70000	0.8444 ± 0.0016	0.8464 ± 0.0017
0.80000	0.8321 ± 0.0017	0.8432 ± 0.0017
0.90000	0.8458 ± 0.0017	0.8437 ± 0.0017
1.00000	0.8527 ± 0.0017	0.8540 ± 0.0017
Optimally Moderated Cask Interior (SG = 1.0), Vary External Density		
0.00000	0.8527 ± 0.0017	0.8540 ± 0.0017
0.00100	0.8482 ± 0.0018	0.8513 ± 0.0016
0.00178	0.8532 ± 0.0017	0.8513 ± 0.0016
0.00316	0.8516 ± 0.0017	0.8531 ± 0.0017
0.00562	0.8546 ± 0.0017	0.8539 ± 0.0017
0.01000	0.8521 ± 0.0018	0.8517 ± 0.0019
0.01780	0.8528 ± 0.0018	0.8515 ± 0.0018
0.03160	0.8543 ± 0.0017	0.8526 ± 0.0017
0.05620	0.8506 ± 0.0018	0.8503 ± 0.0017
0.10000	0.8523 ± 0.0018	0.8542 ± 0.0016
0.17800	0.8507 ± 0.0018	0.8478 ± 0.0016
0.31600	0.8539 ± 0.0017	0.8518 ± 0.0016
0.56200	0.8545 ± 0.0017	0.8525 ± 0.0017
0.70000	0.8512 ± 0.0017	0.8534 ± 0.0017
0.80000	0.8548 ± 0.0017	0.8529 ± 0.0017
0.90000	0.8523 ± 0.0016	0.8522 ± 0.0017
1.00000	0.8540 ± 0.0018	0.8523 ± 0.0017
Vary Internal and External Density Simultaneously		
0.00000	0.8376 ± 0.0018	0.8381 ± 0.0017
0.00100	0.8396 ± 0.0017	0.8382 ± 0.0017
0.00178	0.8404 ± 0.0016	0.8404 ± 0.0017
0.00316	0.8430 ± 0.0016	0.8413 ± 0.0017
0.00562	0.8448 ± 0.0017	0.8391 ± 0.0016
0.01000	0.8400 ± 0.0017	0.8398 ± 0.0017
0.01780	0.8419 ± 0.0017	0.8424 ± 0.0018
0.03160	0.8394 ± 0.0017	0.8439 ± 0.0017
0.05620	0.8437 ± 0.0017	0.8385 ± 0.0017
0.10000	0.8477 ± 0.0017	0.8477 ± 0.0017
0.17800	0.8502 ± 0.0017	0.8469 ± 0.0017
0.31600	0.8463 ± 0.0017	0.8494 ± 0.0018
0.56200	0.8484 ± 0.0017	0.8513 ± 0.0017
0.70000	0.8471 ± 0.0017	0.8459 ± 0.0018
0.80000	0.8440 ± 0.0017	0.8462 ± 0.0016
0.90000	0.8429 ± 0.0017	0.8451 ± 0.0017
1.00000	0.8540 ± 0.0018	0.8523 ± 0.0017

Table 6.4.5-14 Reactivity Results for TRIGA Fuel Elements, Screened Cans, Accident Conditions, Poisoned Basket

Moderator SG	Casks Touching ($k_{eff} \pm \sigma$)	8 Foot Center-To-Center ($k_{eff} \pm \sigma$)
Dry Exterior and Neutron Shield, Vary Internal Moderator		
0.00000	0.9022 ± 0.0015	0.9015 ± 0.0016
0.00100	0.9019 ± 0.0016	0.9022 ± 0.0016
0.00178	0.8998 ± 0.0016	0.9003 ± 0.0016
0.00316	0.8992 ± 0.0016	0.9009 ± 0.0016
0.00562	0.8995 ± 0.0017	0.9015 ± 0.0017
0.01000	0.8998 ± 0.0017	0.8956 ± 0.0017
0.01780	0.8979 ± 0.0017	0.9003 ± 0.0017
0.03160	0.8966 ± 0.0018	0.8946 ± 0.0016
0.05620	0.8949 ± 0.0015	0.8889 ± 0.0015
0.10000	0.8893 ± 0.0018	0.8844 ± 0.0017
0.17800	0.8843 ± 0.0018	0.8822 ± 0.0016
0.31600	0.8772 ± 0.0017	0.8765 ± 0.0016
0.56200	0.8635 ± 0.0018	0.8640 ± 0.0017
0.70000	0.8586 ± 0.0017	0.8657 ± 0.0017
0.80000	0.8620 ± 0.0016	0.8594 ± 0.0016
0.90000	0.8622 ± 0.0016	0.8600 ± 0.0017
1.00000	0.8662 ± 0.0017	0.8629 ± 0.0018
Optimally Moderated Internal (SG = 0.0), Vary Neutron Shield and Exterior		
0.00000	0.9022 ± 0.0015	0.9015 ± 0.0016
0.00100	0.8970 ± 0.0016	0.8644 ± 0.0017
0.00178	0.8910 ± 0.0016	0.8596 ± 0.0018
0.00316	0.8862 ± 0.0015	0.8542 ± 0.0016
0.00562	0.8789 ± 0.0016	0.8457 ± 0.0016
0.01000	0.8687 ± 0.0015	0.8438 ± 0.0017
0.01780	0.8618 ± 0.0017	0.8409 ± 0.0018
0.03160	0.8539 ± 0.0016	0.8386 ± 0.0017
0.05620	0.8482 ± 0.0017	0.8403 ± 0.0018
0.10000	0.8427 ± 0.0015	0.8381 ± 0.0017
0.17800	0.8433 ± 0.0017	0.8418 ± 0.0016
0.31600	0.8424 ± 0.0018	0.8405 ± 0.0018
0.56200	0.8422 ± 0.0017	0.8391 ± 0.0017
0.70000	0.8438 ± 0.0017	0.8399 ± 0.0016
0.80000	0.8429 ± 0.0018	0.8407 ± 0.0017
0.90000	0.8423 ± 0.0017	0.8445 ± 0.0016
1.00000	0.8398 ± 0.0016	0.8383 ± 0.0017
Vary Interior, Exterior and Neutron Shield Simultaneously		
0.00000	0.9022 ± 0.0015	0.9015 ± 0.0016
0.00100	0.8948 ± 0.0016	0.8662 ± 0.0016
0.00178	0.8932 ± 0.0017	0.8577 ± 0.0016
0.00316	0.8881 ± 0.0016	0.8524 ± 0.0017
0.00562	0.8762 ± 0.0016	0.8429 ± 0.0017
0.01000	0.8722 ± 0.0017	0.8431 ± 0.0017
0.01780	0.8628 ± 0.0016	0.8412 ± 0.0017
0.03160	0.8586 ± 0.0016	0.8450 ± 0.0017
0.05620	0.8533 ± 0.0017	0.8448 ± 0.0018
0.10000	0.8496 ± 0.0017	0.8458 ± 0.0017
0.17800	0.8494 ± 0.0017	0.8489 ± 0.0017
0.31600	0.8500 ± 0.0017	0.8459 ± 0.0017
0.56200	0.8489 ± 0.0018	0.8488 ± 0.0018
0.70000	0.8443 ± 0.0017	0.8463 ± 0.0017
0.80000	0.8459 ± 0.0017	0.8407 ± 0.0018
0.90000	0.8421 ± 0.0017	0.8483 ± 0.0017
1.00000	0.8540 ± 0.0018	0.8504 ± 0.0019

Table 6.4.5-15 Single Package 10 CFR 71.55(b)(3) Evaluation k_{eff} Summary, TRIGA Fuel Element, Nonpoisoned Basket

Description	$k_{eff} \pm \sigma$	k_s
Single Cask / Inner Shell Reflected with H_2O	0.80664 ± 0.00136	0.82616
Single Cask / Inner Shell and Lead Reflected with H_2O	0.84194 ± 0.00130	0.86134
Single Cask / Inner Shell, Lead & Outer Shell Reflected with H_2O	0.84398 ± 0.00128	0.86334
Single Intact Cask Reflected with H_2O	0.84446 ± 0.00126	0.86392

Table 6.4.5-16 Single Package 10 CFR 71.55(b)(3) Evaluation k_{eff} Summary, TRIGA Fuel Element, Poisoned Basket

Description	$k_{eff} \pm \sigma$	k_s
Single Cask / Inner Shell Reflected with H_2O	0.85480 ± 0.00135	0.87430
Single Cask / Inner Shell and Lead Reflected with H_2O	0.87788 ± 0.00136	0.89740
Single Cask / Inner Shell, Lead & Outer Shell Reflected with H_2O	0.88369 ± 0.00133	0.90315
Single Intact Cask Reflected with H_2O	0.88117 ± 0.00131	0.90059

6.4.6 TRIGA Fuel Cluster Rods

This section presents the criticality evaluation for the NAC-LWT with nonpoisoned and poisoned basket modules for intact and failed TRIGA fuel cluster rods. In the nonpoisoned configuration, up to 480 intact TRIGA fuel cluster rods can be transported in the NAC-LWT cask. In the poisoned configuration, up to 560 intact TRIGA fuel cluster rods can be transported in the NAC-LWT cask. Up to six TRIGA fuel cluster rods can be contained in sealed canisters. The analyses are performed to satisfy the requirements of 10 CFR Parts 71.55 and 71.59, as well as IAEA Transportation Safety Standards (TS-R-1).

The design basis TRIGA fuel cluster rod is evaluated for the most reactive basket and intact fuel configurations, including both geometric perturbations and manufacturing tolerances, under wet and dry conditions in Section 6.4.6.1. The most reactive cask configuration with three baskets of intact design-basis TRIGA fuel and two baskets of fuel in sealed cans, is evaluated under normal and accident conditions in Section 6.4.6.2. Preferential flooding of the sealed failed fuel cans is also evaluated. The maximum k_{eff} of the NAC-LWT cask loaded with design-basis TRIGA fuel cluster rods is evaluated under normal and accident conditions in Section 6.4.6.3. A single package evaluation, in accordance with 10 CFR 71.55(b)(3), is performed in Section 6.4.6.4. The analyses demonstrates that, including all calculational and mechanical uncertainties, the NAC-LWT cask remains subcritical ($k_s < 0.95$) under normal and accident conditions.

6.4.6.1 Most Reactive Fuel and Basket Configurations

The primary basket tolerances affecting system reactivity are geometric tolerances, including the positioning of the fuel cluster rods and aluminum tube insert in the cell opening, the size of the cell opening; and manufacturing tolerances, including the thickness of the steel plate dividing the basket openings. The effect of these tolerances is evaluated sequentially in this section.

6.4.6.1.1 Geometric Perturbations

The TRIGA fuel cluster rods are held in place by basket modules and a fuel rod insert (Figure 6.2.6-1) with a welded, 4 × 4 array of 0.75 inch OD aluminum tubes. The TRIGA fuel cluster rods, one per insert tube, may shift to any location in a tube. Wet and dry conditions of the TRIGA fuel cluster rods are evaluated to determine the most reactive fuel and basket configuration.

Table 6.4.6-1 and Table 6.4.6-2 show the cask k_{eff} for the nonpoisoned and poisoned baskets with TRIGA fuel cluster rods. The effects evaluated in the tables include fuel movement within the fuel rod inserts and partial loadings under wet and dry moderation conditions.

The most reactive wet configuration contains 16 TRIGA fuel cluster rods moved outward from the center of each 4 × 4 insert array and the inserts moved to the center of the basket with k_{eff} = 0.7571 ± 0.0025 and 0.7995 ± 0.0026, for the nonpoisoned and poisoned basket configurations, respectively. This wet configuration maximizes the moderation between TRIGA fuel cluster rods within wet inserts and maximizes the interaction between inserts. It is referred to as the wet configuration for TRIGA fuel cluster rods.

The dry configuration selected as most reactive, including no water in the neutron shield, contains 16 TRIGA fuel cluster rods moved inward to the center of each 4 × 4 insert array and the inserts moved to the center of the basket with k_{eff} = 0.8047 ± 0.0020 and 0.7489 ± 0.0019 for the non-poisoned and poisoned basket configurations, respectively. This dry configuration minimizes the neutron leakage of TRIGA fuel cluster rods within the dry basket and is referred to as the dry configuration.

Finally, the effect of partial fuel element loading was examined. Table 6.4.6-1 and Table 6.4.6-2 show that partial loading of the elements in the basket generally serves to decrease the reactivity for both the wet and dry poisoned and nonpoisoned baskets. Although the case with one rod removed from the wet, nonpoisoned basket has a higher k_{eff} than the most reactive full load configuration, the difference in k_{eff} values is significantly less than 2σ. This makes the result statistically insignificant, and the full loading cases can be selected for further evaluation as stated above.

6.4.6.1.2 Manufacturing Tolerance Perturbations

The manufacturing tolerance analyses were performed by sequentially analyzing perturbations to the most reactive configurations from Section 6.4.6.1.1 and retaining appropriate perturbations. First, the effect of reducing the basket plate thickness was examined. Table 6.4.6-3 and Table 6.4.6-4 show that, for the nonpoisoned and poisoned baskets, reducing the thickness of the basket plates increases the reactivity of the system. Thus, this configuration is utilized for the subsequent analyses.

Next, the dimensional tolerances of the aluminum tube inserts were evaluated. Three different cases were examined. The first case examined an increase in the aluminum tube diameter, while

retaining the nominal thickness, the second case examined a decrease in the aluminum tube diameter while retaining the nominal wall thickness, and the third case examined the effect of reducing the aluminum tube thickness. The results presented in Table 6.4.6-3 and Table 6.4.6-4 show that, for the nonpoisoned and poisoned basket configurations, the highest k_{eff} values are obtained for the aluminum tubes at maximum diameter, and for the dry case with the aluminum tubes at minimum thickness. While these cases produced the highest values of k_{eff}, it should be noted that the differences between these results and the previous case is insignificant because they are within 2σ of one another.

After incorporating the previously described modifications, the effect of minimizing the basket insert opening was examined. As shown in Table 6.4.6-3 and Table 6.4.6-4, this perturbation results in equal or higher k_{eff} values for 3 of the 4 cases, with the dry, nonpoisoned case resulting in a slight decrease in k_{eff}. As previously described, these differences are considered insignificant because they differ by less than 2σ. Nevertheless, because this perturbation is expected to increase the interaction between the individual baskets, it is retained in the most reactive configuration for further analysis.

Therefore, the most reactive case for intact fuel in the poisoned basket is selected as a wet configuration consisting of the following features: fuel elements moved away from the center of the aluminum center, aluminum insert moved towards the basket center, minimum divider plate thickness, minimum basket opening, and maximum aluminum tube insert diameter. The resulting reactivity for this system is, $k_{eff} = 0.8025 \pm 0.0025$. Likewise, the most reactive case for intact fuel in the nonpoisoned basket is selected as a dry configuration consisting of the following features: fuel elements moved toward the center of the aluminum insert, aluminum insert moved towards the basket center, minimum divider plate thickness, and minimum basket opening. The resulting reactivity for this system is, $k_{eff} = 0.8129 \pm 0.0021$.

6.4.6.2 Sealed Cans Criticality Evaluation

Criticality calculations were performed for sealed failed fuel cans in the top and base basket modules of the cask. Three cases are examined for each basket combination, an all dry system, a full wet system, and a preferentially wet system with water only in the sealed failed fuel can. Fuel in sealed cans is modeled both homogeneously, heterogeneously, and with partial loadings. The three central modules contain intact fuel in the most reactive wet or dry configurations, as appropriate, as determined in Section 6.4.5.2. The reactivities of the failed fuel combinations are

compared to the reactivities of respective intact fuel configurations, and moderator density studies are performed on the most reactive configurations in Section 6.4.6.3.

Table 6.4.6-5 and Table 6.4.6-6 show the results of the preferential flooding and partial loading studies of the sealed failed fuel can configurations with TRIGA fuel cluster rods in nonpoisoned and poisoned baskets. Each sealed can contains up to six equivalent TRIGA fuel cluster rods. The most reactive cases for the nonpoisoned and poisoned baskets contain maximum outer diameter, preferential wet sealed fuel cans filled with a homogeneous mixture of fuel material and water. The most reactive nonpoisoned and poisoned cases are k_{eff} = 0.8669 ± 0.0022 and k_{eff} = 0.8384 ± 0.0021, respectively.

6.4.6.3 Moderator Density Criticality Evaluations for TRIGA Fuel Cluster Rods

The evaluations for normal and accident conditions include moderator density variations in the cask cavity and external environment to the cask. One evaluation is performed for each basket (nonpoisoned/poisoned) combination. Table 6.4.6-7 and Table 6.4.6-8 show the most reactive configurations for these combinations as determined in Section 6.4.6.2. The tables contain results for infinite axial length models for the intact fuel and finite models with cask end caps for failed fuel. Comparing the reactivity of the more conservative infinite models with finite models is acceptable, provided the result with the highest k_{eff} is always selected. Alternately, converting infinite models to finite models is equally acceptable.

As seen in Table 6.4.6-7 and Table 6.4.6-8, the most reactive nonpoisoned and poisoned basket configurations with TRIGA fuel cluster rods contain two baskets with sealed cans preferentially flooded with a dry cask, k_{eff} = 0.8669 ± 0.0022 and k_{eff} = 0.8384 ± 0.0021, respectively. These configurations are chosen for moderator density variations.

Results of the moderator density variation cases for normal and accident conditions for the nonpoisoned and poisoned basket configurations are presented in Table 6.4.6-9 through Table 6.4.6-12.

As seen in Table 6.4.6-10, the most reactive configuration for the TRIGA fuel cluster rods in the nonpoisoned basket, analyzed conservatively without end caps, contains 5 baskets with intact fuel under accident conditions with no water in the cask interior, neutron shield, or exterior, k_{eff} = 0.8756 ± 0.0023. Per Section 6.5.3, this corresponds to k_s = 0.8970.

As seen in Table 6.4.6-12, the most reactive configuration for the TRIGA fuel cluster rods in the poisoned basket, contains two baskets with maximum diameter sealed cans, preferentially flooded, under accident conditions with no water in the cask interior, neutron shield, or exterior, $k_{eff} = 0.8399 \pm 0.0021$. Per Section 6.5.3, this corresponds to $k_s = 0.8609$.

6.4.6.4 Single Package Criticality Evaluation

To satisfy 10 CFR 71.55(b)(3), an analysis of the reflection of the containment system (inner shell) by water is performed on a single wet cask. Successive replacement of the cask radial shields with water reflection is also evaluated for each basket (poisoned/nonpoisoned) configuration. As seen in Table 6.4.6-13 and Table 6.4.6-14, the reactivity of the system drops as each radial shield of the cask is replaced by water, from the full cask surrounded by water, to the inner shell surrounded by water.

6.4.6.5 Increased Fuel Dimensional / Mass Parameter Evaluation

The TRIGA fuel cluster rod contents evaluated previously in this Section, and as presented in Table 6.2.6-1 and Table 6.2.6-2, are based on design basis nominal dimensional and compositional values. To ensure that criticality safety is maintained for parameter values slightly different from those listed in the tables, a set of calculations are performed with increased active fuel length, increased fuel pellet diameter, decreased cladding thickness, and corresponding increases in the uranium and zirconium masses due to the increased volume.

Calculations are performed for two cases based on the most reactive configuration presented in Section 6.4.6.3, which is for the nonpoisoned basket configuration. In each case, the active fuel length is increased to 22.5 inches, the cladding thickness is decreased to 0.015 inch, and the pellet diameter is set at 0.52 inch for the first case, then 0.53 inch for the second case. The results are presented in Table 6.4.6-15.

As seen in the results, the increase in fuel pellet diameter up to 0.53 inch results in an increase in k_s of less than 1.5%. The resulting value is well below the 0.95 limit. Additionally, the increasing reactivity trend is indicative that the increase in fuel pellet diameter results in an increase in reactivity. The increased active fuel height, retaining the overall height the same, results in more fissile material, and reduces the axial gap between the fissile material in each basket. Finally, reducing the cladding thickness increases the reactivity of the system in two ways, increasing the moderator volume and allowing the fuel cluster rods to shift closer to the center of each cluster rod insert. This shifted configuration was demonstrated to be the most reactive intact rod configuration in Section 6.4.6.1.1.

6.4.6.6 Conclusion

Thus, including all calculational and mechanical uncertainties, an infinite array of NAC-LWT casks remains sub-critical, and is below the 0.95 limit, corrected for bias and uncertainty, under normal and accident conditions with:

Nonpoisoned Baskets:

1. 480 TRIGA fuel cluster rods,
2. Sealed cans (top and bottom baskets only) with up to six TRIGA fuel cluster rods and remainder of baskets filled with intact fuel.

Poisoned Baskets:

1. 560 TRIGA fuel cluster rods,
2. Sealed cans (top and bottom baskets only) with up to six TRIGA fuel cluster rods and remainder of baskets filled with intact fuel.

Increased Fuel Parameters:

1. Maximum Fuel Pellet Diameter – 0.53 inch
2. Minimum Cladding Thickness – 0.015 inch
3. Maximum Active Fuel Height – 22.5 inches
4. Maximum Uranium Mass – 48.6 grams
5. Maximum ^{235}U Mass – 45.4 grams
6. Maximum Zirconium Mass – 421 grams

Table 6.4.6-1 Cask k_{eff} with TRIGA Fuel Cluster Rods – Fuel Rod Placement Perturbations, Nonpoisoned Basket

Basket Configuration	Wet Case Results $k_{eff} \pm \sigma$	Dry Case Results $k_{eff} \pm \sigma$
Nominal Centered Fuel and Al Insert	0.7340 ± 0.0026	0.8001 ± 0.0019
Elements Moved To Al Insert Center	0.7110 ± 0.0027	0.8076 ± 0.0019
Elements Moved Away From Al Insert Center	0.7458 ± 0.0026	0.8005 ± 0.0020
Al Insert Moved To Basket Center[1]	0.7571 ± 0.0025	0.8047 ± 0.0020
Al Insert Moved Away From Basket Center[1]	0.7391 ± 0.0025	0.8027 ± 0.0020
1 Rod Removed From Each Al Insert	0.7576 ± 0.0026	0.7782 ± 0.0020
2 Rods Removed From Each Al Insert	0.7558 ±0.0024	0.7503 ± 0.0020
3 Rods Removed From Each Al Insert	0.7414 ± 0.0022	-

Notes:

1. The most reactive fuel positioning is retained.

Table 6.4.6-2 Cask k_{eff} with TRIGA Fuel Cluster Rods – Fuel Rod Placement Perturbations, Poisoned Basket

Basket Configuration	Wet Case Results $k_{eff} \pm \sigma$	Dry Case Results $k_{eff} \pm \sigma$
Nominal Centered Fuel and Al Insert	0.7809 ± 0.0026	0.7435 ± 0.0020
Elements Moved To Al Insert Center	0.7654 ± 0.0025	0.7501 ± 0.0019
Elements Moved Away From Al Insert Center	0.7922 ± 0.0027	0.7468 ± 0.0020
Al Insert Moved To Basket Center[1]	0.7995 ± 0.0026	0.7489 ± 0.0019
Al Insert Moved Away From Basket Center[1]	0.7914 ± 0.0027	0.7476 ± 0.0022
1 Rod Removed From Each Al Insert	0.7956 ± 0.0027	0.7163 ± 0.0019
2 Rods Removed From Each Al Insert	0.7882 ± 0.0026	0.6831 ± 0.0019
3 Rods Removed From Each Al Insert	0.7764 ± 0.0026	-

Notes:

1. The most reactive fuel in tube motion is retained.

Table 6.4.6-3 Axially Infinite Cask k_{eff} with TRIGA Fuel Cluster Rods – Basket and Insert Manufacturing Tolerance Perturbations, Nonpoisoned Basket

Basket Configuration	Wet Case Results $k_{eff} \pm \sigma$	Dry Case Results $k_{eff} \pm \sigma$
Base Case[1]	0.7571 ± 0.0025	0.8047 ± 0.0020
Thin SS Basket Plates	0.7652 ± 0.0025	0.8140 ± 0.0020
Maximum Al Insert Tube Diameter[2]	0.7653 ± 0.0027	0.8146 ± 0.0022
Minimum Al Insert Tube Diameter[2]	0.7487 ± 0.0025	0.8084 ± 0.0019
Minimum Al Insert Tube Thickness[2]	0.7625 ± 0.0026	0.8157 ± 0.0021
Minimum Basket Opening[2]	0.7682 ± 0.0026 [3]	0.8129 ± 0.0021

Notes:

1. Most reactive configurations as determined in Section 6.4.6.1.1.
2. Incorporates minimum thickness stainless steel, basket divider plates.
3. Maximum aluminum tube diameter.

Table 6.4.6-4 Axially Infinite Cask k_{eff} with TRIGA Fuel Cluster Rods – Basket and Insert Manufacturing Tolerance Perturbations, Poisoned Basket

Basket Configuration	Wet Case Results $k_{eff} \pm \sigma$	Dry Case Results $k_{eff} \pm \sigma$
Base Case[1]	0.7995 ± 0.0026	0.7489 ± 0.0019
Thin SS Basket Plates	0.8019 ± 0.0024	0.7513 ± 0.0020
Maximum Al Insert Tube Diameter[2]	0.8055 ± 0.0027	0.7512 ± 0.0019
Minimum Al Insert Tube Diameter[2]	0.7969 ± 0.0026	0.7507 ± 0.0018
Minimum Al Insert Tube Thickness[2]	0.7995 ± 0.0023	0.7518 ± 0.0019
Minimum Basket Opening[2]	0.8025 ± 0.0025 [3]	0.7518 ± 0.0018 [4]

Notes:

1. Most reactive configurations as determined in Section 6.4.6.1.1.
2. Incorporates minimum thickness stainless steel, basket divider plates.
3. Maximum aluminum tube diameter.
4. Minimum aluminum tube thickness.

Table 6.4.6-5 Sealed Can Preferential Flooding and Partial Loading Reactivity Evaluations for TRIGA Fuel Rod Clusters, Nonpoisoned Basket

Description	$k_{eff} \pm \sigma$ Dry Cask/Dry Can	$k_{eff} \pm \sigma$ Wet Cask/Wet Can	$k_{eff} \pm \sigma$ Dry Cask/Wet Can
1 Solid Fuel Lump	0.7184 ± 0.0025	0.7654 ± 0.0024	0.6954 ± 0.0022
2 Solid Fuel Lumps	0.7053 ± 0.0021	0.7546 ± 0.0025	0.6721 ± 0.0020
3 Solid Fuel Lumps	0.6946 ± 0.0022	0.7597 ± 0.0025	0.6704 ± 0.0022
4 Solid Fuel Lumps	0.6983 ± 0.0020	0.7672 ± 0.0026	0.6714 ± 0.0023
5 Solid Fuel Lumps	0.6995 ± 0.0024	0.7620 ± 0.0028	0.6723 ± 0.0022
Mixture Full Can Height	0.6917 ± 0.0021	0.7592 ± 0.0024	0.8669 ± 0.0022
Mixture Half Can Height	0.6932 ± 0.0021	0.7582 ± 0.0025	0.7226 ± 0.0022
Mixture Full Can Height, 50 % mass	0.6807 ± 0.0022	0.7606 ± 0.0025	0.7416 ± 0.0021

Table 6.4.6-6 Sealed Can Preferential Flooding and Partial Loading Reactivity Evaluations for TRIGA Fuel Rod Clusters, Poisoned Basket

Description	$k_{eff} \pm \sigma$ Dry Cask/Dry Can	$k_{eff} \pm \sigma$ Wet Cask/Wet Can	$k_{eff} \pm \sigma$ Dry Cask/Wet Can
1 Solid Fuel Lump	0.6957 ± 0.0022	0.7937 ± 0.0025	0.6662 ± 0.0020
2 Solid Fuel Lumps	0.6704 ± 0.0021	0.7942 ± 0.0026	0.6405 ± 0.0022
3 Solid Fuel Lumps	0.6610 ± 0.0020	0.7959 ± 0.0026	0.6389 ± 0.0019
4 Solid Fuel Lumps	0.6592 ± 0.0020	0.7986 ± 0.0025	0.6389 ± 0.0022
5 Solid Fuel Lumps	0.6561 ± 0.0019	0.8001 ± 0.0023	0.6409 ± 0.0020
Mixture Full Can Height	0.6507 ± 0.0019	0.7993 ±0.0025	0.8384 ± 0.0021
Mixture Half Can Height	0.6575 ± 0.0019	0.8045 ± 0.0029	0.6741 ± 0.0022
Mixture Full Can Height, 50 % mass	0.6422 ± 0.0019	0.7992 ± 0.0027	0.6957 ± 0.0020

Table 6.4.6-7 Summary of Most Reactive Configurations, TRIGA Fuel Cluster Rods, Nonpoisoned Basket

	Wet	Dry	Preferential
Intact Fuel	0.7682 ± 0.0026	0.8129 ± 0.0021	-
Sealed Fuel Cans[1]	0.7672 ± 0.0026	0.7184 ± 0.0025	0.8669 ± 0.0022

Notes:

1. Remainder of baskets filled with intact fuel.

Table 6.4.6-8 Summary of Most Reactive Configurations, TRIGA Fuel Cluster Rods, Poisoned Basket

	Wet	Dry	Preferential
Intact Fuel	0.8025 ± 0.0025	0.7518 ± 0.0018	-
Sealed Fuel Cans[1]	0.8045 ± 0.0029	0.6957 ± 0.0022	0.8384 ± 0.0021

Notes:

1. Remainder of baskets filled with intact fuel.

Table 6.4.6-9 Reactivity Results for TRIGA Fuel Cluster Rods, Sealed Cans, Normal Conditions, Nonpoisoned Basket

Moderator SG	Casks Touching ($k_{eff} \pm \sigma$)	8 Foot Center-To-Center ($k_{eff} \pm \sigma$)
Dry Exterior, Vary Internal Density		
0.00000	0.7292 ± 0.0023	0.7270 ± 0.0025
0.00100	0.7294 ± 0.0024	0.7258 ± 0.0026
0.00178	0.7262 ± 0.0025	0.7312 ± 0.0025
0.00316	0.7267 ± 0.0024	0.7316 ± 0.0024
0.00562	0.7277 ± 0.0024	0.7294 ± 0.0024
0.01000	0.7240 ± 0.0024	0.7312 ± 0.0023
0.01780	0.7249 ± 0.0025	0.7279 ± 0.0025
0.03160	0.7307 ± 0.0026	0.7322 ± 0.0025
0.05620	0.7392 ± 0.0024	0.7333 ± 0.0024
0.10000	0.7345 ± 0.0024	0.7349 ± 0.0025
0.17800	0.7354 ± 0.0025	0.7339 ± 0.0024
0.31600	0.7298 ± 0.0025	0.7285 ± 0.0025
0.56200	0.7074 ± 0.0024	0.7100 ± 0.0026
0.70000	0.7064 ± 0.0022	0.7055 ± 0.0026
0.80000	0.7140 ± 0.0027	0.7083 ± 0.0024
0.90000	0.7137 ± 0.0026	0.7201 ± 0.0024
1.00000	0.7168 ± 0.0026	0.7216 ± 0.0027
Optimally Moderated Cask Interior (SG = 0.05620), Vary External Density		
0.00000	0.7292 ± 0.0023	0.7270 ± 0.0025
0.00100	0.7354 ± 0.0024	0.7352 ± 0.0028
0.00178	0.7351 ± 0.0025	0.7360 ± 0.0026
0.00316	0.7347 ± 0.0024	0.7347 ± 0.0023
0.00562	0.7329 ± 0.0025	0.7372 ± 0.0025
0.01000	0.7303 ± 0.0023	0.7316 ± 0.0024
0.01780	0.7306 ± 0.0024	0.7296 ± 0.0027
0.03160	0.7296 ± 0.0025	0.7339 ± 0.0024
0.05620	0.7321 ± 0.0023	0.7324 ± 0.0022
0.10000	0.7369 ± 0.0023	0.7305 ± 0.0021
0.17800	0.7325 ± 0.0024	0.7343 ± 0.0025
0.31600	0.7307 ± 0.0026	0.7324 ± 0.0024
0.56200	0.7297 ± 0.0028	0.7359 ± 0.0025
0.70000	0.7341 ± 0.0021	0.7300 ± 0.0022
0.80000	0.7316 ± 0.0024	0.7359 ± 0.0024
0.90000	0.7334 ± 0.0025	0.7313 ± 0.0026
1.00000	0.7308 ± 0.0025	0.7318 ± 0.0023
Vary Internal and External Density Simultaneously		
0.00000	0.7292 ± 0.0023	0.7270 ± 0.0025
0.00100	0.7291 ± 0.0023	0.7275 ± 0.0025
0.00178	0.7271 ± 0.0026	0.7309 ± 0.0024
0.00316	0.7316 ± 0.0025	0.7271 ± 0.0024
0.00562	0.7286 ± 0.0027	0.7277 ± 0.0023
0.01000	0.7288 ± 0.0025	0.7254 ± 0.0024
0.01780	0.7329 ± 0.0024	0.7296 ± 0.0024
0.03160	0.7309 ± 0.0026	0.7300 ± 0.0026
0.05620	0.7321 ± 0.0023	0.7313 ± 0.0026
0.10000	0.7364 ± 0.0024	0.7299 ± 0.0025
0.17800	0.7344 ± 0.0026	0.7335 ± 0.0023
0.31600	0.7299 ± 0.0024	0.7301 ± 0.0026
0.56200	0.7139 ± 0.0026	0.7118 ± 0.0025
0.70000	0.7024 ± 0.0025	0.7025 ± 0.0027
0.80000	0.7116 ± 0.0024	0.7029 ± 0.0023
0.90000	0.7177 ± 0.0028	0.7142 ± 0.0024
1.00000	0.7204 ± 0.0025	0.7187 ± 0.0026

Table 6.4.6-10 Reactivity Results for TRIGA Fuel Cluster Rods, Sealed Can, Accident Conditions, Nonpoisoned Basket

Moderator SG	Casks Touching ($k_{eff} \pm \sigma$)	8 Foot Center-To-Center ($k_{eff} \pm \sigma$)
Dry Exterior and Neutron Shield, Vary Internal Moderator		
0.00000	0.8669 ± 0.0022	0.8756 ± 0.0023
0.00100	0.8725 ± 0.0022	0.8687 ± 0.0022
0.00178	0.8737 ± 0.0022	0.8668 ± 0.0022
0.00316	0.8721 ± 0.0024	0.8744 ± 0.0024
0.00562	0.8703 ± 0.0022	0.8693 ± 0.0024
0.01000	0.8716 ± 0.0022	0.8646 ± 0.0021
0.01780	0.8658 ± 0.0022	0.8614 ± 0.0021
0.03160	0.8620 ± 0.0023	0.8620 ± 0.0021
0.05620	0.8536 ± 0.0022	0.8561 ± 0.0025
0.10000	0.8345 ± 0.0023	0.8373 ± 0.0023
0.17800	0.8138 ± 0.0022	0.8152 ± 0.0024
0.31600	0.7862 ± 0.0021	0.7830 ± 0.0024
0.56200	0.7570 ± 0.0025	0.7500 ± 0.0024
0.70000	0.7439 ± 0.0023	0.7424 ± 0.0027
0.80000	0.7383 ± 0.0025	0.7404 ± 0.0026
0.90000	0.7415 ± 0.0027	0.7391 ± 0.0025
1.00000	0.7398 ± 0.0026	0.7303 ± 0.0026
Optimally Moderated Internal (SG = 0.0), Vary Neutron Shield and Exterior		
0.00000	0.8669 ± 0.0022	0.8756 ± 0.0023
0.00100	0.8620 ± 0.0022	0.7950 ± 0.0023
0.00178	0.8488 ± 0.0022	0.7755 ± 0.0025
0.00316	0.8366 ± 0.0023	0.7509 ± 0.0024
0.00562	0.8209 ± 0.0022	0.7403 ± 0.0024
0.01000	0.7994 ± 0.0023	0.7341 ± 0.0024
0.01780	0.7795 ± 0.0022	0.7272 ± 0.0022
0.03160	0.7618 ± 0.0024	0.7270 ± 0.0025
0.05620	0.7497 ± 0.0025	0.7251 ± 0.0025
0.10000	0.7395 ± 0.0023	0.7238 ± 0.0025
0.17800	0.7300 ± 0.0023	0.7244 ± 0.0025
0.31600	0.7280 ± 0.0024	0.7285 ± 0.0022
0.56200	0.7311 ± 0.0025	0.7283 ± 0.0024
0.70000	0.7322 ± 0.0024	0.7243 ± 0.0025
0.80000	0.7305 ± 0.0025	0.7267 ± 0.0024
0.90000	0.7237 ± 0.0022	0.7324 ± 0.0023
1.00000	0.7286 ± 0.0024	0.7287 ± 0.0025
Vary Interior, Exterior and Neutron Shield Simultaneously		
0.00000	0.8669 ± 0.0022	0.8756 ± 0.0023
0.00100	0.8615 ± 0.0023	0.7989 ± 0.0022
0.00178	0.8550 ± 0.0023	0.7755 ± 0.0025
0.00316	0.8397 ± 0.0022	0.7520 ± 0.0024
0.00562	0.8268 ± 0.0022	0.7439 ± 0.0024
0.01000	0.7988 ± 0.0025	0.7333 ± 0.0025
0.01780	0.7788 ± 0.0024	0.7305 ± 0.0023
0.03160	0.7600 ± 0.0023	0.7259 ± 0.0024
0.05620	0.7510 ± 0.0024	0.7350 ± 0.0024
0.10000	0.7444 ± 0.0024	0.7349 ± 0.0024
0.17800	0.7397 ± 0.0025	0.7298 ± 0.0024
0.31600	0.7284 ± 0.0025	0.7297 ± 0.0024
0.56200	0.7106 ± 0.0022	0.7056 ± 0.0024
0.70000	0.7051 ± 0.0025	0.7004 ± 0.0025
0.80000	0.7146 ± 0.0025	0.7104 ± 0.0027
0.90000	0.7107 ± 0.0025	0.7195 ± 0.0026
1.00000	0.7204 ± 0.0025	0.7251 ± 0.0025

Table 6.4.6-11 Reactivity Results for TRIGA Fuel Cluster Rods, Sealed Cans, Normal Conditions, Poisoned Basket

Moderator SG	Casks Touching ($k_{eff} \pm \sigma$)	8 Foot Center-To-Center ($k_{eff} \pm \sigma$)
Dry Exterior, Vary Internal Density		
0.00000	0.7274 ± 0.0026	0.7319 ± 0.0024
0.00100	0.7342 ± 0.0022	0.7283 ± 0.0023
0.00178	0.7296 ± 0.0024	0.7268 ± 0.0023
0.00316	0.7286 ± 0.0024	0.7328 ± 0.0024
0.00562	0.7294 ± 0.0023	0.7277 ± 0.0023
0.01000	0.7309 ± 0.0022	0.7338 ± 0.0024
0.01780	0.7319 ± 0.0023	0.7308 ± 0.0023
0.03160	0.7338 ± 0.0023	0.7334 ± 0.0023
0.05620	0.7349 ± 0.0024	0.7290 ± 0.0023
0.10000	0.7328 ± 0.0021	0.7339 ± 0.0026
0.17800	0.7346 ± 0.0024	0.7339 ± 0.0023
0.31600	0.7332 ± 0.0026	0.7315 ± 0.0023
0.56200	0.7324 ± 0.0024	0.7308 ± 0.0024
0.70000	0.7245 ± 0.0025	0.7304 ± 0.0023
0.80000	0.7401 ± 0.0025	0.7310 ± 0.0024
0.90000	0.7455 ± 0.0025	0.7375 ± 0.0028
1.00000	0.7573 ± 0.0027	0.7593 ± 0.0026
Optimally Moderated Cask Interior (SG = 1.0), Vary External Density		
0.00000	0.7274 ± 0.0026	0.7319 ± 0.0024
0.00100	0.7667 ± 0.0026	0.7623 ± 0.0026
0.00178	0.7635 ± 0.0024	0.7652 ± 0.0025
0.00316	0.7636 ± 0.0026	0.7596 ± 0.0027
0.00562	0.7675 ± 0.0028	0.7636 ± 0.0027
0.01000	0.7697 ± 0.0025	0.7661 ± 0.0026
0.01780	0.7634 ± 0.0025	0.7615 ± 0.0029
0.03160	0.7664 ± 0.0027	0.7641 ± 0.0024
0.05620	0.7635 ± 0.0030	0.7688 ± 0.0026
0.10000	0.7599 ± 0.0029	0.7676 ± 0.0024
0.17800	0.7622 ± 0.0024	0.7637 ± 0.0024
0.31600	0.7620 ± 0.0026	0.7690 ± 0.0023
0.56200	0.7685 ± 0.0030	0.7643 ± 0.0028
0.70000	0.7632 ± 0.0025	0.7684 ± 0.0028
0.80000	0.7645 ± 0.0028	0.7657 ± 0.0027
0.90000	0.7615 ± 0.0028	0.7624 ± 0.0027
1.00000	0.7641 ± 0.0028	0.7659 ± 0.0025
Vary Internal and External Density Simultaneously		
0.00000	0.7274 ± 0.0026	0.7319 ± 0.0024
0.00100	0.7328 ± 0.0022	0.7281 ± 0.0024
0.00178	0.7279 ± 0.0025	0.7297 ± 0.0024
0.00316	0.7306 ± 0.0023	0.7310 ± 0.0023
0.00562	0.7323 ± 0.0024	0.7331 ± 0.0025
0.01000	0.7291 ± 0.0026	0.7291 ± 0.0024
0.01780	0.7306 ± 0.0024	0.7309 ± 0.0024
0.03160	0.7291 ± 0.0022	0.7314 ± 0.0023
0.05620	0.7292 ± 0.0026	0.7299 ± 0.0024
0.10000	0.7302 ± 0.0026	0.7356 ± 0.0025
0.17800	0.7363 ± 0.0024	0.7288 ± 0.0023
0.31600	0.7366 ± 0.0025	0.7316 ± 0.0025
0.56200	0.7296 ± 0.0026	0.7300 ± 0.0025
0.70000	0.7318 ± 0.0023	0.7276 ± 0.0025
0.80000	0.7350 ± 0.0025	0.7385 ± 0.0024
0.90000	0.7423 ± 0.0027	0.7385 ± 0.0024
1.00000	0.7641 ± 0.0028	0.7659 ± 0.0029

Table 6.4.6-12 Reactivity Results for TRIGA Fuel Cluster Rods, Sealed Cans, Accident Conditions, Poisoned Basket

Moderator SG	Casks Touching ($k_{eff} \pm \sigma$)	8 Foot Center-To-Center ($k_{eff} \pm \sigma$)
Dry Exterior and Neutron Shield, Vary Internal Moderator		
0.00000	0.8384 ± 0.0021	0.8375 ± 0.0023
0.00100	0.8394 ± 0.0022	0.8343 ± 0.0021
0.00178	0.8376 ± 0.0022	0.8316 ± 0.0022
0.00316	0.8373 ± 0.0022	0.8319 ± 0.0024
0.00562	0.8399 ± 0.0021	0.8336 ± 0.0025
0.01000	0.8356 ± 0.0022	0.8321 ± 0.0023
0.01780	0.8380 ± 0.0022	0.8314 ± 0.0022
0.03160	0.8302 ± 0.0025	0.8208 ± 0.0021
0.05620	0.8240 ± 0.0021	0.8188 ± 0.0024
0.10000	0.8127 ± 0.0023	0.8112 ± 0.0023
0.17800	0.7993 ± 0.0024	0.7936 ± 0.0022
0.31600	0.7773 ± 0.0024	0.7738 ± 0.0027
0.56200	0.7616 ± 0.0026	0.7559 ± 0.0023
0.70000	0.7570 ± 0.0025	0.7578 ± 0.0022
0.80000	0.7647 ± 0.0026	0.7589 ± 0.0025
0.90000	0.7728 ± 0.0028	0.7671 ± 0.0026
1.00000	0.7802 ± 0.0026	0.7803 ± 0.0026
Optimally Moderated Internal (SG = 0.0), Vary Neutron Shield and Exterior		
0.00000	0.8384 ± 0.0021	0.8375 ± 0.0023
0.00100	0.8282 ± 0.0022	0.7710 ± 0.0023
0.00178	0.8210 ± 0.0021	0.7593 ± 0.0024
0.00316	0.8150 ± 0.0022	0.7532 ± 0.0023
0.00562	0.7993 ± 0.0023	0.7398 ± 0.0024
0.01000	0.7882 ± 0.0024	0.7336 ± 0.0024
0.01780	0.7664 ± 0.0026	0.7326 ± 0.0024
0.03160	0.7546 ± 0.0024	0.7290 ± 0.0023
0.05620	0.7480 ± 0.0022	0.7285 ± 0.0023
0.10000	0.7387 ± 0.0022	0.7267 ± 0.0022
0.17800	0.7308 ± 0.0023	0.7265 ± 0.0026
0.31600	0.7324 ± 0.0023	0.7310 ± 0.0025
0.56200	0.7278 ± 0.0025	0.7291 ± 0.0022
0.70000	0.7320 ± 0.0023	0.7317 ± 0.0025
0.80000	0.7320 ± 0.0024	0.7268 ± 0.0026
0.90000	0.7313 ± 0.0025	0.7291 ± 0.0026
1.00000	0.7329 ± 0.0025	0.7329 ± 0.0025
Vary Interior, Exterior and Neutron Shield Simultaneously		
0.00000	0.8384 ± 0.0021	0.8375 ± 0.0023
0.00100	0.8269 ± 0.0024	0.7802 ± 0.0024
0.00178	0.8258 ± 0.0021	0.7625 ± 0.0022
0.00316	0.8089 ± 0.0022	0.7525 ± 0.0023
0.00562	0.7928 ± 0.0022	0.7409 ± 0.0025
0.01000	0.7825 ± 0.0023	0.7308 ± 0.0025
0.01780	0.7721 ± 0.0023	0.7305 ± 0.0026
0.03160	0.7552 ± 0.0023	0.7327 ± 0.0023
0.05620	0.7457 ± 0.0023	0.7283 ± 0.0025
0.10000	0.7420 ± 0.0024	0.7343 ± 0.0025
0.17800	0.7365 ± 0.0023	0.7322 ± 0.0026
0.31600	0.7379 ± 0.0024	0.7333 ± 0.0024
0.56200	0.7292 ± 0.0026	0.7333 ± 0.0022
0.70000	0.7286 ± 0.0023	0.7307 ± 0.0027
0.80000	0.7334 ± 0.0023	0.7292 ± 0.0023
0.90000	0.7516 ± 0.0026	0.7517 ± 0.0024
1.00000	0.7608 ± 0.0029	0.7608 ± 0.0029

Table 6.4.6-13 Single Package 10 CFR 71.55(b)(3) Evaluation k_{eff} Summary, TRIGA Fuel Cluster Rod, Nonpoisoned Basket

Description	$k_{eff} \pm \sigma$	k_s
Single Cask / Inner Shell Reflected with H_2O	0.73003 ± 0.00254	0.75191
Single Cask / Inner Shell and Lead Reflected with H_2O	0.76100 ± 0.00243	0.78266
Single Cask / Inner Shell, Lead & Outer Shell Reflected with H_2O	0.76366 ± 0.00240	0.78526
Single Intact Cask Reflected with H_2O	0.76360 ± 0.00273	0.78586

Table 6.4.6-14 Single Package 10 CFR 71.55(b)(3) Evaluation k_{eff} Summary, TRIGA Fuel Cluster Rod, Poisoned Basket

Description	$k_{eff} \pm \sigma$	k_s
Single Cask / Inner Shell Reflected with H_2O	0.76615 ± 0.00265	0.78825
Single Cask / Inner Shell and Lead Reflected with H_2O	0.80117 ± 0.00287	0.82371
Single Cask / Inner Shell, Lead & Outer Shell Reflected with H_2O	0.80106 ± 0.00250	0.82286
Single Intact Cask Reflected with H_2O	0.79815 ± 0.00228	0.81951

Table 6.4.6-15 Increased Fuel Dimensional Parameter k_{eff} Summary, TRIGA Fuel Cluster Rod, Nonpoisoned Basket

Description	$k_{eff} \pm \sigma$	k_s
Base Case (Section 6.4.6.3)	0.8756 ± 0.0023	0.8970
22.5-inch Active Fuel Height 0.015-inch Cladding Thickness 0.52-inch Fuel Pellet Diameter	0.8793 ± 0.0024	0.9009
22.5-inch Active Fuel Height 0.015-inch Cladding Thickness 0.53-inch Fuel Pellet Diameter	0.8876 ± 0.0021	0.9086

6.4.7 DIDO Fuel Assemblies

This section presents the criticality analyses for the NAC-LWT cask with the DIDO fuel assembly and basket configuration. Criticality analyses of the seven assembly arrangement with the most limiting assembly type is performed to satisfy the criticality safety requirements of 10 CFR Parts 71.55 and 71.59, as well as IAEA Transportation Safety Standards (TS-R-1). In this analysis, the bounding DIDO fuel assembly type is determined, and infinite and finite arrays of NAC-LWT casks loaded with the design basis DIDO fuel are studied for criticality under normal and accident conditions. Moderator density in the cavity, neutron shield tank and outside is varied to determine the maximum k_{eff}. The analyses demonstrate that, including all calculational and mechanical uncertainties, the NAC-LWT remains subcritical under normal and accident conditions for all DIDO fuel assemblies.

6.4.7.1 Maximum Reactivity DIDO Assembly

This evaluation determines the maximum reactivity based on LEU, MEU and HEU fuel assembly configurations. Assemblies and baskets are modeled at nominal characteristics under normal conditions (i.e., the neutron shield is assumed intact). The cask interior and exterior are flooded with full density water. Based on the thickness of the neutron shield little interaction between casks is expected resulting in minimal impact of exterior moderator density variations. The results in Table 6.4.7-1 show that the maximum reactivity is obtained from HEU assemblies. The HEU assembly is more reactive than the LEU and MEU assemblies due to reduced parasitic absorption by ^{238}U. The fuel assembly is modeled with uniform cylinder spacing, referred to as "loose fuel elements" in this section, which has reactivity significantly higher than the reactivity of the crimped fuel element.

As demonstrated, the reactivity for LEU and MEU fuel assemblies is significantly lower than that of the HEU assembly. Shipment of LEU, MEU and HEU assemblies in the same basket is therefore permissible.

6.4.7.2 Radial and Axial Assembly Shifting Under Normal Conditions

The reactivity result in Table 6.4.7-1 shows that fuel assemblies axially shifted towards the adjoining basket (i.e., three groups of two baskets) are more reactive than those placed at the top or bottom of the basket. Shifting fuel assemblies in adjoining baskets towards one another brings the maximum fissile material into its closest proximity.

Radial outward shifting of both crimped and loose fuel assemblies shows that system reactivity decreases when shifting the assembly radially out from the center of the cask. Patterns designated as "in" shift the six peripheral fuel assemblies towards the basket center with the centered tube assembly pushed out to approach the +x axis assembly. The radial "out" pattern similarly pushes the six peripheral assemblies away from the basket center. The "custom" pattern indicated in the result table represents the "in" pattern with the center assembly shifted out at 45 degrees. The crimped pattern indicated as "single" corresponds to all assemblies being crimped in the same direction (for this evaluation at an angle of 45 degrees). For the loose fuel cylinder model, there appears to be no statistically significant reactivity difference between the centered or shifted radially in fuel assemblies. For the crimped pattern, crimping the fuel assembly radially out provides for a significant increase in reactivity in the radially shifted in assembly configuration. No significant difference in reactivity for modified crimp directions is shown in the radially out assembly configuration.

6.4.7.3 Radial Shifting and Exterior Moderator Density Changes Under Accident Conditions

The cask accident configuration is one where the material of the neutron shield is replaced by the cask exterior material definition. Both loose and crimped assemblies are evaluated at full density water in the cask interior and at a void exterior under various radial shift conditions. All cases are based on the alternate axial shifting of fuel shown in Section 6.4.7.2 to be the most reactive. Results of these analyses are shown in Table 6.4.7-2. As expected, the void exterior condition produces the maximum reactivity configuration. Reactivity increases due to increased interaction between individual casks in the array.

In addition to the shifted standard "in" configuration, the inward shifted configuration with a centered middle assembly is also evaluated (designated as InC in the result table). This configuration is slightly more reactive than the configuration with all assemblies centered, but it is within the statistical uncertainty band (2 sigma) of the Monte Carlo base result. Mechanical perturbation and uncertainty results are therefore evaluated with the all assemblies centered configuration.

Table 6.4.7-3 displays results for test cases based on modifying the material of the aluminum shell surrounding the basket and the heat transfer shunts in the center of the basket. The base case for this analysis is the radially centered, fully moderated interior, dry exterior configuration. Replacing the shell material by water or steel in the accident model inhibits interaction between

packages and produces lower reactivities in the infinite array of casks. Modeling the heat transfer shunts as all water increases reactivity slightly. This supports modeling the shunts as a set of three small rods with a smaller cross section area.

6.4.7.4 Basket Manufacturing Tolerance Evaluation

In this evaluation, set basket tolerances are applied to the criticality evaluation. The base case for this evaluation is the cask accident model (i.e, neutron shield replaced by exterior moderator which in this case is void) with centered fuel assembly. As shown Table 6.5.7-4, basket tolerances do not produce a significant reactivity increase. Note that the tube wall thickness minimum tolerance is set to a zero percent change. The minimum tube wall case is, therefore, identical to the base case. All further analysis is, therefore, set to nominal basket parameters.

6.4.7.5 Fuel Assembly Tolerance Evaluation

This evaluation contains the fuel assembly perturbation studies. Each of the parameters is evaluated independently with the results compared to the cask accident condition base case. For fuel cylinder pitch, two studies are performed. The first fixes the inner plate (cylinder) and varies the outer three cylinders and is noted as "IF." The second fixes the outer plate and is noted as "OF." Per the reactivity results in Table 6.4.7-5, tolerances that produce an increase in reactivity are:

- Minimum plate thickness (increases moderator between plates)
- Minimum clad thickness
- Maximum plate pitch (outer diameter fixed; increasing the outer diameter will decrease the amount of moderator between assemblies)
- Minimum active fuel height (reduces the space between fissile material in the alternating shifted model)
- Minimum element height (reduces the space between fissile material in the alternating shifted model)
- Maximum fissile mass
- Maximum uranium weight percent (minimum impact but is added to the final reactivity models)

6.4.7.6 Maximum Reactivity Configuration

The parameters shown in Section 6.4.7.5 to increase system reactivity are combined to form a worst case cask payload configuration. The limiting fuel assembly description based on the

critical fuel assembly parameters is shown in Table 6.4.7-12. Table 6.4.7-6 displays the evaluation results of the worst case configured DIDO NAC-LWT. Since the radially in configuration with a centered basket middle assembly was statistically the same as the all centered configuration (see Table 6.4.7-2), both configurations are evaluated with the toleranced fuel parameters. The most reactive configuration for the DIDO assembly in the infinite array configuration is above 0.95. To remain below 0.95 under all conditions, a finite array of 8 casks in close pitch configuration is modeled. The array is reflected by a water boundary condition and is evaluated with a flooded cask interior and void cask exterior. Both eight cask array configurations result in maximum k_s below 0.95. The CSI for the eight cask accident configuration is 12.5. Based on the normal to accident condition reactivity difference of 0.04 Δk, versus the 0.01 Δk that 0.95 was exceeded for the infinite array, the CSI for normal condition is 0 (infinite array is acceptable).

6.4.7.7 Moderator Density Variation Reactivity Configuration

Table 6.4.7-7 contains a cask interior and exterior moderator density variation study for the HEU fuel assembly in the accident configuration. All basket and fuel parameters are set to nominal conditions and an infinite array of casks is evaluated. The basket shows a relatively constant reactivity between cask interior densities of 1.0 g/cm^3 and 0.9 g/cm^3. While reactivity increases above the two sigma (95/95) uncertainty band typically applied in this calculation as statistically significant, the results are within the three sigma (99% confidence) band and are considered constant for the purposes of this calculation (Note that the maximum reactivity of the 8-cask array is below 0.92). At lower interior water densities the reactivity begins to decrease significantly. The exterior density study demonstrates that any significant amount of cask exterior moderator density will reduce the interaction between casks in the array.

6.4.7.8 Single Package Criticality Evaluation

To satisfy 10 CFR 71.55(b)(3), an analysis of the reflection of the containment system (inner shell) by water is performed on a single wet cask. Successive replacement of the cask radial shields with water reflection is also evaluated. A significant decrease in reactivity occurs when the lead gamma shield is replaced by water. The results from this evaluation can be seen in Table 6.4.7-8.

6.4.7.9 Reduced Clad Thickness Evaluations

This section documents the reactivity change due to a reduction in the DIDO element minimum clad thickness to 0.025 cm. The analysis in the previous sections is for a minimum clad thickness of 0.0325 cm.

The effect of the reduced clad thickness on system reactivity is determined by repeating cases from Section 6.4.7.5 and Section 6.4.7.6. Table 6.4.7-9 repeats the Section 6.4.7.5 minimum clad thickness case for the reduced value and compares it to the main section results. As expected, the reduced minimum clad thickness yields a proportional increase in k_{eff}. Table 6.4.7-10 shows the results for the worst-case tolerance combination with the reduced clad thickness for the cases discussed in Section 6.4.7.6. The maximum k_{eff} is based on an eight-cask array with a void exterior. All cases show a slight increase in reactivity due to the reduced clad thickness.

6.4.7.10 Expanded Inner and Outer Shell Diameter Evaluations

Based on the fuel assembly tolerance and moderator studies, a combination of a reduced inner diameter fuel tube ID (Tube 1) with a maximized outer fuel tube ID (Tube 4) is expected to maximize system reactivity (i.e., fuel plates are under-moderated with the previously evaluated conditions and increased pitch will increase system reactivity). Based on tolerances previously applied, the minimum Tube 1 ID is 5.88 cm and the maximum Tube 4 OD is 9.52 cm. This range is evaluated by fixing the Tube 1 ID at minimum and evaluating the nominal, minimum and maximum Tube 4 OD according to the values in the following list.

Tube Number	Min OD (cm)	Nom OD (cm)	Max OD (cm)
1	6.01	6.01	6.01
2	7.05	7.11	7.18
3	8.08	8.22	8.35
4	9.12	9.32	9.52

For this study, the tube pitch is a calculated variable and is larger than the maximum pitch considered in the previous calculation sections.

Table 6.4.7-11 documents the results of the tube diameter study. Based on the trend of increasing reactivity with increasing outer tube OD, the system remains under-moderated. The maximum k_s for the system is 0.9304 for an eight-cask array. Note that significant margin exists in these results, as the basket tube material is modeled as aluminum rather than stainless steel. System reactivity for the steel tube basket at the specified maximum reactivity configuration is < 0. 8.

6.4.7.11 Code Bias and Code Bias Uncertainty Adjustments

A calculation of k_s under normal and accident conditions can now be made based on the previous results and based on the KENO-Va validation statistics presented in Section 6.5.2 for high enriched uranium fuel. The value k_s is calculated based on the KENO-Va Monte Carlo average plus any biases and uncertainties associated with the methods and the modeling, i.e.:

$$k_s = k_{eff} + \Delta k_{Bias} + \Delta k_{BU} + 2\sigma_{MC} \leq 0.95$$

In the validation presented in Section 6.5.2, a bias of -0.0044 (allowance for overprediction of k_{eff}) and a 95/95 method uncertainty of ± 0.0181 was determined. For added conservatism, the -0.0044 bias correction is neglected. With these biases and uncertainties, the equation for k_s becomes:

$$k_s = k_{eff} + 0.0181 + 2\sigma_{MC}$$

k_s values for the relevant analysis are included in Tables 6.4.7-1 through Table 6.4.7-11. The maximum k_s, 0.9304, for the DIDO shipment results from the eight-cask array accident configuration model.

For both normal and accident conditions, the calculated k_{eff} values, after correction for biases and uncertainties, are well below the 0.95 limit. The analyses demonstrate that, including all calculational and mechanical uncertainties, an infinite array of NAC-LWT casks with DIDO fuel remains subcritical under normal and accident conditions.

Table 6.4.7-1 Normal Condition HEU, LEU, MEU DIDO Evaluation

Fuel Type	Fuel Configuration	Crimp Pattern	Radial Shift Pattern	Axial Shift Pattern	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
LEU	Loose	N/A	Centered	Down	0.82771	0.00067	0.82905	0.84715	-0.03689	-55.1
LEU	Loose	N/A	Centered	Alternating	0.83842	0.00070	0.83982	0.85792	-0.02612	-37.3
LEU	Crimped	Single	Centered	Down	0.81887	0.00069	0.82025	0.83835	-0.04569	-66.2
LEU	Crimped	Single	Centered	Alternating	0.83112	0.00068	0.83248	0.85058	-0.03346	-49.2
MEU	Loose	N/A	Centered	Down	0.84006	0.00070	0.84146	0.85956	-0.02448	-35.0
MEU	Loose	N/A	Centered	Alternating	0.85333	0.00072	0.85477	0.87287	-0.01117	-15.5
MEU	Crimped	Single	Centered	Down	0.83259	0.00070	0.83399	0.85209	-0.03195	-45.6
MEU	Crimped	Single	Centered	Alternating	0.84336	0.00069	0.84474	0.86284	-0.02120	-30.7
HEU	Loose	N/A	Centered	Down	0.85243	0.00070	0.85383	0.87193	-0.01211	-17.3
HEU	Loose	N/A	Centered	Alternating	0.86462	0.00066	0.86594	0.88404	--	--
HEU	Loose	N/A	Centered	Up	0.85275	0.00071	0.85417	0.87227	-0.01177	-16.6
HEU	Loose	N/A	In	Alternating	0.86361	0.00071	0.86503	0.88313	-0.00091	-1.3
HEU	Loose	N/A	Out	Alternating	0.85625	0.00070	0.85765	0.87575	-0.00829	-11.8
HEU	Loose	N/A	Custom	Alternating	0.86562	0.00072	0.86706	0.88516	0.00112	1.6
HEU	Crimped	Single	Centered	Down	0.84084	0.00072	0.84228	0.86038	-0.02366	-32.9
HEU	Crimped	Single	Centered	Alternating	0.85512	0.00069	0.85650	0.87460	-0.00944	-13.7
HEU	Crimped	Single	Centered	Up	0.84075	0.00070	0.84215	0.86025	-0.02379	-34.0
HEU	Crimped	Single	In	Alternating	0.85628	0.00072	0.85772	0.87582	-0.00822	-11.4
HEU	Crimped	Single	Out	Alternating	0.84484	0.00072	0.84628	0.86438	-0.01966	-27.3
HEU	Crimped	Single	Custom	Alternating	0.85688	0.00069	0.85826	0.87636	-0.00768	-11.1
HEU	Crimped	In	In	Alternating	0.84841	0.00071	0.84983	0.86793	-0.01611	-22.7
HEU	Crimped	Out	Out	Alternating	0.84118	0.00072	0.84262	0.86072	-0.02332	-32.4
HEU	Crimped	In	Out	Alternating	0.84552	0.00067	0.84686	0.86496	-0.01908	-28.5
HEU	Crimped	Out	In	Alternating	0.85786	0.00074	0.85934	0.87744	-0.00660	-8.9

Table 6.4.7-2 HEU DIDO Accident Evaluation – Radial Shift and Exterior Moderator Density Variation

Fuel Configuration	Crimp Pattern	Radial Shift Pattern	Interior Moderator Density (g/cm³)	Exterior Moderator Density (g/cm³)	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
Loose	N/A	Centered	0.9998	0.9998	0.86276	0.00070	0.86416	0.88226	--	--
Loose	N/A	In	0.9998	0.9998	0.86468	0.00070	0.86608	0.88418	0.00192	2.7
Crimped	Out	Centered	0.9998	0.9998	0.85355	0.00068	0.85491	0.87301	-0.00925	-13.6
Crimped	Out	In	0.9998	0.9998	0.85666	0.00069	0.85804	0.87614	-0.00612	-8.9
Loose	N/A	Centered	0.9998	0.0001	0.90900	0.00069	0.91038	0.92848	--	--
Loose	N/A	In	0.9998	0.0001	0.90808	0.00071	0.90950	0.92760	-0.00088	-1.2
Loose	N/A	InC	0.9998	0.0001	0.91011	0.00069	0.91149	0.92959	0.00111	1.6
Crimped	Out	Centered	0.9998	0.0001	0.89962	0.00071	0.90104	0.91914	-0.00934	-13.2
Crimped	Out	In	0.9998	0.0001	0.90116	0.00069	0.90254	0.92064	-0.00784	-11.4

Table 6.4.7-3 DIDO Heat Shunt and Aluminum Shell Evaluation Results

Case Description	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
Shell modeled as steel	0.90100	0.00067	0.90234	0.92044	-0.00804	-12.0
Shell modeled as water	0.90382	0.00070	0.90522	0.92332	-0.00516	-7.4
Aluminum shunts modeled as water	0.91157	0.00067	0.91291	0.93101	0.00253	3.8

Table 6.4.7-4 DIDO Basket Geometric Tolerance Study Results

Fuel Tube Outer Diameter Tolerance	Fuel Tube Thickness Tolerance	Fuel Tube Height Tolerance	Fuel Basket Base Plate Tolerance	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
Min	Nominal	Nominal	Nominal	0.90979	0.00070	0.91119	0.92929	0.00081	1.2
Max	Nominal	Nominal	Nominal	0.90959	0.00069	0.91097	0.92907	0.00059	0.9
Nominal	Min	Nominal	Nominal	0.90900	0.00069	0.91038	0.92848	--	--
Nominal	Max	Nominal	Nominal	0.90489	0.00071	0.90631	0.92441	-0.00407	-5.7
Nominal	Nominal	Min	Nominal	0.90954	0.00068	0.91090	0.92900	0.00052	0.8
Nominal	Nominal	Max	Nominal	0.90953	0.00069	0.91091	0.92901	0.00053	0.8
Nominal	Nominal	Nominal	Min	0.90922	0.00067	0.91056	0.92866	0.00018	0.3
Nominal	Nominal	Nominal	Max	0.90858	0.00068	0.90994	0.92804	-0.00044	-0.6

Table 6.4.7-5 DIDO Fuel Assembly Tolerance Study Results

Fuel Cylinder Diameter Tolerance	Fuel Plate Thickness Tolerance	Fuel Plate Clad Thickness Tolerance	Fuel Cylinder Pitch Tolerance	Active Fuel Length Tolerance	Fuel Assembly Height Tolerance	^{235}U Mass Tolerance	Uranium Weight Fraction Tolerance	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
Min	--	--	--	--	--	--	--	0.91024	0.00069	0.91162	0.92972	0.00124	1.8
Max	--	--	--	--	--	--	--	0.90691	0.00067	0.90825	0.92635	-0.00213	-3.2
--	Min	--	--	--	--	--	--	0.91188	0.00067	0.91322	0.93132	0.00284	4.2
--	Max	--	--	--	--	--	--	0.90539	0.00068	0.90675	0.92485	-0.00363	-5.3
--	--	Min	--	--	--	--	--	0.91253	0.00069	0.91391	0.93201	0.00353	5.1
--	--	Max	--	--	--	--	--	0.90685	0.00069	0.90823	0.92633	-0.00215	-3.1
--	--	--	IF - Max	--	--	--	--	0.90993	0.00068	0.91129	0.92939	0.00091	1.3
--	--	--	IF - Min	--	--	--	--	0.90864	0.00071	0.91006	0.92816	-0.00032	-0.5
--	--	--	OF - Max	--	--	--	--	0.91175	0.00068	0.91311	0.93121	0.00273	4.0
--	--	--	OF - Min	--	--	--	--	0.90787	0.00065	0.90917	0.92727	-0.00121	-1.9
--	--	--	--	Min	--	--	--	0.91067	0.00071	0.91209	0.93019	0.00171	2.4
--	--	--	--	Max	--	--	--	0.90853	0.00068	0.90989	0.92799	-0.00049	-0.7
--	--	--	--	--	Min	--	--	0.91108	0.00066	0.91240	0.93050	0.00202	3.1
--	--	--	--	--	Max	--	--	0.90735	0.00069	0.90873	0.92683	-0.00165	-2.4
--	--	--	--	--	--	Min	--	0.89234	0.00070	0.89374	0.91184	-0.01664	-23.8
--	--	--	--	--	--	Max	--	0.92431	0.00068	0.92567	0.94377	0.01529	22.5
--	--	--	--	--	--	--	Min	0.90761	0.00068	0.90897	0.92707	-0.00141	-2.1
--	--	--	--	--	--	--	Max	0.91070	0.00070	0.91210	0.93020	0.00172	2.5

Table 6.4.7-6 DIDO Fuel Maximum Reactivity Combinations

Cask Array	Radial Shift Pattern	Fuel Cylinder Diameter Tolerance	Fuel Plate Thickness Tolerance	Fuel Plate Clad Thickness Tolerance	Fuel Cylinder Pitch Tolerance	Active Fuel Length Tolerance	Fuel Assembly Height Tolerance	^{235}U Mass Tolerance	Uranium Weight Fraction Tolerance	k_{eff}	σ	$k_{eff}+2\sigma$	k_s
Infinite	Centered	Nominal	Min	Min	OF-Max	Min	Min	Max	Max	0.93813	0.00070	0.93953	0.95763
Infinite	InC	Nominal	Min	Min	OF-Max	Min	Min	Max	Max	0.93639	0.00073	0.93785	0.95595
8 cask	Centered	Nominal	Min	Min	OF-Max	Min	Min	Max	Max	0.89310	0.00072	0.89454	0.91264
8 cask	InC	Nominal	Min	Min	OF-Max	Min	Min	Max	Max	0.89596	0.00070	0.89736	0.91546

Table 6.4.7-7 Moderator Density Study for the Infinite Array of Casks (Nominal Fuel and Basket Configuration)

Radial Shift Pattern	Interior Moderator Density (g/cm^3)	Exterior Moderator Density (g/cm^3)	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
EXTERIOR MODERATOR DENSITY STUDY								
Centered	0.9998	0.9	0.86274	0.00066	0.86406	0.88216	-0.04632	-70.2
Centered	0.9998	0.8	0.86320	0.00071	0.86462	0.88272	-0.04576	-64.5
Centered	0.9998	0.6	0.86400	0.00070	0.86540	0.88350	-0.04498	-64.3
Centered	0.9998	0.4	0.86367	0.00073	0.86513	0.88323	-0.04525	-62.0
Centered	0.9998	0.2	0.86441	0.00070	0.86581	0.88391	-0.04457	-63.7
Centered	0.9998	0.1	0.86822	0.00073	0.86968	0.88778	-0.04070	-55.8
INTERIOR MODERATOR DENSITY STUDY								
Centered	0.975	0.0001	0.91103	0.00069	0.91241	0.93051	0.00203	2.9
Centered	0.95	0.0001	0.91097	0.00066	0.91229	0.93039	0.00191	2.9
Centered	0.925	0.0001	0.90942	0.00070	0.91082	0.92892	0.00044	0.6
Centered	0.9	0.0001	0.91079	0.00070	0.91219	0.93029	0.00181	2.6
Centered	0.875	0.0001	0.90928	0.00068	0.91064	0.92874	0.00026	0.4
Centered	0.85	0.0001	0.90869	0.00072	0.91013	0.92823	-0.00025	-0.3
Centered	0.8	0.0001	0.90563	0.00088	0.90739	0.92549	-0.00299	-3.4
Centered	0.6	0.0001	0.88126	0.00102	0.88330	0.90140	-0.02708	-26.5
Centered	0.4	0.0001	0.80903	0.00118	0.81139	0.82949	-0.09899	-83.9
Centered	0.2	0.0001	0.62941	0.00122	0.63185	0.64995	-0.27853	-228.3
Centered	0.0001	0.0001	0.13951	0.00043	0.14037	0.15847	-0.77001	-1790.7
InC	0.975	0.0001	0.90855	0.00067	0.90989	0.92799	-0.00049	-0.7
InC	0.95	0.0001	0.90809	0.00072	0.90953	0.92763	-0.00085	-1.2
InC	0.925	0.0001	0.90723	0.00072	0.90867	0.92677	-0.00171	-2.4
InC	0.9	0.0001	0.90644	0.00071	0.90786	0.92596	-0.00252	-3.5
InC	0.875	0.0001	0.90525	0.00067	0.90659	0.92469	-0.00379	-5.7
InC	0.85	0.0001	0.90377	0.00075	0.90527	0.92337	-0.00511	-6.8
InC	0.8	0.0001	0.90218	0.00070	0.90358	0.92168	-0.00680	-9.7
InC	0.0001	0.0001	0.87289	0.00073	0.87435	0.89245	-0.03603	-49.4

Table 6.4.7-8 DIDO Single Package 10 CFR 71.55(b)(3) Evaluation k_{eff} Summary

Description	$k_{eff} \pm \sigma$	k_s
Single Cask / Inner Shell Reflected with H_2O	0.83670±0.00075	0.85630
Single Cask / Inner Shell and Lead Reflected with H_2O	0.88638±0.00070	0.90588
Single Cask / Inner Shell, Lead & Outer Shell Reflected with H_2O	0.89275±0.00070	0.91225
Single Intact Cask Reflected with H_2O	0.89352±0.00070	0.91302

Table 6.4.7-9 DIDO Fuel Assembly Tolerance Study Results (Reduced Clad Thickness)

Clad Thickness	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk
0.0425 cm (Nominal)	0.90900	0.00069	0.91038	0.92848	--
0.0325 cm (Min)	0.91253	0.00069	0.91391	0.93201	0.00353
0.0250 cm (Revised Min)	0.91578	0.00069	0.91716	0.93526	0.00678

Table 6.4.7-10 DIDO Fuel Maximum Reactivity Combinations (Reduced Clad Thickness)

Cask Array	Radial Shift Pattern	k_{eff}	σ	$k_{eff}+2\sigma$	k_s
Infinite	Centered	0.93921	0.00071	0.94063	0.95873
Infinite	InC	0.93866	0.00072	0.94010	0.95820
8 cask	Centered	0.89293	0.00071	0.89435	0.91245
8 cask	InC	0.89762	0.00071	0.89904	0.91714

Note: Fuel and basket configuration as detailed in Table 6.4.7-6.

Table 6.4.7-11 DIDO Fuel Maximum Reactivity Combinations (Reduced Clad and Maximum Pitch)

Configuration	k_{eff}	σ	$k_{eff}+2\sigma$	k_s
Minimum outer diameter	0.90282	0.00070	0.90422	0.92232
Nominal outer diameter	0.90770	0.00072	0.90914	0.92724
Maximum outer diameter	0.91088	0.00070	0.91228	0.93038

Note: All cases include the minimum inner diameter and the maximum reactivity fuel and basket configuration in an 8-cask array as specified in Sections 6.4.7.6 and 6.1.1.1 as bounding.

Table 6.4.7-12 DIDO Bounding Configurations

Parameter	Value
Number of Fuel Cylinders	4
Plate thickness	≥ 0.130 cm
Clad thickness	≥ 0.025 cm
^{235}U content per Assembly	≤ 190 g
Enrichment wt % ^{235}U	≤ 94
Active Fuel Height	≥ 58.75 cm
Assembly Height[1]	≥ 61.5 cm
Min Tube ID	5.88 cm
Max. Tube OD	9.52 cm

Note:

1. Assembly height provides for spacing of fissile material. An optional spacer may be used to maintain spacing if the assembly is cut to shorter than 61.5 cm.

6.4.8 General Atomics Irradiated Fuel Material

This section presents the criticality analyses for the NAC-LWT cask with GA IFM. Criticality analyses are performed to satisfy the criticality safety requirements of 10 CFR Parts 71.55 and 71.59, as well as IAEA Transportation Safety Standards (TS-R-1). All criticality evaluations performed herein use an axially infinite model. An analysis of the NAC-LWT with a payload of either RERTR or HTGR fuel material shows that the TRIGA elements in the RERTR enclosure are more reactive than the HTGR fuel matrix. A detailed study of the combined payload evaluates TRIGA pitch, TRIGA array type (square or rectangular), interior moderator density including preferential flooding, and exterior moderator density. A single cask evaluation is also performed to comply with 10 CFR 71.55(b)(3). The analyses demonstrate that, including all calculational and mechanical uncertainties, the NAC-LWT remains subcritical under normal and accident conditions for the two GA IFM packages (FHUs).

6.4.8.1 Payload Evaluation

The results of the payload evaluation are used to determine the largest contributor to system reactivity. Four models were executed, with the characteristics listed below:

- TRIGA elements on rectangular 4×5 1.40 cm pitch.
- Flooded and dry HTGR fuel matrix.
- Interior (TRIGA package and cask cavity) moderator density at 0.9982 g/cm^3.
- Exterior moderator density at 0.9982 g/cm^3.

Results are shown in Table 6.4.8-1. Since the TRIGA fuel is the dominant contributor to the system reactivity, the TRIGA bias will be applied in order to calculated the bias-adjusted k_s. The bias is discussed in further detail in Section 6.4.8.8.

6.4.8.2 TRIGA Pitch/Array Evaluation

The combined payload model is used to evaluate the TRIGA element pitch in either a 'Rectangular' or 'Square' array as defined in Section 6.3.7. The HTGR FHU is modeled as dry in this configuration with the remaining cask void spaces flooded. Rectangular and square array results are shown in Table 6.4.8-2 and Table 6.4.8-3, respectively. In the rectangular array, the pitch is limited to 1.65 cm before interferences are created in the model. A larger pitch is possible in the square array, with a value of 1.73 cm allowed by the modeled geometry. The maximum reactivity is calculated for the square array with a pitch of 1.73 cm. Thus, the 1.73 cm pitch is employed in the optimum moderator density studies.

6.4.8.3 Interior Moderator Density Evaluation

The combined payload model is used to vary the interior moderator density with intact TRIGA elements in a square array on a 1.73 cm pitch. Based on the results shown in Table 6.4.8-4, a full density water package interior maximizes system reactivity at full density water exterior moderation.

6.4.8.4 HTGR Matrix Moderator Density Evaluation

The combined payload model is used to vary water density in the HTGR fuel matrix using the fully flooded TRIGA elements in a square array on a 1.73 cm pitch. Based on the results shown in Table 6.4.8-5, a water density of 1.0 g/cc for water homogenized with the HTGR fuel matrix maximizes system reactivity. Note that this configuration is conservative in that the HTGR fuel occupies part of the homogenized volume and full density water cannot occupy the same volume.

6.4.8.5 Exterior Moderator Density Evaluation

The combined payload model is used to vary the exterior moderator density with intact TRIGA elements in a square array on a 1.73 cm pitch. Interior moderator in the FHUs is set to full moderation as indicated by the evaluations in Sections 6.4.8.3 and 6.4.8.4. The cavity exterior to the FHUs is also flooded. Based on the results shown in Table 6.4.8-6, no significant change in system reactivity is obtained if the exterior moderator density varies below full density water. The maximum reactivity change of 2.9 $\Delta k/\sigma$ was obtained at an exterior water density of 0.0001 g/cc. This change, while outside the 2 $\Delta k/\sigma$ typical threshold for a significant change in reactivity, is less than 2.2×10^{-3} Δk and, therefore, not significant.

Note that the material description of the water neutron shield and the exterior moderator are identical in these evaluations addressing accident condition concerns (loss of neutron shield).

6.4.8.6 Partial Flooding Evaluation

During accident conditions, the loss of neutron shielding has the potential to increase neutronic interaction between casks in the infinite array. Significant amounts of moderator outside the FHUs, but in the flooded cask cavity, serves to isolate casks under the accident condition of loss of neutron shield. To investigate the potential impact of preferential flooding, an additional model is created. The model preferentially floods the RERTR and HTGR FHUs, with a separate interior moderator material filling the balance of the NAC-LWT cavity.

A full set of studies evaluating the reactivity changes associated with varying cavity interior, FHU, and exterior moderator densities is summarized in Tables 6.4.8-7 through 6.4.8-11. The studies indicate that the most reactive configuration is for flooding of the RERTR and HTGR enclosures (FHUs) with interior and exterior void (loss of neutron shield). This configuration produces the maximum reactivity FHUs, while maximizing interaction between the FHUs within the cask and between casks.

6.4.8.7 Single Cask Evaluation

The 10 CFR 71.55(b)(3) requires an evaluation of the NAC-LWT with the containment system fully reflected by water. The containment for the NAC-LWT is the cask inner shell. While no operating condition results in a removal of the cask outer shell and lead gamma shield, each of the partial flooding cases at four combinations of interior and exterior moderator is reevaluated by removing the lead and outer shells (including neutron shield), and reflecting the system by water at full density on the X and Y faces (the z faces are mirrored to yield an axially infinite model). The results of this analysis are shown in Table 6.4.8-12 and demonstrate that the system reactivity decreases with the removal of the lead, outer shell and neutron shield reflectors.

6.4.8.8 Damaged TRIGA Fuel Evaluation

The combined payload model with a homogenized TRIGA fuel description is used to evaluate the system reactivity in the event that both the intact and sectioned fuel elements become damaged. Models are executed by varying the volume fraction of water in the TRIGA fuel mixture from zero to unity. The maximum volume fraction is 0.6816 based on the FHU cavity volume (7140 cm^3) and the total volume of TRIGA elements (2273 cm^3), which does not consider the volume of the aluminum tubing within the FHU primary enclosure.

Based on the results summarized in Table 6.4.8-13, homogenized TRIGA elements are more reactive than intact TRIGA elements. Evaluation results documented in Table 6.4.8-13 are based

on infinite cask array models. A single cask evaluation of the maximum water volume fraction case yielded a k_{eff} of 0.38885 ± 0.00066.

6.4.8.9 Code Bias and Code Bias Uncertainty Adjustments

As shown in Section 6.4.8.1, the TRIGA elements in the RERTR enclosure are more reactive than the HTGR fuel matrix in its enclosure. Therefore, code bias and code uncertainty adjustments are based on the TRIGA fuel element critical benchmarks in Section 6.5. 3.

A calculation of k_s under normal and accident conditions can now be made based on the previous results and based on the KENO-Va validation statistics presented in Section 6.5.3. The value k_s is calculated based on the KENO-Va Monte Carlo average plus any biases and uncertainties associated with the methods and the modeling, i.e.:

$$k_s = k_{eff} + \Delta k_{Bias} + \Delta k_{BU} + 2\sigma_{MC} \leq 0.95$$

In the validation presented in Section 6.5.3, a negative bias (allowance for overprediction of k_{eff}) and a 95/95 method uncertainty of ± 0.0168 was determined. The negative bias correction is neglected. Thus, the equation for k_s becomes:

$$k_s = k_{eff} + 0.0168 + 2\sigma_{MC}$$

The k_s values for the relevant analysis are included in Tables 6.4.8-1 through Table 6.4.8-13. The maximum k_s, 0.74015, for the GA IFM shipment results from an infinite height model with an infinite number of casks.

For both normal and accident conditions, the calculated k_{eff} values, after correction for uncertainty, are well below the 0.95 limit. The analyses demonstrate that, including all calculational and mechanical uncertainties, an infinite array of NAC-LWT casks with GA IFM remains subcritical under normal and accident conditions.

Table 6.4.8-1 GA IFM Payload Evaluation Result Summary

Payload	Cavity Moderator Density [g/cm^3]	HTGR Moderator Density [g/cm^3]	RERTR Moderator Density [g/cm^3]	Exterior Moderator Density [g/cm^3]	TRIGA Pitch [cm]	TRIGA Array	$k_{eff} \pm \sigma$
Combined	0.9882	0	0.9882	0.9882	1.40	Rectangular	0.44192±0.00073
RERTR	0.9882	0	0.9882	0.9882	1.40	Rectangular	0.42870±0.00080
HTGR	0.9882	0	0.9882	0.9882	N/A	N/A	0.06611±0.00020
HTGR	0.9882	0.9882	0.9882	0.9882	N/A	N/A	0.36907±0.00053

Table 6.4.8-2 GA IFM TRIGA Rectangular Array Pitch Evaluation Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	0	1	1	1.40	Rectangular	0.44192	0.00073	0.46018	0.44338	0.00000	0.0
1	0	1	1	1.50	Rectangular	0.45796	0.00078	0.47632	0.45952	0.01614	20.7
1	0	1	1	1.60	Rectangular	0.47647	0.00080	0.49487	0.47807	0.03469	43.4
1	0	1	1	1.65	Rectangular	0.48529	0.00079	0.50367	0.48687	0.04349	55.1

Table 6.4.8-3 GA IFM TRIGA Square Array Pitch Evaluation Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	0	1	1	1.40	Square	0.44618	0.00073	0.46444	0.44764	0.00000	0.0
1	0	1	1	1.50	Square	0.46343	0.00080	0.48183	0.46503	0.01739	21.7
1	0	1	1	1.60	Square	0.48072	0.00078	0.49908	0.48228	0.03464	44.4
1	0	1	1	1.65	Square	0.49026	0.00078	0.50862	0.49182	0.04418	56.6
1	0	1	1	1.70	Square	0.49727	0.00077	0.51561	0.49881	0.05117	66.5
1	0	1	1	1.73	Square	0.50289	0.00079	0.52127	0.50447	0.05683	71.9

Table 6.4.8-4 GA IFM Interior Moderator Density Evaluation Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1.00	0	1.00	1	1.73	Square	0.50289	0.00079	0.52127	0.50447	0.00000	0.0
0.95	0	0.95	1	1.73	Square	0.48897	0.00077	0.50731	0.49051	-0.01396	-18.1
0.90	0	0.90	1	1.73	Square	0.47787	0.00079	0.49625	0.47945	-0.02502	-31.7
0.85	0	0.85	1	1.73	Square	0.46611	0.00076	0.48443	0.46763	-0.03684	-48.5
0.80	0	0.80	1	1.73	Square	0.45420	0.00077	0.47254	0.45574	-0.04873	-63.3
0.75	0	0.75	1	1.73	Square	0.44289	0.00073	0.46115	0.44435	-0.06012	-82.4
0.70	0	0.70	1	1.73	Square	0.42888	0.00071	0.44710	0.43030	-0.07417	-104.5
0.65	0	0.65	1	1.73	Square	0.41568	0.00073	0.43394	0.41714	-0.08733	-119.6
0.60	0	0.60	1	1.73	Square	0.40369	0.00069	0.42187	0.40507	-0.09940	-144.1
0.55	0	0.55	1	1.73	Square	0.39298	0.00069	0.41116	0.39436	-0.11011	-159.6
0.50	0	0.50	1	1.73	Square	0.38075	0.00069	0.39893	0.38213	-0.12234	-177.3
0.45	0	0.45	1	1.73	Square	0.36922	0.00069	0.38740	0.37060	-0.13387	-194.0
0.40	0	0.40	1	1.73	Square	0.35645	0.00067	0.37459	0.35779	-0.14668	-218.9
0.35	0	0.35	1	1.73	Square	0.34396	0.00064	0.36204	0.34524	-0.15923	-248.8
0.30	0	0.30	1	1.73	Square	0.33007	0.00064	0.34815	0.33135	-0.17312	-270.5
0.25	0	0.25	1	1.73	Square	0.31618	0.00059	0.33416	0.31736	-0.18711	-317.1
0.20	0	0.20	1	1.73	Square	0.29802	0.00056	0.31594	0.29914	-0.20533	-366.7
0.15	0	0.15	1	1.73	Square	0.27758	0.00057	0.29552	0.27872	-0.22575	-396.1
0.10	0	0.10	1	1.73	Square	0.24971	0.00052	0.26755	0.25075	-0.25372	-487.9
0.05	0	0.05	1	1.73	Square	0.21145	0.00048	0.22921	0.21241	-0.29206	-608.5

Table 6.4.8-5 GA IFM HTGR Matrix Moderator Density Evaluation Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	0.00	1	1	1.73	Square	0.50289	0.00079	0.52127	0.50447	0.00000	0.0
1	0.05	1	1	1.73	Square	0.50363	0.00076	0.52195	0.50515	0.00068	0.9
1	0.10	1	1	1.73	Square	0.50425	0.00079	0.52263	0.50583	0.00136	1.7
1	0.15	1	1	1.73	Square	0.50570	0.00076	0.52402	0.50722	0.00275	3.6
1	0.20	1	1	1.73	Square	0.50755	0.00077	0.52589	0.50909	0.00462	6.0
1	0.25	1	1	1.73	Square	0.50701	0.00078	0.52537	0.50857	0.00410	5.3
1	0.30	1	1	1.73	Square	0.50888	0.00079	0.52726	0.51046	0.00599	7.6
1	0.35	1	1	1.73	Square	0.50994	0.00079	0.52832	0.51152	0.00705	8.9
1	0.40	1	1	1.73	Square	0.51168	0.00079	0.53006	0.51326	0.00879	11.1
1	0.45	1	1	1.73	Square	0.51327	0.00079	0.53165	0.51485	0.01038	13.1
1	0.50	1	1	1.73	Square	0.51492	0.00078	0.53328	0.51648	0.01201	15.4
1	0.55	1	1	1.73	Square	0.51524	0.00080	0.53364	0.51684	0.01237	15.5
1	0.60	1	1	1.73	Square	0.51628	0.00078	0.53464	0.51784	0.01337	17.1
1	0.65	1	1	1.73	Square	0.51911	0.00077	0.53745	0.52065	0.01618	21.0
1	0.70	1	1	1.73	Square	0.52034	0.00076	0.53866	0.52186	0.01739	22.9
1	0.75	1	1	1.73	Square	0.52100	0.00074	0.53928	0.52248	0.01801	24.3
1	0.80	1	1	1.73	Square	0.52193	0.00076	0.54025	0.52345	0.01898	25.0
1	0.85	1	1	1.73	Square	0.52120	0.00075	0.53950	0.52270	0.01823	24.3
1	0.90	1	1	1.73	Square	0.52407	0.00074	0.54235	0.52555	0.02108	28.5
1	0.95	1	1	1.73	Square	0.52482	0.00076	0.54314	0.52634	0.02187	28.8
1	1.00	1	1	1.73	Square	0.52764	0.00070	0.54584	0.52904	0.02457	35.1

Table 6.4.8-6 GA IFM Exterior Moderator Density Evaluation Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	1	1	1.00	1.73	Square	0.52764	0.00070	0.54584	0.52904	0.00000	0.0
1	1	1	0.95	1.73	Square	0.52634	0.00073	0.54460	0.52780	-0.00124	-1.7
1	1	1	0.90	1.73	Square	0.52787	0.00077	0.54621	0.52941	0.00037	0.5
1	1	1	0.85	1.73	Square	0.52539	0.00073	0.54365	0.52685	-0.00219	-3.0
1	1	1	0.80	1.73	Square	0.52733	0.00075	0.54563	0.52883	-0.00021	-0.3
1	1	1	0.75	1.73	Square	0.52921	0.00079	0.54759	0.53079	0.00175	2.2
1	1	1	0.70	1.73	Square	0.52632	0.00071	0.54454	0.52774	-0.00130	-1.8
1	1	1	0.65	1.73	Square	0.52551	0.00073	0.54377	0.52697	-0.00207	-2.8
1	1	1	0.60	1.73	Square	0.52695	0.00079	0.54533	0.52853	-0.00051	-0.6
1	1	1	0.55	1.73	Square	0.52712	0.00078	0.54548	0.52868	-0.00036	-0.5
1	1	1	0.50	1.73	Square	0.52612	0.00077	0.54446	0.52766	-0.00138	-1.8
1	1	1	0.45	1.73	Square	0.52584	0.00076	0.54416	0.52736	-0.00168	-2.2
1	1	1	0.40	1.73	Square	0.52669	0.00076	0.54501	0.52821	-0.00083	-1.1
1	1	1	0.35	1.73	Square	0.52661	0.00076	0.54493	0.52813	-0.00091	-1.2
1	1	1	0.30	1.73	Square	0.52735	0.00078	0.54571	0.52891	-0.00013	-0.2
1	1	1	0.25	1.73	Square	0.52644	0.00076	0.54476	0.52796	-0.00108	-1.4
1	1	1	0.20	1.73	Square	0.52775	0.00080	0.54615	0.52935	0.00031	0.4
1	1	1	0.15	1.73	Square	0.52812	0.00075	0.54642	0.52962	0.00058	0.8
1	1	1	0.10	1.73	Square	0.52904	0.00073	0.54730	0.53050	0.00146	2.0
1	1	1	0.05	1.73	Square	0.52655	0.00072	0.54479	0.52799	-0.00105	-1.5
1	1	1	0.00	1.73	Square	0.52970	0.00073	0.54796	0.53116	0.00212	2.9

Table 6.4.8-7 GA IFM Partial Flooding Comparison Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0	1	0	0	1.73	Square	0.57362	0.00054	0.59150	0.57470	0.00000	0.0
0	1	1	0	1.73	Square	0.70197	0.00076	0.72029	0.70349	0.12879	169.5

Table 6.4.8-8 GA IFM Partial Flooding Interior Moderator Density, Void Exterior Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0.0	1	1	0	1.73	Square	0.70197	0.00076	0.72029	0.70349	0.00000	0.0
0.1	1	1	0	1.73	Square	0.63582	0.00076	0.65414	0.63734	-0.06615	-87.0
0.2	1	1	0	1.73	Square	0.59419	0.00074	0.61247	0.59567	-0.10782	-145.7
0.3	1	1	0	1.73	Square	0.57060	0.00078	0.58896	0.57216	-0.13133	-168.4
0.4	1	1	0	1.73	Square	0.55551	0.00073	0.57377	0.55697	-0.14652	-200.7
0.5	1	1	0	1.73	Square	0.54367	0.00074	0.56195	0.54515	-0.15834	-214.0
0.6	1	1	0	1.73	Square	0.53824	0.00074	0.55652	0.53972	-0.16377	-221.3
0.7	1	1	0	1.73	Square	0.53478	0.00075	0.55308	0.53628	-0.16721	-222.9
0.8	1	1	0	1.73	Square	0.53243	0.00074	0.55071	0.53391	-0.16958	-229.2
0.9	1	1	0	1.73	Square	0.53192	0.00075	0.55022	0.53342	-0.17007	-226.8
1.0	1	1	0	1.73	Square	0.52970	0.00073	0.54796	0.53116	-0.17233	-236.1

Table 6.4.8-9 GA IFM Partial Flooding Interior Moderator Density, Water Exterior Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0.0	1	1	1	1.73	Square	0.55598	0.00074	0.57426	0.55746	0.00000	0.0
0.1	1	1	1	1.73	Square	0.54649	0.00073	0.56475	0.54795	-0.00951	-13.0
0.2	1	1	1	1.73	Square	0.53804	0.00075	0.55634	0.53954	-0.01792	-23.9
0.3	1	1	1	1.73	Square	0.53458	0.00073	0.55284	0.53604	-0.02142	-29.3
0.4	1	1	1	1.73	Square	0.52971	0.00076	0.54803	0.53123	-0.02623	-34.5
0.5	1	1	1	1.73	Square	0.52610	0.00074	0.54438	0.52758	-0.02988	-40.4
0.6	1	1	1	1.73	Square	0.52725	0.00075	0.54555	0.52875	-0.02871	-38.3
0.7	1	1	1	1.73	Square	0.52668	0.00071	0.54490	0.52810	-0.02936	-41.4
0.8	1	1	1	1.73	Square	0.52630	0.00077	0.54464	0.52784	-0.02962	-38.5
0.9	1	1	1	1.73	Square	0.52711	0.00074	0.54539	0.52859	-0.02887	-39.0
1.0	1	1	1	1.73	Square	0.52764	0.00070	0.54584	0.52904	-0.02842	-40.6

Table 6.4.8-10 GA IFM Partial Flooding Exterior Moderator Density, Void Interior Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0	1	1	0.0	1.73	Square	0.70197	0.00076	0.72029	0.70349	0.00000	0.0
0	1	1	0.1	1.73	Square	0.56743	0.00075	0.58573	0.56893	-0.13456	-179.4
0	1	1	0.2	1.73	Square	0.55761	0.00075	0.57591	0.55911	-0.14438	-192.5
0	1	1	0.3	1.73	Square	0.55699	0.00076	0.57531	0.55851	-0.14498	-190.8
0	1	1	0.4	1.73	Square	0.55603	0.00072	0.57427	0.55747	-0.14602	-202.8
0	1	1	0.5	1.73	Square	0.55553	0.00071	0.57375	0.55695	-0.14654	-206.4
0	1	1	0.6	1.73	Square	0.55550	0.00073	0.57376	0.55696	-0.14653	-200.7
0	1	1	0.7	1.73	Square	0.55648	0.00075	0.57478	0.55798	-0.14551	-194.0
0	1	1	0.8	1.73	Square	0.55610	0.00075	0.57440	0.55760	-0.14589	-194.5
0	1	1	0.9	1.73	Square	0.55524	0.00075	0.57354	0.55674	-0.14675	-195.7
0	1	1	1.0	1.73	Square	0.55598	0.00074	0.57426	0.55746	-0.14603	-197.3

Table 6.4.8-11 GA IFM Partial Flooding Exterior Moderator Density, Water Interior Result Summary

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
1	1	1	0.0	1.73	Square	0.52970	0.00073	0.54796	0.53116	0.00000	0.0
1	1	1	0.1	1.73	Square	0.52904	0.00073	0.54730	0.53050	-0.00066	-0.9
1	1	1	0.2	1.73	Square	0.52775	0.00080	0.54615	0.52935	-0.00181	-2.3
1	1	1	0.3	1.73	Square	0.52735	0.00078	0.54571	0.52891	-0.00225	-2.9
1	1	1	0.4	1.73	Square	0.52669	0.00076	0.54501	0.52821	-0.00295	-3.9
1	1	1	0.5	1.73	Square	0.52612	0.00077	0.54446	0.52766	-0.00350	-4.5
1	1	1	0.6	1.73	Square	0.52695	0.00079	0.54533	0.52853	-0.00263	-3.3
1	1	1	0.7	1.73	Square	0.52632	0.00071	0.54454	0.52774	-0.00342	-4.8
1	1	1	0.8	1.73	Square	0.52733	0.00075	0.54563	0.52883	-0.00233	-3.1
1	1	1	0.9	1.73	Square	0.52787	0.00077	0.54621	0.52941	-0.00175	-2.3
1	1	1	1.0	1.73	Square	0.52764	0.00070	0.54584	0.52904	-0.00212	-3.0

Table 6.4.8-12 GA IFM Partial Flooding Single Cask Result Comparison

Cavity (g/cc)	HTGR (g/cc)	RERTR (g/cc)	Exterior (g/cc)	TRIGA Pitch (cm)	TRIGA Array	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0	1	1	0	1.73	Square	0.70197	0.00076	0.72029	0.70349	0.00000	0.0
0	1	1	0	1.73	Square	0.42657	0.00066	0.44469	0.42789	-0.27560	-417.6
1	1	1	0	1.73	Square	0.52970	0.00073	0.54796	0.53116	0.00000	0.0
1	1	1	0	1.73	Square	0.52108	0.00074	0.53936	0.52256	-0.00860	-11.6
0	1	1	1	1.73	Square	0.55598	0.00074	0.57426	0.55746	0.00000	0.0
0	1	1	1	1.73	Square	0.45370	0.00074	0.47198	0.45518	-0.10228	-138.2
1	1	1	1	1.73	Square	0.52764	0.00070	0.54584	0.52904	0.00000	0.0
1	1	1	1	1.73	Square	0.52056	0.00076	0.53888	0.52208	-0.00696	-9.2

Table 6.4.8-13 GA IFM Damaged TRIGA Fuel Result Summary

Cavity (g/cc)	HTGR (g/cc)	Exterior (g/cc)	TRIGA Config.	TRIGA H_2O (g/cc)	k_{eff}	σ	k_s	$k_{eff}+2\sigma$	Δk	$\Delta k/\sigma$
0	1	0	Homog.	0.0001	0.53943	0.00055	0.55733	0.54053	-0.18282	-332.4
0	1	0	Homog.	0.1000	0.55711	0.00055	0.57501	0.55821	-0.16514	-300.3
0	1	0	Homog.	0.2000	0.57987	0.00054	0.59775	0.58095	-0.14240	-263.7
0	1	0	Homog.	0.3000	0.60672	0.00062	0.62476	0.60796	-0.11539	-186.1
0	1	0	Homog.	0.4000	0.63609	0.00062	0.65413	0.63733	-0.08602	-138.7
0	1	0	Homog.	0.5000	0.66661	0.00064	0.68469	0.66789	-0.05546	-86.7
0	1	0	Homog.	0.6000	0.69621	0.00067	0.71435	0.69755	-0.02580	-38.5
0	1	0	Homog.	0.6816	0.72199	0.00068	0.74015	0.72335	0.00000	0.0
0	1	0	Homog.	0.7000	0.72738	0.00069	0.74556	0.72876	0.00541	7.8
0	1	0	Homog.	0.8000	0.75724	0.00070	0.77544	0.75864	0.03529	50.4
0	1	0	Homog.	0.9000	0.78650	0.00071	0.80472	0.78792	0.06457	90.9
0	1	0	Homog.	1.0000	0.81239	0.00073	0.83065	0.81385	0.09050	124.0

6.4.9 PULSTAR Fuel Contents

This section presents the criticality analyses for the NAC-LWT cask with PULSTAR fuel contents. Criticality analyses are performed to satisfy the criticality safety requirements of 10 CFR Parts 71.55 and 71.59, as well as IAEA TS-R-1. All criticality evaluations performed herein use an axially finite cask model. An analysis of the NAC-LWT with each of the four postulated basket loadings shows that damaged PULSTAR fuel elements in a can are most reactive.

The maximum reactivity is based on the following model characteristics.

- 14 cans (25 elements per can) in the top and base modules
- 14 intact assemblies in the two intermediate modules
- Flooded cans
- Void cask cavity and exterior
- Loss of neutron shield

A single cask evaluation is also performed to comply with 10 CFR 71.55(b)(3). The analyses demonstrate that, including all calculational and mechanical uncertainties, the NAC-LWT remains subcritical under normal and accident conditions.

6.4.9.1 Intact Assembly Payload

An intact PULSTAR fuel assembly is placed in each of the 28 cells in the 28 MTR basket assembly. Results of the mechanical perturbation, axial and radial shift are shown in Table 6.4.9-1 through Table 6.4.9-3. Optimum moderator studies for the cask are shown in Figure 6.4.9-2. All intact fuel assembly runs are based on an infinite cask array model.

From a base model, which has the PULSTAR fuel assemblies centered in the module cell and touching the module base plates, various component shift and module plate thickness combinations are evaluated. Assembly shift results, shown in Table 6.4.9-1, indicate that a basket assembly with PULSTAR fuel assemblies in the "Xlong" alignment and axially alternated represents the most reactive scenario for intact fuel assemblies. The "modified" Ylong configuration represents a mix of rotations and is shown in Figure 6.4.9-1. Considering assembly shifts the maximum k_{eff} is 0.80517 ± 0.00083.

Mechanical perturbation results from a study of plate thickness and cell opening size are shown in Table 6.4.9-2. This study indicates that a maximum module cell width produces a slight increase in reactivity for a maximum k_{eff} of 0.80929 ± 0.00084.

Previous evaluations documented in this section are based on a flooded pellet to clad gap and fuel parameters producing the maximum lattice H/U ratio. Minimum H/U ratio and dry gap cases are run to verify that the lattice is under moderated and that appropriate fuel parameters were chosen for the base analysis. The results of this analysis are listed in Table 6.4.9-3 and clearly demonstrate that the element lattice is under moderated and that the flooded pellet to clad gap and maximum H/U lattice model options are conservative for the analysis.

Graphical results of the optimum moderator density studies are shown in Figure 6.4.9-2. This study further confirms that the assembly is under moderated and that maximum system reactivity is obtained from a flooded cask cavity with a dry cask exterior and neutron shield.

The CSI for intact fuel assemblies is 0 as an infinite array of cask is modeled and maximum reactivity is well below the 0.95 licensing limit.

6.4.9.2 Intact Elements – Fuel Rod Insert

A single KENO-Va case is executed to demonstrate that a payload of 448 PULSTAR fuel elements (16 elements per 4×4 insert; 28 MTR basket cells) is significantly less reactive than the assembly model containing 28 intact assemblies (700 elements).

For a model with the insert radially centered within the cell, alternating axial shifting, full density water in the cavity, and a void exterior, the calculated k_{eff} is 0.70076 ± 0.00079. This reactivity is substantially lower than that of the intact assemblies. Therefore no further analysis is performed with the rod insert configuration.

6.4.9.3 Canned Elements

Intact or damaged (failed) PULSTAR fuel elements and nonfuel components of fuel assemblies may be placed into either of the PULSTAR cans. Each configuration is individually evaluated.

Intact Fuel Elements

Intact fuel element models place 25 rods into the can in a 0.66-inch square pitch. This pitch is the maximum allowed by the modeled can cavity width and is conservative as the elements were significantly under moderated at their smaller "in assembly" pitch. A can is placed into each of the 28 MTR basket assembly cells in an alternate axial shift configuration with the cask and canister cavity flooded. The alternate shift configuration was determined to be most reactive in the intact assembly analysis. For an infinite array of casks under accident condition (void exterior and neutron shield) a k_{eff} of 0.89919 ± 0.00083 is calculated. Results in Table 6.4.9-4 indicate that the preferential flooding of the canister cavity with a void cask cavity for the same physical configuration results in k_{eff} of 0.98516 ± 0.00076. Additional evaluations and limitations, are therefore, required to document an acceptable system configuration. KENO models with cans restricted to the top and base modules and intact fuel assemblies in the remaining two modules reduces system reactivity significantly as documented in Table 6.4.9-4. Without the neutron shield (accident conditions) there is substantial neutronic coupling between casks in an array and limiting the number of casks produces a significant additional reactivity reduction. For the mixed loaded three-cask array, the calculated k_{eff} is 0.84910 ± 0.00079. A limit of a three-cask array produces a CSI of 33.4 under the accident conditions modeled. System reactivity for a normal condition infinite array of casks loaded with damaged fuel cans is low, $k_{eff} < 0.2$. The normal condition based CSI is therefore 0.

Damaged (Failed) Elements

Damaged elements are modeled as a homogenized fuel and water mixture within the can cavity. Analysis trends for the homogenized contents are similar to those for the intact elements in a can. Bias and uncertainty adjusted system reactivity of the damaged fuel elements is higher than allowed for a full cask load (28 cans), but restricting the cask array under accident condition to three casks and limiting each cask's contents to 14 damaged fuel cans, seven in each of the top and base basket modules, and intact fuel assemblies or rod holders in the intermediate basket modules, produces acceptable reactivities as shown in Table 6.4.9-5. For the 3-cask array, the maximum calculated k_{eff} is 0.86961 ± 0.00081.

6.4.9.4 Single Cask Evaluation

The 10 CFR 71.55(b)(3) requires an evaluation of the NAC-LWT with the containment system fully reflected by water. The containment for the NAC-LWT is the cask inner shell. While no operating condition results in a removal of the cask outer shell and lead gamma shield, each of the partial flooding cases at four combinations of interior and exterior moderator is reevaluated by removing the lead and outer shells (including neutron shield), and reflecting the system by water at full density on the X, Y, and Z faces. Using the maximum reactivity model from Section 6.4.9.3, the calculated k_{eff} is 0.72674 ± 0.00087.

6.4.9.5 Code Bias and Code Bias Uncertainty Adjustments

PULSTAR fuel elements are similar to LWR fuel rods with a shorter active fuel length and smaller assembly array. While the enrichment for PULSTAR fuel is outside the enrichment range validated for LWR fuel, Figure 6.5.1-2 shows no statistical trend in k_{eff} versus enrichment. Further, any trend that may be postulated from the critical benchmarks indicates a higher predicted k_{eff} value at higher enrichments. Therefore, code bias and code uncertainty adjustments are based on the LWR fuel assembly critical benchmarks in Section 6.5.1.

A calculation of k_s under normal and accident conditions can now be made based on the previous results and based on the KENO-Va validation statistics presented in Section 6.5.1. The value k_s is calculated based on the KENO-Va Monte Carlo average plus any biases and uncertainties associated with the methods and the modeling, i.e.:

$$k_s = k_{eff} + \Delta k_{Bias} + \Delta k_{BU} + 2\sigma_{MC} \leq 0.95$$

In the validation presented in Section 6.5.1, a bias of ± 0.0052 and a 95/95 method uncertainty of ± 0.0087 were determined. Thus, the equation for k_s becomes as follows.

$$k_s = k_{eff} + 0.0139 + 2\sigma_{MC}$$

The k_s values for each evaluated payload are summarized in Table 6.4.9-6. The maximum k_s, 0.88513, results from a mixed loading of intact assemblies and canned elements.

For both normal and accident conditions, the calculated k_{eff} values, after correction for uncertainty, are well below the 0.95 limit. The analyses demonstrate that, including all calculational and mechanical uncertainties, an array of NAC-LWT casks with PULSTAR fuel remains subcritical under normal and accident conditions.

6.4.9.7 Allowable Cask Loading

Based on the results of the previous sections, the following cask loadings are permissible. For intact elements, any combination of assemblies and 4×4 rod inserts may be loaded into any module cell. Up to 14 damaged fuel cans each containing up to 25 PULSTAR fuel elements may be loaded in the top and base modules only; module cells loaded without cans may contain any combination of intact assemblies or 4×4 rod inserts. Each can is allowed the equivalent fissile material content of 25 fuel elements in either intact or damaged (failed) form. Damaged fuel may include fuel debris.

Figure 6.4.9-1 PICTURE Schematic of Modified PULSTAR Fuel Assembly Alignment Configuration

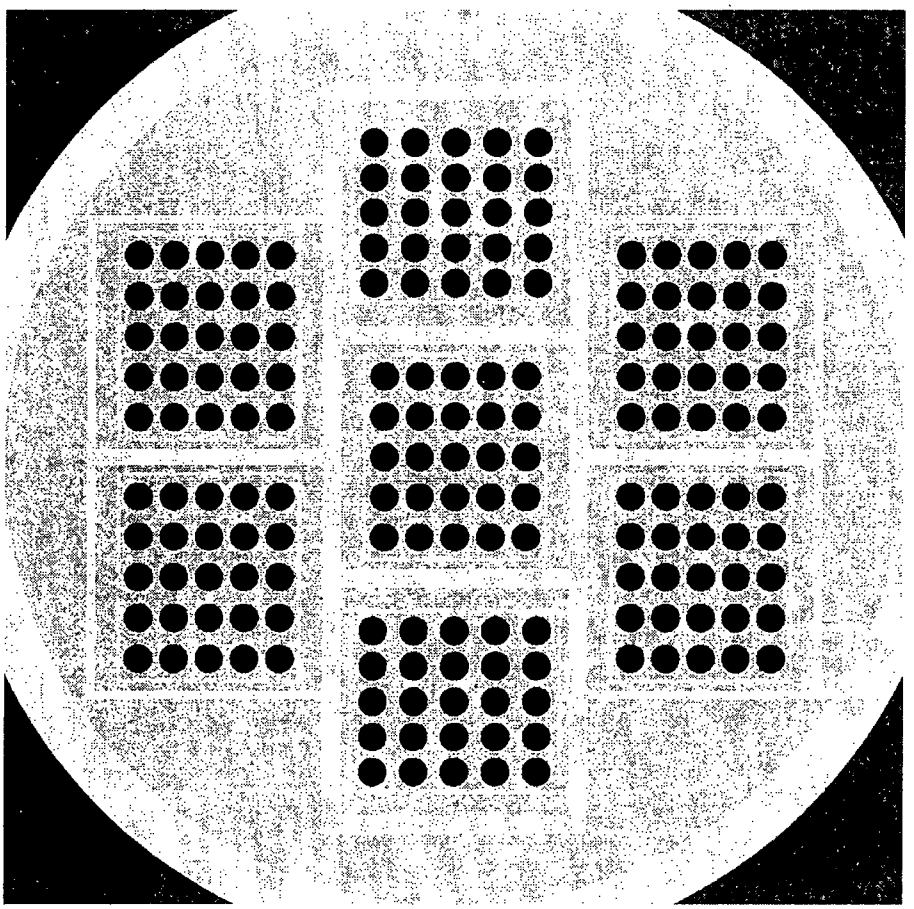

Figure 6.4.9-2 PULSTAR Intact Assembly Model Moderator Density Study Graphical Results

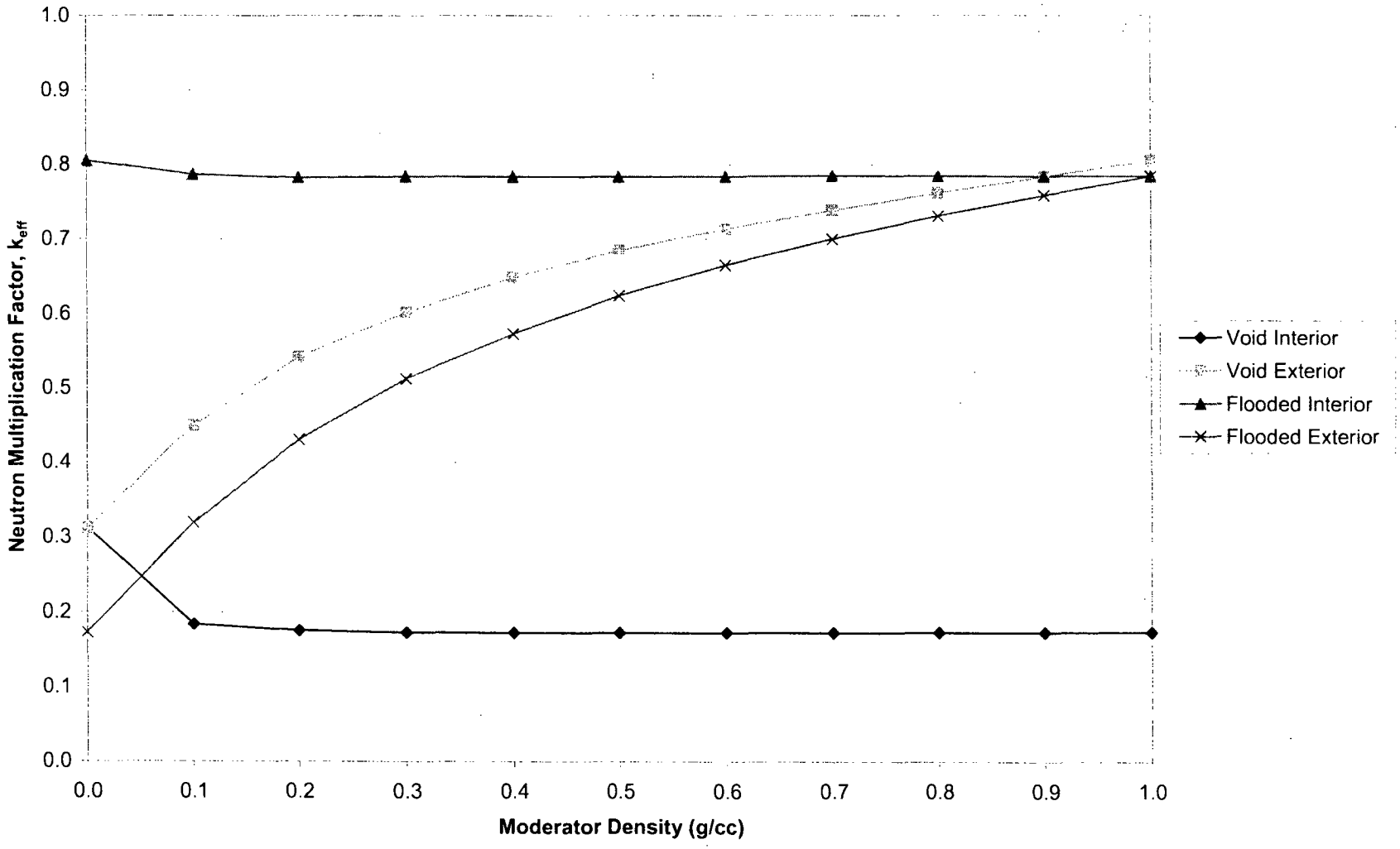

Table 6.4.9-1 PULSTAR Intact Assembly Shift Results

Alignment	Radial Shift	Axial Shift	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	Δk/σ
Ylong	Centered	Centered	0.78916	0.00081	0.79078	--	--
Ylong	In	Centered	0.77268	0.00085	0.77438	-0.01648	-14.0
Ylong	Out	Centered	0.78773	0.00081	0.78935	-0.00143	-1.2
Xlong	Centered	Centered	0.79134	0.00083	0.79300	--	--
Xlong	In	Centered	0.77006	0.00080	0.77166	-0.02128	-18.5
Xlong	Out	Centered	0.78979	0.00080	0.79139	-0.00155	-1.3
Ylong	Centered	Alternating	0.80182	0.00084	0.80350	--	--
Ylong	In	Alternating	0.78767	0.00081	0.78929	-0.01415	-12.1
Ylong	Out	Alternating	0.80176	0.00081	0.80338	-0.00006	-0.1
Xlong	Centered	Alternating	0.80517	0.00083	0.80683	--	--
Xlong	In	Alternating	0.77968	0.00083	0.78134	-0.02549	-21.7
Xlong	Out	Alternating	0.80522	0.00080	0.80682	0.00005	0.0
Mod. Ylong	Centered	Alternating	0.80348	0.00087	0.80522	--	--
Mod. Ylong	In	Alternating	0.78247	0.00082	0.78411	-0.02101	-17.6
Mod. Ylong	Out	Alternating	0.80427	0.00081	0.80589	0.00079	0.7

Table 6.4.9-2 PULSTAR Intact Assembly Mechanical Perturbation Results

Alignment	Radial Shift	Axial Shift	Basket Cell Opening	Basket Plate Thickness	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	Δk/σ
Xlong	Centered	Alternating	Min	Min	0.80517	0.00083	0.80683	--	--
Xlong	Centered	Alternating	Nominal	Nominal	0.80202	0.00084	0.80370	-0.00315	-2.7
Xlong	Centered	Alternating	Max	Max	0.78640	0.00081	0.78802	-0.01877	-16.2
Xlong	Centered	Alternating	Max	Min	0.80929	0.00084	0.81097	--	--
Xlong	In	Alternating	Max	Min	0.78826	0.00082	0.78990	-0.01691	-14.5
Xlong	Out	Alternating	Max	Min	0.80056	0.00081	0.80218	-0.00461	-4.0

Table 6.4.9-3 PULSTAR Intact Assembly Lattice Moderator Ratio Results

Alignment	Radial Shift	Axial Shift	Basket	Lattice H/U Ratio	Pellet to Clad Gap (g/cc)	Interior (g/cc)	Exterior (g/cc)	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	Δk/σ
Xlong	Centered	Alternating	Min	Max	1	1	0	0.80517	0.00083	0.80683	--	--
Xlong	Centered	Alternating	Min	Max	1	1	0	0.79497	0.00080	0.79657	-0.01020	-8.8
Xlong	Centered	Alternating	Min	Max	1	1	0	0.80517	0.00083	0.80683	--	--
Xlong	Centered	Alternating	Min	Min	0	1	0	0.79541	0.00080	0.79701	-0.00976	-8.5

Table 6.4.9-4 PULSTAR Canned Intact Element Results

Cask Array	# Cans per Cask	Assembly Alignment	Interior (g/cc)	Exterior (g/cc)	Can (g/cc)	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	Δk/σ
Infinite	28	--	1	0	1	0.89919	0.00083	0.90085	--	--
Infinite	28	--	0	0	1	0.98516	0.00076	0.98668	0.08597	76.4
Infinite	28	--	1	0	0	0.52383	0.00066	0.52515	-0.46133	-458.3
Infinite	14	Xlong	0	0	1	0.92654	0.00079	0.92812	--	--
Single	14	Xlong	0	0	1	0.84286	0.00083	0.84452	-0.08368	-73.0
3 Casks	14	Xlong	0	0	1	0.84910	0.00079	0.85068	-0.07744	-69.3
Infinite; Water Neutron Shield	14	Xlong	0	0	0	0.17042	0.00023	0.17088	-0.75612	-919.0

Table 6.4.9-5 PULSTAR Canned Homogenized Element Results

Cask Array	# Cans per Cask	Assembly Alignment	Interior (g/cc)	Exterior (g/cc)	Can (g/cc)	k_{eff}	σ	$k_{eff}+2\sigma$	Δk	Δk/σ
Infinite	28	--	1	0	1	0.92819	0.00079	0.92977	--	--
Infinite	28	--	0	0	1	1.01473	0.00075	1.01623	0.08654	79.4
Infinite	28	--	1	0	0	0.52684	0.00067	0.52818	-0.48789	-485.1
Infinite	14	Xlong	0	0	1	0.94917	0.00074	0.95065	--	--
Single	14	Xlong	0	0	1	0.86031	0.00081	0.86193	-0.08886	-81.0
3 Casks	14	Xlong	0	0	1	0.86961	0.00081	0.87123	-0.07956	-72.5
Infinite; Water Neutron Shield	14	Xlong	0	0	0	0.16471	0.00023	0.16517	-0.78446	-1012.3

Table 6.4.9-6 PULSTAR Maximum Reactivity Summary

Configuration	Cask Array	$k_{eff} + 2\sigma$	k_s	CSI
28 Intact Assemblies	Infinite	0.81097	0.82487	0
28 16-Element Fuel Rod Inserts	Infinite	0.70234	0.71624	0
14 Intact Assemblies & 14 Cans w/Intact Elements	3	0.85068	0.86458	33.4
14 Intact Assemblies & 14 Cans w/Homogenized Elements	3	0.87123	0.88513	33.4

6.4.10 ANSTO Basket Payloads

This section presents the criticality analyses for the NAC-LWT cask with the spiral fuel assemblies and MOATA plate bundles in the ANSTO basket configuration. This evaluation meets the criticality safety requirements of 10 CFR Parts 71.55 and 71.59, as well as IAEA Transportation Safety Standards (TS-R-1). In this analysis, the bounding assembly characteristics are determined and infinite arrays of NAC-LWT casks are studied to determine bounding basket configurations for criticality under normal and accident conditions. Moderator density in the cavity, neutron shield tank and outside is varied to determine the maximum k_{eff}. The analyses demonstrate that, including all calculational and mechanical uncertainties, the NAC-LWT remains subcritical under normal and accident conditions for spiral fuel assemblies and MOATA plate bundles in the ANSTO basket configuration.

6.4.10.1 Spiral Fuel Assemblies

Initial evaluations document the reactivity of the fuel assembly in a nominal configuration basket. The cask model is set to accident conditions with neutron shield and cask exterior material voided. This base model is then modified to evaluate basket configuration and fuel material changes individually or in combination. For all evaluations, the ^{235}U enrichment percentage is set to its maximum value, as increased ^{235}U weight percent minimizes parasitic absorption in ^{238}U.

Reactivity results for the mechanical perturbation studies of the system and tolerances applied to the fuel material definition are included in Table 6.4.10-1. Manufacturing tolerance studies of the basket are listed in Table 6.4.10-2. Basket tolerance studies, as well as fuel studies shown later, rely on a base model containing maximum tolerance fissile material mass and uranium weight percent in the fuel meat.

The majority of evaluations presented in this section are based on a volume-conserving model with three fuel rings. This model requires a significant decrease in core thickness to conserve fuel meat volume, with only a minimal change to the plate thickness. As shown in Table 6.4.10-1, the model based on the original fuel plate dimension has a slightly higher reactivity. The increased reactivity in the plate-based model is the result of a smaller clad thickness than the one applied to the volume-conserving model. Evaluations performed later in this section reduce the clad to a minimum (0.01 cm) and, therefore, bound the as-manufactured plate configuration. Further calculations are, therefore, all based on a volume-conserving base model.

Maximum reactivity material, basket tolerances, and mechanical perturbation configurations are listed in the following bullets.

- Radial shift in – close approach active fuel
  There is no statistically significant difference between a shifted middle fuel element and a centered middle fuel element. The centered middle fuel element is chosen to continue the remaining evaluations.
- Axial alternating shift – close approach active fuel

- Maximum ^{235}U mass and maximum uranium weight percentage

  Within the range of uranium weight percentages evaluated, there is no effect on system reactivity. As documented in the MTR evaluation set, a large increase in uranium percentage (well beyond reasonable manufacturing limits) will increase reactivity. Therefore, maximum uranium percentage is retained for the remaining reactivity evaluations.

- Minimum fuel tube thickness
  For the tube specified, minimum tube thickness equals nominal thickness (tolerance is defined as -0%, +22%).

- No significant effect associated with other basket tolerances
  As reduced basket bottom plate and tube height removes absorber material from the system, the remaining reactivity evaluations set these variables to minimum.
  Fuel tube OD is set to maximum as it shows a slight, if not significant, reactivity increase. Increasing tube OD trades off raised moderation against increased absorber in the larger tube.

Next, fuel assembly dimensional effects are evaluated. The results of the fuel tolerance studies are documented in Table 6.4.10-3. The maximum system reactivity fuel configuration is itemized in the following bullets.

- Minimum plate thickness – increases moderator available between inner and outer assembly sleeves

- Minimum clad thickness
  Maximum reactivity obtained from a case where clad thickness is conservatively set to a minimum of 0.01 cm.

- Minimum active fuel height – reduces the space between fissile material in the alternating shifted model

- Minimum element height – reduces the space between fissile material in the alternating shifted model
  Set to active fuel height to remove variable as a potential licensing limit.

- Minimum sleeve (shell dimensions) – conservatively set to 0.01 cm thick
  Provides additional moderation in the system.

- Maximum plate pitch
  Plates were modeled as a set of three cylinders at various pitches. Maximum reactivity is obtained from a system with the middle cylinder centered between inner and outer aluminum assembly shells (sleeves) and the remaining cylinders pushed away from the center. This significantly increases the pitch between fuel materials above the 10 plate as-built assembly. Inner and outer sleeve (shell) dimensions were conservatively set to a thickness of 0.01 cm. This was done to increase volume inside the annular region, maximizing the volume available for fuel and moderator.

Cask interior and exterior moderator density variation studies are included in Table 6.4.10-4. Moderator density variations are performed on the most-reactive basket and cask configuration under the accident condition (i.e., loss of neutron shield integrity). These studies demonstrate that for a fully moderated cask interior, any increase in cask exterior moderator density reduces reactivity by decoupling the casks in the array. This data is consistent with the lower reactivity obtained from the normal condition case, where the cask water neutron shield isolates casks in the infinite array. The reactivity curve for modified interior density demonstrates that within the statistical uncertainty of the evaluation, a fully moderated cask interior represents a bounding condition. No significant variations in reactivity occur for moderator densities above 0.9 g/cm^3. A plot of the interior density study is shown in Figure 6.4.10-1.

Results for a nominal condition infinite cask array, worst-case configuration accident condition (voided neutron shield) and normal conditions of operations (filled neutron shield) arrays, and for a single cask with a fully reflected containment boundary are included in Table 6.4.10-5. Maximum bias adjusted system reactivity is 0.746, well below the 0.95 safety limit for the system. As an infinite array of casks is subcritical under both normal and accident conditions, the criticality safety index (CSI) is 0.

The reactivity evaluation of the NAC-LWT cask containing up to 42 spiral fuel assemblies (elements), demonstrates that subcritical margin ($k_s \leq 0.95$) can be maintained under the following conditions:

Parameter	Value
Number of Fuel Plates	10
Plate Thickness	≥ 0.124 cm
Active Fuel Height	≥ 59.075 cm
^{235}U Content per Element	≤160
Enrichment wt % ^{235}U	≤ 85

6.4.10.2 MOATA Plate Bundles

Initial evaluations document the reactivity of the plate bundle in a nominal configuration basket. The cask model is set to accident conditions with neutron shield and cask exterior material voided. This base model is then modified to evaluate basket configuration and fuel material changes individually or in combination. Results of these evaluations are documented in Table 6.4.10-6 and Table 6.4.10-7. Basket tolerance studies, as well as fuel studies shown later, rely on a base model containing maximum tolerance fissile material mass and uranium weight percent in the fuel meat. For all evaluations, the ^{235}U enrichment percentage is set to its maximum value as increased ^{235}U weight percent minimizes parasitic absorption in ^{238}U.

Maximum reactivity material, basket tolerances, and mechanical perturbation configurations are listed in the following bullets.

- Radial shift in – close approach active fuel
  No statistically significant difference between shifted middle fuel element and a centered middle fuel element. The centered middle fuel element is chosen to continue the remaining evaluations.
- Axial alternating shift – close approach active fuel
- Maximum ^{235}U mass and maximum uranium weight percentage
- Minimum fuel tube thickness
  For the tube specified, minimum tube thickness equals nominal thickness (tolerance is defined as -0%, +22%).
- No significant effect associated with other basket tolerances
  As reduced basket bottom plate and tube height removes absorber material from the system, the remaining reactivity evaluations set these variables to minimum.
  Fuel tube OD is retained at nominal as there is no significant effect on system reactivity for this variable, and offsetting neutronic effects occur for a change in tube size (e.g., increasing OD increases parasitic absorber and separates fissile material but provides additional moderator in the fuel region).

Next, fuel assembly dimensional and material effects are evaluated. The results of the fuel tolerance studies are documented in Table 6.4.10-8. Maximum system reactivity fuel configuration is itemized in the following bullets.

- Maximum active fuel width
  The tolerance applied to the active fuel width is one-half the distance between active fuel width and plate width. Applying this tolerance (0.3175 cm for the nominal plate width and 0.3366 cm for the maximum tolerance plate width) significantly increases system reactivity. Maximum allowed active fuel width by this analysis is 7.32 cm (conservatively rounded down from the 7.3266 cm evaluated).
- Maximum plate width
  Plate width variation taken independently has no effect on system reactivity. Analysis tied plate width to active fuel width, as no tolerance on the actual fuel width was available. Increasing plate width thereby increased the maximum active fuel width, which was shown to be bounding.
- Nominal plate thickness
  Plate bundle moderator to fuel ration (H/U) is controlled by the plate spacer thickness not plate thickness. Therefore, there is no significant effect of plate thickness on the bundle reactivity.
- Minimum clad thickness
  Maximum reactivity obtained from a case where clad thickness is conservatively set to a minimum of 0.01 cm.
- Nominal active fuel height
  Contrary to the spiral fuel and DIDO evaluation set, no significant effect of active fuel height was observed in the calculations.
- Minimum element height – reduces the space between fissile materials in the alternating shifted model
  Set to active fuel height to remove variable as a potential licensing limit. Note that the end-fitting structure of the plate bundle will assure significant separation between active fuel regions.
- Maximum plate spacer
  A conservative maximum spacer of 0.18 cm thickness was evaluated and shown to be bounding.
- Replacing aluminum side plates by water
  Provides additional moderation in the system.

Cask interior and exterior moderator density variation studies are included in Table 6.4.10-9 These studies demonstrate that for a fully moderated cask interior, any increase in cask exterior density reduces reactivity by decoupling the casks in the array. This data is consistent for reduced reactivity obtained from the normal condition case where the cask water neutron shield

isolates casks in the infinite array modeled. The reactivity curve for modified interior density demonstrates that within the statistical uncertainty of the evaluation, a fully moderated cask interior represents a bounding condition. No significant variations in reactivity occur for moderator densities above 0.95 g/cm^3. A plot of the interior density study is shown in Figure 6.4.10-2.

Results for a nominal condition infinite cask array, worst-case configuration accident condition (voided neutron shield) and normal conditions of operation (filled neutron shield) arrays, and for a single cask with a fully reflected containment boundary are included in Table 6.4.10-10. Maximum bias adjusted system reactivity is 0.763, well below the 0.95 safety limit for the system. As an infinite array of casks is subcritical under both normal and accident conditions, the criticality safety index (CSI) is 0.

The reactivity evaluation of the NAC-LWT cask containing up to 42 MOATA plate bundles demonstrates that subcritical margin ($k_s \leq 0.95$) can be maintained under the following conditions.

Parameter	MOATA Plate Bundle
Max. Number of Fuel Plates	14
Spacer Thickness	≤ 0.18 cm
Active Fuel Width	≤ 7.32 cm
^{235}U Content per Plate	≤22.3
Enrichment wt % ^{235}U	≤ 92

6.4.10.3 Mixed Basket Loading – Spiral Assemblies Basket and Plate Bundle Basket

The NAC-LWT may transport a combination of spiral elements and plate bundle elements. Given the low, and similar, reactivity of each payload, the combination of payloads is not expected to increase reactivity. A combination of three baskets of spiral elements and three baskets of plate bundles is evaluated to support the bounding statement. Casks are evaluated once with the top three baskets loaded with plate bundles and the bottom three baskets loaded with spiral elements, and once with an alternating spiral elements and plate bundles set. As shown in the following list, there is no increase in reactivity associated with mixed loading of plate bundles and spiral elements.

# Casks	Condition	Description	k_{eff}	σ	$k_{eff}+2\sigma$
Infinite Array	Accident	Nominal case of MOATA plate bundle load	0.68207	0.00078	0.68363
Infinite Array	Accident	Nominal case of spiral fuel	0.65957	0.00066	0.66089
Infinite Array	Accident	Alternating MOATA and spiral fuel load	0.67249	0.00068	0.67385
Infinite Array	Accident	Stack of 3 MOATA baskets and 3 spiral baskets	0.67403	0.00069	0.67541

Figure 6.4.10-1 Spiral Fuel - Moderator Density Plot

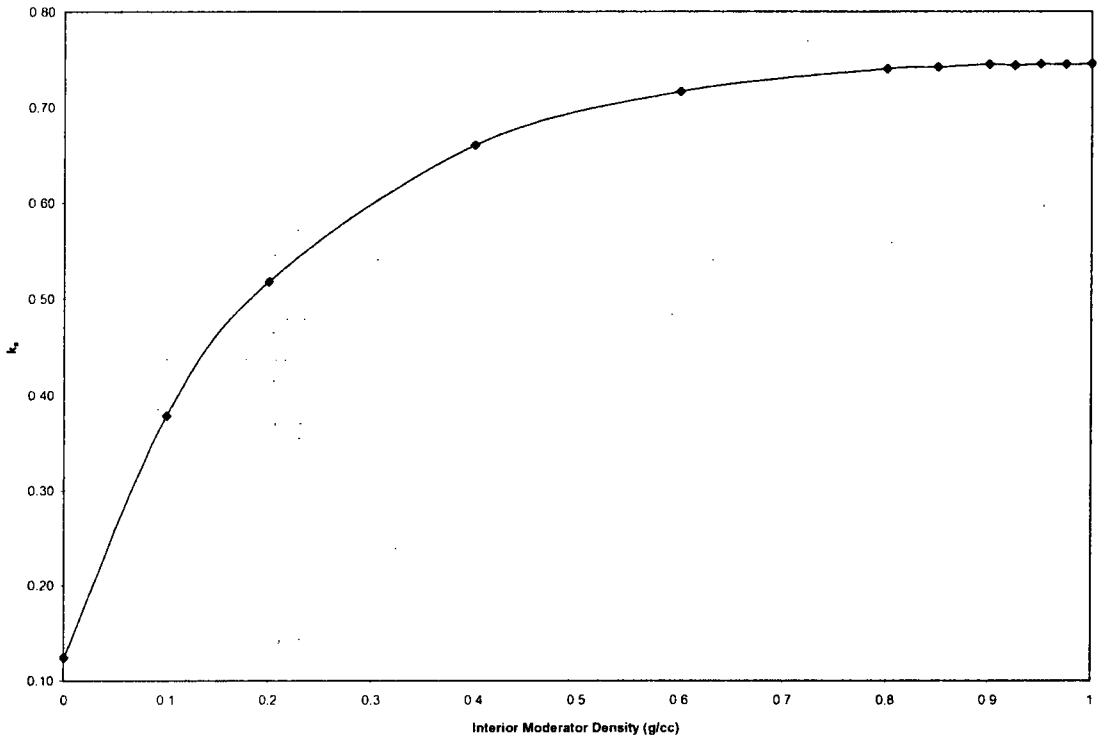

Figure 6.4.10-2 MOATA Plate Bundle -Moderator Density Plot

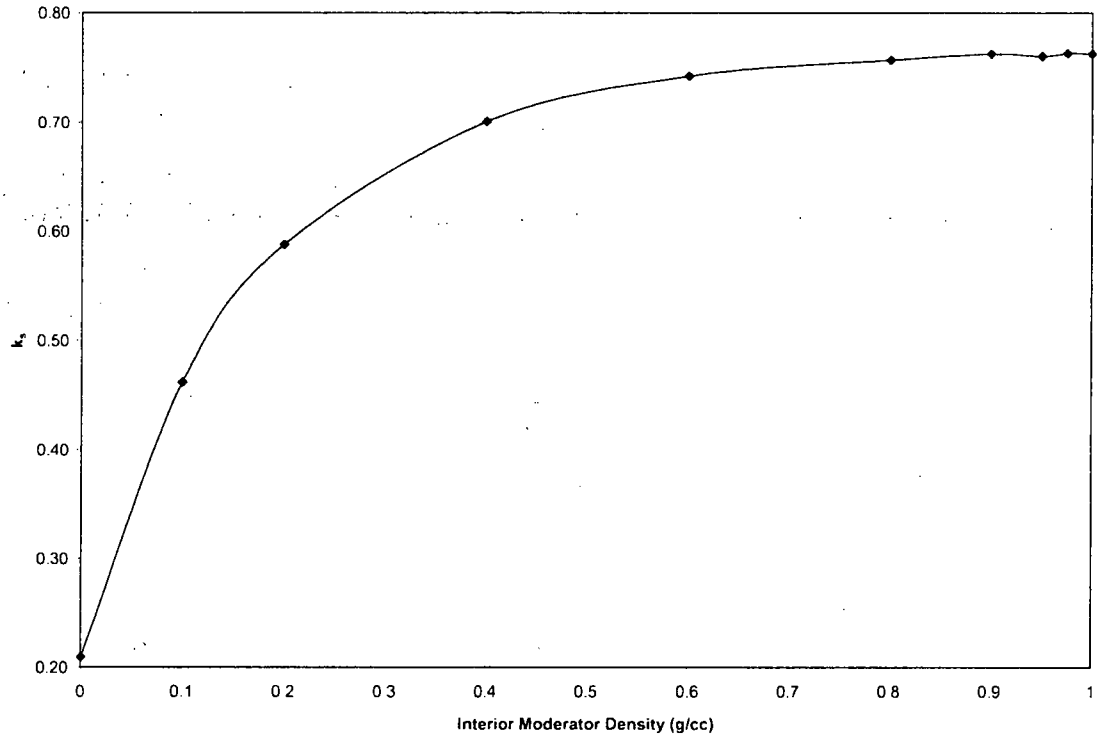

Table 6.4.10-1 Spiral Fuel Assembly - Base Data Comparisons

Base Data[1]	Cask Condition	Radial Shift Pattern	Axial Shift Pattern	^{235}U Mass Tolerance	Uranium Weight Fraction Tolerance	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
Volume	Accident	CenteredC	Down	Nominal	Nominal	0.65222	0.00064	0.65350	0.67160	-0.00862	-13.5
Volume	Accident	CenteredC	Alternating	Nominal	Nominal	0.65957	0.00066	0.66089	0.67899	-0.00123	-1.9
Plate	Accident	CenteredC	Alternating	Nominal	Nominal	0.66084	0.00064	0.66212	0.68022	--	--
Volume	Accident	CenteredC	Alternating	Min	Nominal	0.63917	0.00067	0.64051	0.65861	-0.02161	-32.3
Volume	Accident	CenteredC	Alternating	Max	Nominal	0.68143	0.00065	0.68273	0.70083	0.02061	31.7
Volume	Accident	CenteredC	Alternating	Nominal	Min	0.65967	0.00066	0.66099	0.67909	-0.00113	-1.7
Volume	Accident	CenteredC	Alternating	Nominal	Max	0.66025	0.00065	0.66155	0.67965	-0.00057	-0.9
Volume	Accident	OutC	Alternating	Nominal	Nominal	0.65823	0.00062	0.65947	0.67757	-0.00265	-4.3
Volume	Accident	In	Alternating	Nominal	Nominal	0.66333	0.00063	0.66459	0.68269	0.00247	3.9
Volume	Accident	InC	Alternating	Nominal	Nominal	0.66273	0.00069	0.66411	0.68221	0.00199	2.9
Volume	Accident	InC	Alternating	Max	Nominal	0.68337	0.00066	0.68469	0.70279	0.02257	34.2

[1] Refers to cylindrical fuel approximation being based on the original plate dimension or on volume (i.e., H/U ratio) conserving model.

Table 6.4.10-2 Spiral Fuel Assembly - Basket Tolerance Evaluations

Fuel Tube Outer Diameter Tolerance	Fuel Tube Thickness Tolerance	Fuel Tube Height Tolerance	Fuel Basket Base Plate Tolerance	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
Nominal	Nominal	Nominal	Nominal	0.68310	0.00069	0.68448	0.70258	--	--
Min	Nominal	Nominal	Nominal	0.68153	0.00066	0.68285	0.70095	-0.00163	-2.5
Max	Nominal	Nominal	Nominal	0.68410	0.00067	0.68544	0.70354	0.00096	1.4
Nominal	Min	Nominal	Nominal	0.68310	0.00069	0.68448	0.70258	--	--
Nominal	Max	Nominal	Nominal	0.65917	0.00067	0.66051	0.67861	-0.02397	-35.8
Nominal	Nominal	Min	Nominal	0.68368	0.00067	0.68502	0.70312	0.00054	0.8
Nominal	Nominal	Max	Nominal	0.68218	0.00065	0.68348	0.70158	-0.00100	-1.5
Nominal	Nominal	Nominal	Min	0.68341	0.00067	0.68475	0.70285	0.00027	0.4
Nominal	Nominal	Nominal	Max	0.68325	0.00064	0.68453	0.70263	0.00005	0.1
Min	Min	Min	Min	0.68254	0.00064	0.68382	0.70192	-0.00066	-1.0
Nominal	Min	Min	Min	0.68316	0.00068	0.68452	0.70262	0.00004	0.1
Max	Min	Min	Min	0.68434	0.00068	0.68570	0.70380	0.00122	1.8

Table 6.4.10-3 Spiral Fuel Assembly – Fuel Tolerance Evaluations

Fuel Plate Thickness Tolerance	Fuel Plate Clad Thickness Tolerance	Active Fuel Length Tolerance	Element Height Tolerance	H/U Study (Plate Location)	Inner & Outer Shells	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	0.68310	0.00069	0.68448	0.70258	--	--
Min	Nominal	Nominal	Nominal	Nominal	Nominal	0.68643	0.00067	0.68777	0.70587	0.00329	4.9
Max	Nominal	Nominal	Nominal	Nominal	Nominal	0.68082	0.00067	0.68216	0.70026	-0.00232	-3.5
Nominal	No Clad	Nominal	Nominal	Nominal	Nominal	0.69059	0.00067	0.69193	0.71003	0.00745	11.1
Nominal	Min	Nominal	Nominal	Nominal	Nominal	0.68737	0.00066	0.68869	0.70679	0.00421	6.4
Nominal	Max	Nominal	Nominal	Nominal	Nominal	0.68003	0.00064	0.68131	0.69941	-0.00317	-5.0
Nominal	Nominal	Min	Nominal	Nominal	Nominal	0.68619	0.00067	0.68753	0.70563	0.00305	4.6
Nominal	Nominal	Max	Nominal	Nominal	Nominal	0.68111	0.00068	0.68247	0.70057	-0.00201	-3.0
Nominal	Nominal	Nominal	Fuel	Nominal	Nominal	0.68821	0.00065	0.68951	0.70761	0.00503	7.7
Nominal	Nominal	Nominal	Min	Nominal	Nominal	0.68512	0.00066	0.68644	0.70454	0.00196	3.0
Nominal	Nominal	Nominal	Max	Nominal	Nominal	0.68125	0.00068	0.68261	0.70071	-0.00187	-2.8
Nominal	Nominal	Nominal	Nominal	Min	Nominal	0.67318	0.00066	0.67450	0.69260	-0.00998	-15.1
Nominal	Nominal	Nominal	Nominal	Max	Nominal	0.69131	0.00066	0.69263	0.71073	0.00815	12.3
Nominal	Nominal	Nominal	Nominal	Min	Min	0.67580	0.00068	0.67716	0.69526	-0.00732	-10.8
Nominal	Nominal	Nominal	Nominal	Nominal	Min	0.69148	0.00067	0.69282	0.71092	0.00834	12.4
Nominal	Nominal	Nominal	Nominal	Max	Min	0.70408	0.00067	0.70542	0.72352	0.02094	31.3
Min	No Clad	Min	Fuel	Max	Min	0.72459	0.00066	0.72591	0.74401	0.04143	62.8

Table 6.4.10-4 Spiral Fuel Assembly - Moderator Density Variations

Set	Interior Moderator Density (g/cm^3)	Exterior Moderator Density (g/cm^3)	k_{eff}	σ	$k_{eff}+2\sigma$	k_s
H1	0.9998	0.0001	0.72640	0.00067	0.72774	0.74584
	0.9998	0.1	0.69875	0.00066	0.70007	0.71817
	0.9998	0.5	0.69587	0.00067	0.69721	0.71531
	0.9998	0.9998	0.69661	0.00067	0.69795	0.71605
H2	0.9998	0.0001	0.72640	0.00067	0.72774	0.74584
	0.975	0.0001	0.72575	0.00066	0.72707	0.74517
	0.95	0.0001	0.72604	0.00066	0.72736	0.74546
	0.925	0.0001	0.72466	0.00068	0.72602	0.74412
	0.9	0.0001	0.72562	0.00066	0.72694	0.74504
	0.85	0.0001	0.72273	0.00067	0.72407	0.74217
	0.8	0.0001	0.72102	0.00069	0.72240	0.74050
	0.6	0.0001	0.69709	0.00068	0.69845	0.71655
	0.4	0.0001	0.63905	0.00150	0.64205	0.66015
	0.2	0.0001	0.49709	0.00138	0.49985	0.51795
	0.1	0.0001	0.35749	0.00125	0.35999	0.37809
	0.0001	0.0001	0.10524	0.00046	0.10616	0.12426

Table 6.4.10-5 Spiral Fuel Assembly - Maximum Reactivity Case Summary

# Casks	Condition	Description	k_{eff}	σ	$k_{eff}+2\sigma$	k_s
Infinite Array	Accident	Nominal configuration accident case	0.66084	0.00064	0.66212	0.68022
Infinite Array	Accident	Maximum reactivity material and shift case nominal fuel and basket configuration	0.68310	0.00069	0.68448	0.70258
Infinite Array	Accident	Maximum reactivity basket tolerance – nominal fuel configuration	0.68434	0.00068	0.68570	0.70380
Infinite Array	Accident	Maximum reactivity fuel tolerance – nominal basket configuration	0.72459	0.00066	0.72591	0.74401
Infinite Array	Accident	Combined maximum reactivity configuration case	0.72640	0.00067	0.72774	0.74584
Infinite Array	Normal	Combined maximum reactivity configuration case	0.69609	0.00069	0.69747	0.71557
Single Cask	N/A	Single cask / inner shell reflected with water - maximum reactivity configuration	0.65762	0.00067	0.65896	0.67706

Table 6.4.10-6 MOATA Plate Bundle - Base Data Comparisons

Cask Condition	Radial Shift Pattern	Axial Shift Pattern	U235 Mass Tolerance	Uranium Weight Fraction Tolerance	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
Accident	CenteredC	Down	Nominal	Nominal	0.67757	0.00074	0.67905	0.69715	-0.00458	-6.2
Accident	CenteredC	Alternating	Nominal	Nominal	0.68207	0.00078	0.68363	0.70173	--	--
Accident	CenteredC	Alternating	Nominal	Min	0.68113	0.00077	0.68267	0.70077	-0.00096	-1.2
Accident	CenteredC	Alternating	Nominal	Max	0.68367	0.00077	0.68521	0.70331	0.00158	2.1
Accident	CenteredC	Alternating	Min	Nominal	0.68163	0.00076	0.68315	0.70125	-0.00048	-0.6
Accident	CenteredC	Alternating	Max	Nominal	0.68624	0.00076	0.68776	0.70586	0.00413	5.4
Accident	OutC	Alternating	Max	Nominal	0.67948	0.00077	0.68102	0.69912	-0.00261	-3.4
Accident	In	Alternating	Max	Nominal	0.69075	0.00078	0.69231	0.71041	0.00868	11.1
Accident	InC	Alternating	Max	Nominal	0.69125	0.00080	0.69285	0.71095	0.00922	11.5
Accident	InC	Alternating	Max	Max	0.69234	0.00078	0.69390	0.71200	0.01027	13.2

Table 6.4.10-7 MOATA Plate Bundle - Basket Tolerance Evaluations

Fuel Tube Outer Diameter Tolerance	Fuel Tube Thickness Tolerance	Fuel Tube Height Tolerance	Fuel Basket Base Plate Tolerance	k_{eff}	σ	$k_{eff}+2\sigma$	k_s	Δk	$\Delta k_{eff}/\sigma$
Nominal	Nominal	Nominal	Nominal	0.69234	0.00078	0.69390	0.71200	--	--
Min	Nominal	Nominal	Nominal	0.68994	0.00077	0.69148	0.70958	-0.00242	-3.1
Max	Nominal	Nominal	Nominal	0.69108	0.00075	0.69258	0.71068	-0.00132	-1.8
Nominal	Min	Nominal	Nominal	0.69234	0.00078	0.69390	0.71200	--	--
Nominal	Max	Nominal	Nominal	0.67140	0.00077	0.67294	0.69104	-0.02096	-27.2
Nominal	Nominal	Min	Nominal	0.69146	0.00080	0.69306	0.71116	-0.00084	-1.0
Nominal	Nominal	Max	Nominal	0.69054	0.00079	0.69212	0.71022	-0.00178	-2.3
Nominal	Nominal	Nominal	Min	0.69152	0.00078	0.69308	0.71118	-0.00082	-1.1
Nominal	Nominal	Nominal	Max	0.69204	0.00079	0.69362	0.71172	-0.00028	-0.4
Max	Min	Min	Min	0.69326	0.00078	0.69482	0.71292	0.00092	1.2
Nominal	Min	Min	Min	0.69364	0.00077	0.69518	0.71328	0.00128	1.7
Min	Min	Min	Min	0.69024	0.00079	0.69182	0.70992	-0.00208	-2.6

Table 6.4.10-8 MOATA Plate Bundle - Fuel Tolerance Evaluations

Fuel Plate Width Tolerance	Fuel Plate Thickness Tolerance	Fuel Plate Clad Thickness Tolerance	Active Fuel Length Tolerance	Active Fuel Width Tolerance	Element Height Tolerance	Spacer Thickness Tolerance	Side Plate Thickness Tolerance	Side Plate Width Tolerance	k_{eff}	σ	$k_{eff}+2\sigma$	k_∞	Δk	$\Delta k_{eff}/\sigma$
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	0.69234	0.00078	0.69390	0.71200	--	--
Min	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	0.69017	0.00078	0.69173	0.70983	-0.00217	-2.8
Max	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	0.69105	0.00077	0.69259	0.71069	-0.00131	-1.7
Nominal	Min	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	0.69190	0.00078	0.69346	0.71156	-0.00044	-0.6
Nominal	Max	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	0.69192	0.00077	0.69346	0.71156	-0.00044	-0.6
Nominal	Nominal	Min	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	0.69424	0.00077	0.69578	0.71388	0.00188	2.4
Nominal	Nominal	Max	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	0.69150	0.00078	0.69306	0.71116	-0.00084	-1.1
Nominal	Nominal	Nominal	Min	Nominal	Nominal	Nominal	Nominal	Nominal	0.68998	0.00079	0.69156	0.70966	-0.00234	-3.0
Nominal	Nominal	Nominal	Max	Nominal	Nominal	Nominal	Nominal	Nominal	0.69153	0.00078	0.69309	0.71119	-0.00081	-1.0
Nominal	Nominal	Nominal	Nominal	Min	Nominal	Nominal	Nominal	Nominal	0.68240	0.00082	0.68404	0.70214	-0.00986	-12.0
Nominal	Nominal	Nominal	Nominal	Max	Nominal	Nominal	Nominal	Nominal	0.69920	0.00080	0.70080	0.71890	0.00690	8.6
Nominal	Nominal	Nominal	Nominal	Nominal	Fuel	Nominal	Nominal	Nominal	0.70756	0.00079	0.70914	0.72724	0.01524	19.3
Nominal	Nominal	Nominal	Nominal	Nominal	Min	Nominal	Nominal	Nominal	0.69029	0.00077	0.69183	0.70993	-0.00207	-2.7
Nominal	Nominal	Nominal	Nominal	Nominal	Max	Nominal	Nominal	Nominal	0.69220	0.00080	0.69380	0.71190	-0.00010	-0.1
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Min	Nominal	Nominal	0.67080	0.00076	0.67232	0.69042	-0.02158	-28.4
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Max	Nominal	Nominal	0.70952	0.00078	0.71108	0.72918	0.01718	22.0
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Water	Nominal	0.69518	0.00080	0.69678	0.71488	0.00288	3.6
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Min	Nominal	0.69087	0.00079	0.69245	0.71055	-0.00145	-1.8
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Max	Nominal	0.69185	0.00077	0.69339	0.71149	-0.00051	-0.7
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Min	0.69203	0.00075	0.69353	0.71163	-0.00037	-0.5
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Max	0.69179	0.00074	0.69327	0.71137	-0.00063	-0.9
Max	Nominal	Min	Nominal	Max	Fuel	Max	Nominal	Nominal	0.73925	0.00078	0.74081	0.75891	0.04691	60.1
Max	Nominal	Min	Nominal	Max	Fuel	Max	Water	Water	0.74205	0.00081	0.74367	0.76177	0.04977	61.4

Table 6.4.10-9 MOATA Plate Bundle - Moderator Density Variations

Set	Interior Moderator Density (g/cm^3)	Exterior Moderator Density (g/cm^3)	k_{eff}	σ	$k_{eff}+2\sigma$	k_s
H1	0.9998	0.0001	0.74285	0.00081	0.74447	0.76257
	0.9998	0.1	0.71116	0.00081	0.71278	0.73088
	0.9998	0.5	0.70785	0.00080	0.70945	0.72755
	0.9998	0.9998	0.70742	0.00081	0.70904	0.72714
H2	0.9998	0.0001	0.74285	0.00081	0.74447	0.76257
	0.975	0.0001	0.74337	0.00080	0.74497	0.76307
	0.95	0.0001	0.74073	0.00078	0.74229	0.76039
	0.9	0.0001	0.74275	0.00078	0.74431	0.76241
	0.8	0.0001	0.73741	0.00077	0.73895	0.75705
	0.6	0.0001	0.72186	0.00124	0.72434	0.74244
	0.4	0.0001	0.67919	0.00174	0.68267	0.70077
	0.2	0.0001	0.56690	0.00133	0.56956	0.58766
	0.1	0.0001	0.44132	0.00118	0.44368	0.46178
	0.0001	0.0001	0.19016	0.00057	0.19130	0.20940

Table 6.4.10-10 MOATA Plate Bundle - Maximum Reactivity Case Summary

# Casks	Condition	Description	k_{eff}	σ	$k_{eff}+2\sigma$	k_s
Infinite Array	Accident	Nominal configuration accident case	0.68207	0.00078	0.68363	0.70173
Infinite Array	Accident	Maximum reactivity material and shift case	0.69234	0.00078	0.69390	0.71200
Infinite Array	Accident	Maximum reactivity basket tolerance	0.69024	0.00079	0.69182	0.70992
Infinite Array	Accident	Maximum reactivity fuel tolerance	0.74205	0.00081	0.74367	0.76177
Infinite Array	Accident	Combined maximum reactivity configuration case	0.74285	0.00081	0.74447	0.76257
Infinite Array	Normal	Combined maximum reactivity configuration case	0.70622	0.00082	0.70786	0.72596
Single Cask	N/A	Single cask / inner shell reflected with water - maximum reactivity configuration	0.65594	0.00082	0.65758	0.67568

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                                   FREQUENCY FOR GENERATIONS  769 TO 1023
0.6577 TO 0.6612
0.6612 TO 0.6648
0.6648 TO 0.6683
0.6683 TO 0.6719
0.6719 TO 0.6754
0.6754 TO 0.6790     *
0.6790 TO 0.6825     *
0.6825 TO 0.6861     *
0.6861 TO 0.6896     ***
0.6896 TO 0.6931     *
0.6931 TO 0.6967     **
0.6967 TO 0.7002     **
0.7002 TO 0.7038     ***
0.7038 TO 0.7073     *********
0.7073 TO 0.7109     *******
0.7109 TO 0.7144     ***
0.7144 TO 0.7180     **********
0.7180 TO 0.7215     ************
0.7215 TO 0.7251     ******************
0.7251 TO 0.7286     *************
0.7286 TO 0.7322     *************
0.7322 TO 0.7357     ********
0.7357 TO 0.7393     *******
0.7393 TO 0.7428     *************
0.7428 TO 0.7464     ***************
0.7464 TO 0.7499     *********
0.7499 TO 0.7534     **************
0.7534 TO 0.7570     *****************
0.7570 TO 0.7605     *******
0.7605 TO 0.7641     ********
0.7641 TO 0.7676     *********
0.7676 TO 0.7712     ******
0.7712 TO 0.7747     ********
0.7747 TO 0.7783     **********
0.7783 TO 0.7818     ******
0.7818 TO 0.7854     *******
0.7854 TO 0.7889     ***
0.7889 TO 0.7925     *
0.7925 TO 0.7960
0.7960 TO 0.7996     ***
0.7996 TO 0.8031     ****
0.8031 TO 0.8067
0.8067 TO 0.8102     *
0.8102 TO 0.8137
0.8137 TO 0.8173
0.8173 TO 0.8208
0.8208 TO 0.8244
0.8244 TO 0.8279
```

6.6.14 High Fissile Mass LEU (32g ^{235}U per Plate) MTR Fuel Elements

This section contains a sample input file for the evaluation of high fissile mass LEU MTR fuel elements. The file contains partially loaded top and bottom baskets containing the high fissile mass LEU MTR fuel elements and filled (seven elements) intermediate baskets containing maximum reactivity HEU MTR fuel elements.

Figure 6.6.14-1 High Fissile Mass LEU MTR Sample Input

```
=CSAS25
LWT MTR INPUT FOR CASK MODEL - PLATES IN CLOSE & PLATES @ FULL PITCH
'MIN BASKET PLATE - COMMENT CARD REFERS TO NOMINAL PLATE SIZE
' TYPE A FUEL - FULL BASKETS
'     23 PLATES - 20 GRAM U-235 PER PLATE
'     0.123 CM PLATE THICKNESS; 6.6 CM FUEL WIDTH; 56 CM FUEL HEIGHT
'     HEU FUEL COMPOSITION 30 WT%U - 94 WT%235U
' TYPE B FUEL - FULL/PARTIAL BASKETS
'     23 PLATES - 32 GRAM U-235 PER PLATE
'     0.115 CM PLATE THICKNESS; 7.3 CM FUEL WIDTH; 56 CM FUEL HEIGHT
'     LEU FUEL COMPOSITION 75 WT%U - 25 WT%235U
'FUEL SHIFT AXIAL ALTERNATING
27GROUPNDF4  LATTICECELL
' TYPE B FUEL - FULL/PARTIAL BASKET FUEL MATERIAL
URANIUM  1 DEN=19.05 0.21915 293 92235 25 92238 75 END
AL       1 DEN=2.702 0.51503 293 END
' CLAD, MODERATOR, AND CASK MATERIALS
AL    2 1.0    293.0 END
H2O   3 1    293.0 END
AL    4 1.0    293.0 END
SS304 5 1.0    293.0 END
PB    6 1.0    293.0 END
H2O   7 1.E-20 293.0 END
H2O   8 1.E-20 293.0 END
H2O   9 1.0    293.0 END
' TYPE A FUEL - FULL BASKET FUEL MATERIAL
URANIUM  10 DEN=19.05 0.0364 293 92235 94 92238 6 END
AL       10 DEN=2.702 0.59889 293 END
' SPACER MATERIAL
AL    11 1.0    293.0 END
END COMP
SYMMSLABCELL 0.3917 0.075 1 3 0.115 2 END
' DANCOFF CORRECTION FACTOR FOR TYPE A FUEL- FULL BASKET FUEL DEFINITION
MORE DATA DAN(10)=0.5119  RES=10 SLAB 0.083 END MORE

READ PARAM TBA=10 RUN=YES PLT=NO GEN=803 NPG=1000 RND=ABCD1234 END PARAM
READ GEOM
'
' FUEL PLATE CELL UNITS - FULL BASKETS - TYPE A FUEL
'
UNIT 1
COM='MIDDLE FUEL PLATE CELL'
CUBOID 10 1 2P3.3000 2P0.0415 58 2
CUBOID 2 1 2P3.3000 2P0.0615 60 0.0
CUBOID 3 1 2P3.3000 2P0.1957 60 0.0
UNIT 2
COM='TOP FUEL PLATE CELL'
CUBOID 10 1 2P3.3000 2P0.0415 58 2
CUBOID 2 1 2P3.3000 2P0.0615 60 0.0
CUBOID 3 1 2P3.3000 0.0615 -0.1957 60 0.0
UNIT 3
COM='BOTTOM FUEL PLATE CELL'
CUBOID 10 1 2P3.3000 2P0.0415 58 2
CUBOID 2 1 2P3.3000 2P0.0615 60 0.0
CUBOID 3 1 2P3.3000 0.1957 -0.0615 60 0.0
'
UNIT 4
COM='SIDE PLATE'
CUBOID 2 1 2P0.2 2P3.75 60 0.0
'
'FUEL PLATE CELL UNITS - FULL/PARTIAL BASKET -  TYPE B FUEL
'
UNIT 5
COM='MIDDLE FUEL PLATE CELL'
CUBOID 1 1 2P3.6500 2P0.0375 56.7 0.7
CUBOID 2 1 2P3.6500 2P0.0575 57.4 0.0
CUBOID 3 1 2P3.6500 2P0.19585 57.4 0.0
UNIT 6
COM='TOP FUEL PLATE CELL'
CUBOID 1 1 2P3.6500 2P0.0375 56.7 0.7
CUBOID 2 1 2P3.6500 2P0.0575 57.4 0.0
CUBOID 3 1 2P3.6500 0.0575 -0.19585 57.4 0.0
UNIT 7
COM='BOTTOM FUEL PLATE CELL'
CUBOID 1 1 2P3.6500 2P0.0375 56.7 0.7
CUBOID 2 1 2P3.6500 2P0.0575 57.4 0.0
CUBOID 3 1 2P3.6500 0.19585 -0.0575 57.4 0.0
'
UNIT 8
COM='SIDE PLATE'
CUBOID 2 1 2P0.2 2P3.75 57.4 0.0
'
' UNITS 10 TO 100 ELEMENTES SHIFTED DOWN IN BASKET
'
'
' BASKET CENTER ROW ARRAY ELEMENTS
'
UNIT 10
COM='FUEL PLATE ARRAY - PLATES IN 5/16 IN. WEB CENTER'
ARRAY  1 -3.3000 -4.3688 0.0
```

```
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 0.0
HOLE   4  4.1687 0.0 0.0
REPLICATE 5 1 2R0.3556 4R0.0 1
UNIT 11
COM='FUEL ARRAY PLATES IN 5/16 IN. WEB RIGHT'
ARRAY  1 -3.9686 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 0.0
HOLE   4  4.1687 0.0 0.0
REPLICATE 5 1 2R0.3556 4R0.0 1
UNIT 12
COM='FUEL ARRAY PLATES IN 5/16 IN. WEB LEFT'
ARRAY  1 -2.6314 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 0.0
HOLE   4  4.1687 0.0 0.0
REPLICATE 5 1 2R0.3556 4R0.0 1
'
' BASKET TOP ROW ARRAY ELEMENTS
'
UNIT 20
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON RIGHT -  TOP STACK'
ARRAY  1 -2.6314 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 0.0
HOLE   4  4.1687 0.0 0.0
REPLICATE 5 1 0.3048 5R0.0 1
UNIT 21
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON LEFT  - TOP STACK'
ARRAY  1 -3.9686 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 0.0
HOLE   4  4.1687 0.0 0.0
REPLICATE 5 1 0.0 0.3048 4R0.0 1
'
' BASKET BOTTOM ROW ARRAY ELEMENTS
'
UNIT 30
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON RIGHT -  BOTTOM STACK'
ARRAY  1 -2.6314 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 0.0
HOLE   4  4.1687 0.0 0.0
REPLICATE 5 1 0.3048 5R0.0 1
UNIT 31
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON LEFT - BOTTOM STACK'
ARRAY  1 -3.9686 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 0.0
HOLE   4  4.1687 0.0 0.0
REPLICATE 5 1 0.0 0.3048 4R0.0 1
'
' CONSTRUCTION OF BASKET ROWS
'
UNIT 40
COM='2 UNIT ARRAY WITH 1/4 IN. PLATE ON TOP AND SIDES'
ARRAY 2 -9.0428 -4.3688 0.0
REPLICATE 5 1 3R0.3048 0.0 2R0.0 1
UNIT 41
COM='3 UNIT ARRAY WITH REST OF 5/16 WEB'
ARRAY 3 -14.1738 -4.3688 0.0
REPLICATE 5 1 2R0.3556 2R0.7112 2R0.0 1
UNIT 42
COM='2 UNIT ARRAY WITH 1/4 IN. PLATE ON BOTTOM AND SIDES'
ARRAY 4 -9.0428 -4.3688 0.0
REPLICATE 5 1 2R0.3048 0.0 0.3048 2R0.0 1
'
' BASKET UNIT
'
UNIT 50
COM='7 MTR ELEMENTS IN THE LWT'
CYLINDER 3 1 17.0500 73.152 0.0
HOLE 40 0.0 +9.4489 0.0
HOLE 41 0.0  0.0    0.0
HOLE 42 0.0 -9.4489 0.0
CYLINDER 5 1 18.8913   73.152 -1.27
CYLINDER 6 1 33.4963   73.152 -1.27
CYLINDER 5 1 36.5443   73.152 -1.27
CYLINDER 7 1 49.2443   73.152 -1.27
CYLINDER 5 1 49.8539   73.152 -1.27
CUBOID   8 1 4P49.8539 73.152 -1.27
'
' UNITS 110 TO 150 ELEMENTES SHIFTED UP IN BASKET
'
' BASKET CENTER ROW ARRAY ELEMENTS
'
UNIT 110
COM='FUEL PLATE ARRAY - PLATES IN 5/16 IN. WEB CENTER'
ARRAY  1 -3.3000 -4.3688 13.152
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 13.152
HOLE   4  4.1687 0.0 13.152
REPLICATE 5 1 2R0.3556 4R0.0 1
UNIT 111
COM='FUEL ARRAY PLATES IN 5/16 IN. WEB RIGHT'
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ARRAY  1 -3.9686 -4.3688 13.152
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 13.152
HOLE   4  4.1687 0.0 13.152
REPLICATE 5 1 2R0.3556 4R0.0 1
UNIT 112
COM='FUEL ARRAY PLATES IN 5/16 IN. WEB LEFT'
ARRAY  1 -2.6314 -4.3688 13.152
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 13.152
HOLE   4  4.1687 0.0 13.152
REPLICATE 5 1 2R0.3556 4R0.0 1
'
' BASKET TOP ROW ARRAY ELEMENTS
'
UNIT 120
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON RIGHT -  TOP STACK'
ARRAY  1 -2.6314 -4.3688 13.152
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 13.152
HOLE   4  4.1687 0.0 13.152
REPLICATE 5 1 0.3048 5R0.0 1
UNIT 121
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON LEFT - TOP STACK'
ARRAY  1 -3.9686 -4.3688 13.152
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 13.152
HOLE   4  4.1687 0.0 13.152
REPLICATE 5 1 0.0 0.3048 4R0.0 1
'
' BASKET BOTTOM ROW ARRAY ELEMENTS
'
UNIT 130
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON RIGHT -  BOTTOM STACK'
ARRAY  1 -2.6314 -4.3688 13.152
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 13.152
HOLE   4  4.1687 0.0 13.152
REPLICATE 5 1 0.3048 5R0.0 1
UNIT 131
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON LEFT - BOTTOM STACK'
ARRAY  1 -3.9686 -4.3688 13.152
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   4 -4.1687 0.0 13.152
HOLE   4  4.1687 0.0 13.152
REPLICATE 5 1 0.0 0.3048 4R0.0 1
'
' CONSTRUCTION OF BASKET ROWS
'
UNIT 140
COM='2 UNIT ARRAY WITH 1/4 IN. PLATE ON TOP AND SIDES'
ARRAY 5 -9.0428 -4.3688 0.0
REPLICATE 5 1 3R0.3048 0.0 2R0.0 1
UNIT 141
COM='3 UNIT ARRAY WITH REST OF 5/16 WEB'
ARRAY 6 -14.1738 -4.3688 0.0
REPLICATE 5 1 2R0.3556 2R0.7112 2R0.0 1
UNIT 142
COM='2 UNIT ARRAY WITH 1/4 IN. PLATE ON BOTTOM AND SIDES'
ARRAY 7 -9.0428 -4.3688 0.0
REPLICATE 5 1 2R0.3048 0.0 0.3048 2R0.0 1
'
' BASKET UNIT
'
UNIT 150
COM='7 MTR ELEMENTS IN THE LWT'
CYLINDER 3 1 17.0500 73.152 0.0
HOLE 140 0.0 +9.4489 0.0
HOLE 141 0.0  0.0   0.0
HOLE 142 0.0 -9.4489 0.0
CYLINDER 5 1 18.8913   73.152 -1.27
CYLINDER 6 1 33.4963   73.152 -1.27
CYLINDER 5 1 36.5443   73.152 -1.27
CYLINDER 7 1 49.2443   73.152 -1.27
CYLINDER 5 1 49.8539   73.152 -1.27
CUBOID   8 1 4P49.8539 73.152 -1.27
'
' UNITS 210 TO 250 ELEMENTS SHIFTED DOWN IN BASKET - NO FUEL IN CENTER ROW
'
' BASKET CENTER ROW ARRAY ELEMENTS
'
UNIT 210
COM='FUEL PLATE ARRAY - PLATES IN 5/16 IN. WEB CENTER'
CYLINDER 3 1 3.81 73.152 0.0
CYLINDER 11 1 4.1275 73.152 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
REPLICATE 5 1 2R0.3556 4R0.0 1
UNIT 211
COM='FUEL ARRAY PLATES IN 5/16 IN. WEB RIGHT'
CYLINDER 3 1 3.81 73.152 0.0
CYLINDER 11 1 4.1275 73.152 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
REPLICATE 5 1 2R0.3556 4R0.0 1
UNIT 212
COM='FUEL ARRAY PLATES IN 5/16 IN. WEB LEFT'
CYLINDER 3 1 3.81 73.152 0.0
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CYLINDER 11 1 4.1275 73.152 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
REPLICATE 5 1 2R0.3556 4R0.0 1
'
' BASKET TOP ROW ARRAY ELEMENTS
'
UNIT 220
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON RIGHT -  TOP STACK'
ARRAY  11 -3.3314 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   8 -4.1687 0.0 0.0
HOLE   8  4.1687 0.0 0.0
REPLICATE 5 1 0.3048 5R0.0 1
UNIT 221
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON LEFT  - TOP STACK'
ARRAY  11 -3.9686 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   8 -4.1687 0.0 0.0
HOLE   8  4.1687 0.0 0.0
REPLICATE 5 1 0.0 0.3048 4R0.0 1
'
' BASKET BOTTOM ROW ARRAY ELEMENTS
'
UNIT 230
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON RIGHT -  BOTTOM STACK'
ARRAY  11 -3.3314 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   8 -4.1687 0.0 0.0
HOLE   8  4.1687 0.0 0.0
REPLICATE 5 1 0.3048 5R0.0 1
UNIT 231
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON LEFT - BOTTOM STACK'
ARRAY  11 -3.9686 -4.3688 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   8 -4.1687 0.0 0.0
HOLE   8  4.1687 0.0 0.0
REPLICATE 5 1 0.0 0.3048 4R0.0 1
'
' CONSTRUCTION OF BASKET ROWS
'
UNIT 240
COM='2 UNIT ARRAY WITH 1/4 IN. PLATE ON TOP AND SIDES'
ARRAY 12 -9.0428 -4.3688 0.0
REPLICATE 5 1 3R0.3048 0.0 2R0.0 1
UNIT 241
COM='3 UNIT ARRAY WITH REST OF 5/16 WEB'
ARRAY 13 -14.1738 -4.3688 0.0
REPLICATE 5 1 2R0.3556 2R0.7112 2R0.0 1
UNIT 242
COM='2 UNIT ARRAY WITH 1/4 IN. PLATE ON BOTTOM AND SIDES'
ARRAY 14 -9.0428 -4.3688 0.0
REPLICATE 5 1 2R0.3048 0.0 0.3048 2R0.0 1
'
' BASKET UNIT
'
UNIT 250
COM='7 MTR ELEMENTS IN THE LWT'
CYLINDER 3 1 17.0500 73.152 0.0
HOLE 240 0.0 +9.4489 0.0
HOLE 241 0.0  0.0    0.0
HOLE 242 0.0 -9.4489 0.0
CYLINDER 5 1 18.8913   73.152 -1.27
CYLINDER 6 1 33.4963   73.152 -1.27
CYLINDER 5 1 36.5443   73.152 -1.27
CYLINDER 7 1 49.2443   73.152 -1.27
CYLINDER 5 1 49.8539   73.152 -1.27
CUBOID   8 1 4P49.8539 73.152 -1.27
'
' UNITS 310 TO 350 ELEMENTS SHIFTED UP IN BASKET - NO FUEL IN CENTER ROW
'
' BASKET CENTER ROW ARRAY ELEMENTS
'
UNIT 310
COM='FUEL PLATE ARRAY - PLATES IN 5/16 IN. WEB CENTER'
CYLINDER 3 1 3.81 73.152 0.0
CYLINDER 11 1 4.1275 73.152 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
REPLICATE 5 1 2R0.3556 4R0.0 1
UNIT 311
COM='FUEL ARRAY PLATES IN 5/16 IN. WEB RIGHT'
CYLINDER 3 1 3.81 73.152 0.0
CYLINDER 11 1 4.1275 73.152 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
REPLICATE 5 1 2R0.3556 4R0.0 1
UNIT 312
COM='FUEL ARRAY PLATES IN 5/16 IN. WEB LEFT'
CYLINDER 3 1 3.81 73.152 0.0
CYLINDER 11 1 4.1275 73.152 0.0
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
REPLICATE 5 1 2R0.3556 4R0.0 1
'
' BASKET TOP ROW ARRAY ELEMENTS
'
UNIT 320
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON RIGHT -  TOP STACK'
ARRAY  11 -3.3314 -4.3688 15.752
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CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   8 -4.1687 0.0 15.752
HOLE   8  4.1687 0.0 15.752
REPLICATE 5 1 0.3048 5R0.0 1
UNIT 321
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON LEFT - TOP STACK'
ARRAY  11 -3.9686 -4.3688 15.752
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   8 -4.1687 0.0 15.752
HOLE   8  4.1687 0.0 15.752
REPLICATE 5 1 0.0 0.3048 4R0.0 1
'
' BASKET BOTTOM ROW ARRAY ELEMENTS
'
UNIT 330
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON RIGHT -  BOTTOM STACK'
ARRAY  11 -3.3314 -4.3688 15.752
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   8 -4.1687 0.0 15.752
HOLE   8  4.1687 0.0 15.752
REPLICATE 5 1 0.3048 5R0.0 1
UNIT 331
COM='FUEL ARRAY WITH HALF OF 1/4 IN. PLATE ON LEFT - BOTTOM STACK'
ARRAY  11 -3.9686 -4.3688 15.752
CUBOID 3 1 2P4.3688 2P4.3688 73.152 0.0
HOLE   8 -4.1687 0.0 15.752
HOLE   8  4.1687 0.0 15.752
REPLICATE 5 1 0.0 0.3048 4R0.0 1
'
' CONSTRUCTION OF BASKET ROWS
'
UNIT 340
COM='2 UNIT ARRAY WITH 1/4 IN. PLATE ON TOP AND SIDES'
ARRAY 15 -9.0428 -4.3688 0.0
REPLICATE 5 1 3R0.3048 0.0 2R0.0 1
UNIT 341
COM='3 UNIT ARRAY WITH REST OF 5/16 WEB'
ARRAY 16 -14.1738 -4.3688 0.0
REPLICATE 5 1 2R0.3556 2R0.7112 2R0.0 1
UNIT 342
COM='2 UNIT ARRAY WITH 1/4 IN. PLATE ON BOTTOM AND SIDES'
ARRAY 17 -9.0428 -4.3688 0.0
REPLICATE 5 1 2R0.3048 0.0 0.3048 2R0.0 1
'
' BASKET UNIT
'
UNIT 350
COM='7 MTR ELEMENTS IN THE LWT'
CYLINDER 3 1 17.0500 73.152 0.0
HOLE 340 0.0 +9.4489 0.0
HOLE 341 0.0  0.0    0.0
HOLE 342 0.0 -9.4489 0.0
CYLINDER 5 1 18.8913   73.152 -1.27
CYLINDER 6 1 33.4963   73.152 -1.27
CYLINDER 5 1 36.5443   73.152 -1.27
CYLINDER 7 1 49.2443   73.152 -1.27
CYLINDER 5 1 49.8539   73.152 -1.27
CUBOID   8 1 4P49.8539 73.152 -1.27
'
' CASK LID AND BOTTOM STRUCTURE
'
UNIT 460
COM='SIMPLIFIED LID STRUCTURE NAC-LWT'
CYLINDER 5 1 36.5188   13.6775 -14:1351
CYLINDER 8 1 49.8539   13.6775 -14.1351
CUBOID   8 1 4P49.8539 13.6775 -14.1351
UNIT 461
COM='SIMPLIFIED CASK BOTTOM STRUCTURE NAC-LWT'
CYLINDER 6 1 26.3525 2P3.81
CYLINDER 5 1 36.6188 +13.36 -12.7
CYLINDER 8 1 49.8539 +13.36 -12.7
CUBOID   8 1 4P49.8539 +13.36 -12.7
UNIT 462
COM='THIN TOP AND BOTTOM SHELL OF NEUTRON SHIELD - SUBTRACTED FROM LID MODEL'
CYLINDER 5 1 49.8539 0.61 0.0
CUBOID   8 1 4P49.8539 0.61 0.0
'
' STACK OF BASKETS WITH CASK LID AND BOTTOM
'
GLOBAL UNIT 470
COM='STACK OF 6 BASKETS IN CASK WITH LID AND BOTTOM'
ARRAY  40  -49.8539 -49.8539 0.0
END GEOM
READ ARRAY
'
' ARRAYS FOR TYPE A BASKETS
'
' FUEL ELEMENT PLATE ARRAY
'
ARA=1 NUX=1 NUY=23 NUZ=1 FILL 3 21R1 2 END FILL
'
' ARRAYS OF BASKET OPENINGS (TOP, MIDDLE, BOTTOM)
' PLATES AT BOTTOM OF OPENING
'
ARA=2 NUX=2 NUY=1 NUZ=1 FILL 20 21 END FILL
ARA=3 NUX=3 NUY=1 NUZ=1 FILL 12 10 11 END FILL
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ARA=4 NUX=2 NUY=1 NUZ=1 FILL 30 31 END FILL
'
' ARRAYS OF BASKET OPENINGS (TOP, MIDDLE, BOTTOM)
' PLATES AT TOP OF OPENING
'
ARA=5 NUX=2 NUY=1 NUZ=1 FILL 120 121 END FILL
ARA=6 NUX=3 NUY=1 NUZ=1 FILL 112 110 111 END FILL
ARA=7 NUX=2 NUY=1 NUZ=1 FILL 130 131 END FILL
'
' ARRAYS FOR TYPE B  BASKETS
'
ARA=11 NUX=1 NUY=23 NUZ=1 FILL 7 21R5 6 END FILL
'
' ARRAYS OF BASKET OPENINGS (TOP, MIDDLE, BOTTOM)
' PLATES AT BOTTOM OF OPENING
'
ARA=12 NUX=2 NUY=1 NUZ=1 FILL 220 221 END FILL
ARA=13 NUX=3 NUY=1 NUZ=1 FILL 212 210 211 END FILL
ARA=14 NUX=2 NUY=1 NUZ=1 FILL 230 231 END FILL
'
' ARRAYS OF BASKET OPENINGS (TOP, MIDDLE, BOTTOM)
' PLATES AT TOP OF OPENING
'
ARA=15 NUX=2 NUY=1 NUZ=1 FILL 320 321 END FILL
ARA=16 NUX=3 NUY=1 NUZ=1 FILL 312 310 311 END FILL
ARA=17 NUX=2 NUY=1 NUZ=1 FILL 330 331 END FILL
'
' ARRAY OF BASKETS WITH LID AND BOTTOM
'
ARA=40 NUX=1 NUY=1 NUZ=10 FILL 461 462 350 50 150 50 150 250 462 460 END FILL
END ARRAY
READ BOUNDS ALL=MIR END BOUNDS
READ START NST=0 XSM=-17 XSP=17 YSM=-17 YSP=17 ZSM=25 ZSP=475  END BOUNDS
READ PLOT
TTL='X-Y PLOT OF CENTER ELEMENT - FUEL ELEVATION'
SCR=YES PIC=MAT LPI=10
UAX=1.0 VDN=-1.0 NAX=1500
XUL=-5.0 YUL=5.0 ZUL=150.0
XLR=5.0 YLR=-5.0 ZLR=150.0 END
TTL='X-Y PLOT OF BASKET - FUEL ELEVATION'
UAX=1.0 VDN=-1.0 NAX=1500
XUL=-17.0 YUL=17.0 ZUL=50.0
XLR=17.0 YLR=-17.0 ZLR=50.0 END
TTL='X-Y PLOT OF BASKET - FUEL ELEVATION - MIDDLE BASKET'
UAX=1.0 VDN=-1.0 NAX=1500
XUL=-17.0 YUL=17.0 ZUL=150.0
XLR=17.0 YLR=-17.0 ZLR=150.0 END
TTL='X-Y PLOT OF CASK - FUEL ELEVATION'
UAX=1.0 VDN=-1.0 NAX=1500
XUL=-65.0 YUL=65.0 ZUL=150.0
XLR=65.0 YLR=-65.0 ZLR=150.0 END
TTL='Y-Z (X=0) PLOT OF MIDDLE BASKET - CENTER SECTION'
VAX=1.0 WDN=-1.0
XUL=0.0 YUL=-5.0 ZUL=155.0
XLR=0.0 YLR=5.0 ZLR=150.0 END
TTL='Y-Z (X=0) PLOT OF MIDDLE BASKET - CENTER FUEL ELEMENT'
VAX=1.0 WDN=-1.0
XUL=0.0 YUL=-5.0 ZUL=180.0
XLR=0.0 YLR=5.0 ZLR=100.0 END
TTL='Y-Z (X=-2) PLOT OF MIDDLE BASKET'
VAX=1.0 WDN=-1.0
XUL=-2.0 YUL=-15.0 ZUL=180
XLR=-2.0 YLR=15.0 ZLR=100.00 END
TTL='Y-Z (X=-2) PLOT OF CASK - R=17.0'
LPI=5 NAX=1000
VAX=1.0 WDN=-1.0
XUL=-2.0 YUL=-17.0 ZUL=502.0
XLR=-2.0 YLR=17.0 ZLR=-1.0 END
TTL='Y-Z (X=-2) PLOT OF CASK - R=51.0'
VAX=1.0 WDN=-1.0
XUL=-2.0 YUL=-51.0 ZUL=502.0
XLR=-2.0 YLR=51.0 ZLR=-1.0 END
END PLOT
END DATA
END
```

Chapter 7

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 or Alternate 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 470 g, and not exceeding 640 g, 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 (>470 g ^{235}U) will not be loaded with fuel elements (or fuel plates) in basket opening positions 1, 2 and 3, a spacer shall be installed in these three basket openings. The spacer, shown in Figure 1.2-18, is of sufficient height and diameter to ensure that fuel assemblies are prevented from being placed in these openings. The capacity limitation of a maximum of four MTR fuel assemblies is in effect even if a single LEU MTR fuel assembly having >470 g ^{235}U is to be loaded.

5. 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.

6. 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 2,775 cm^2 per package.

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 470 g ^{235}U shall be governed by the loading restrictions in item 4 of Section 7.1.5.1, and 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 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. (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.
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.
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.