January 2024

Revision 24A

NAC-LWT

Legal Weight Truck Cask System

SAFETY ANALYSIS REPORT

Initial Submittal
LANL MOX

NON-PROPRIETARY VERSION

Docket No. 71-9225

NAC INTERNATIONAL

Atlanta Corporate Headquarters: 3930 East Jones Bridge Road, Norcross, Georgia 30092 USA
Phone 770-447-1144, Fax 770-447-1797, www.nacintl.com

Enclosure 1

No. 71-9225 for NAC-LWT Cask

Proposed Changes for Revision 74 of Certificate of Compliance

LANL MOX Fuel

NAC-LWT SAR, Revision 24A

January 2024

CoC Sections (revised)

CoC Page 4 of 34

5.(a)(3)(ii) Drawings (continued)

315-40-188, Rev 1P, LWT TRANSPORT CASK SHIPPING CONFIGURATION, LANL MOX

315-40-189, Rev 1P, TRANSFER TUBE DETAILS, LANL MOX

CoC Sections (new)

CoC Page 20 of 34

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

(xxiv) LANL MOX Fuel Rods

Parameter	PNNL	EXXON	UO_2	ROD 1063	530-000	NIS5
Max. rod OD (inch)	0.565	0.451	0.229	0.55	0.63	0.5
Min. wall thick. (inch)	0.035	0.035	0.015	0.015	0.015	0.015
Rod material	Zr Alloy	Zr Alloy	SS304	Zr Alloy	Zr Alloy	SS316
Max. active length (inch)	35.6	70	36.1	47.913	18	13.5
Max. pellet OD (inch)	0.486	0.372	0.1988	0.48	0.56	0.31
Max. # of rods per transfer tube	4	2	8	3	1	3
Max. # of tubes per cask	16	16	16	12	1	16
Fuel form	Oxide	Oxide	Oxide	Oxide	Oxide or Carbide	Carbide
^{235}U wt%	0.712	0.712	94	0	0	94
^{240}Pu wt%[1]	16	16	0	10	10	4
Pu wt%	5.36	6.31	0	100	100	20
U-235 (g/rod)	6.76	7.71	159.9	0	0	159.58
U (g/rod)	949.85	1083.44	170.11	0	0	169.76
Pu (g/rod)	56.29	76.35	0	1378.77	922.01	42.38
Total U/Pu (g/rod)	1006.14	1159.79	170.11	1378.77	922.01	212.14

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[1] Fissile Pu-239 and Pu-241 comprise the remaining plutonium. A 9 to 1 ratio of Pu-239 to Pu-241 is used.

CoC Page 31 of 34

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

(xxv) For LANL MOX Fuel Rods, as described in Item 5.(b)(1)(xxiv):

Up to sixteen (16) transfer tubes filled with LANL MOX Fuel Rods. Transfer Tubes must be loaded in the PWR/BWR transport can assembly including the Divider Assembly. A Transfer Tube spacer is required at the top and bottom end of the tube. Transfer Tube spacers may be used to separate contents but are not required. Different LANL MOX fuel types may be loaded in the same package but only one fuel type may be loaded into any one Transfer Tube. Empty Transfer Tubes without spacers may be loaded. The maximum total heat load per cask is limited to 25 watts.

CoC Page 32 of 34

5.(c) Criticality Safety Index

For, LANL MOX Fuel Rods described in 5.(b)(1)(xxiv) and limited in 5.(b)(2) (xxv)	25.0

Enclosure 2

No. 71-9225 for NAC-LWT Cask

List of Calculations

NAC-LWT SAR, Revision 24A

January 2024

List of Calculations, NAC-LWT SAR, Revision 24A

Enclosure 1 Contents:

1. 50077-2002 R0
2. 50077-6001 R1

CALCULATIONS WITHHELD IN THEIR ENTIRETY PER 10 CFR 2.390

Enclosure 3

No. 71-9225 for NAC-LWT Cask

List of SAR Changes

NAC-LWT SAR, Revision 24A

January 2024

List of SAR Changes, NAC-LWT SAR, Revision 24A

Chapter 1

- Page 1-ii, updated List of Figures where indicated to reflect changes in the chapter.
- Page 1-iii, updated List of Tables where indicated to reflect changes in the chapter.
- Page 1-vi, updated drawing where indicated to reflect changes in the SAR.
- Page 1-1, modified and added a bullet near the middle of the page where indicated.
- Page 1-2, modified text near the bottom of the embedded table and paragraph below embedded table where indicated.
- Page 1-3, text flow changes.
- Page 1-6, added new bullet near the top of the page where indicated.
- Page 1-7, text flow changes.
- Page 1-10, added text at the end of Table 1.1-1 near the top of the page where indicated.
- Page 1.1-2, modified and added bullets near the top of the page where indicated.
- Page 1.1-4, added paragraph at the bottom of the page where indicated.
- Page 1.2-5, added text in Item 4 in Section 1.2.3 where indicated.
- Page 1.2-7, added Item 28 at the end of Section 1.2.3 where indicated.
- Pages 1.2-8 thru 1.2-11, text flow changes.
- Page 1.2-22, added new Section 1.2.3.18.
- Pages 1.2-47, added new Figure 1.2.3-25.
- Pages 1.2-48 thru 1.2-67, text flow changes.
- Page 1.2-68, added new Table 1.2-20.

Chapter 2

- Pages 2-iii, modified Table of Contents to reflect changes in the chapter where indicated.
- Pages 2-iv, modified Table of Contents to reflect changes in the chapter where indicated.
- Pages 2-v thru vi, text flow changes.
- Pages 2-ix, modified Table of Contents to reflect changes in the chapter where indicated.
- Page 2.2.1-3, added row to Table 2.2.1-1 where indicated.
- Page 2.2.1-5, added two rows in Table 2.2.1-2 where indicated.
- Page 2.6.12-2, added text near top of page where indicated.
- Page 2.6.12-147 thru 2.6.12-150, added new Section 2.6.12.18 where indicated.
- Page 2.6.12-151, added text to Section 2.6.12.19 where indicated.
- Page 2.7.7-110 thru 2.7.7-112, added new Section 2.7.7.20 where indicated.

Chapter 3

- Page 3.1-2, added text near middle of page where indicated.
- Page 3.1-3, text flow changes.
- Page 3.4-63, revised title of Section 3.4.4.7 and created new Subsection for “Maximum Internal Pressure for 16 PWR MOX/UO2 Fuel Rods in a Rod Holder”.
- Page 3.4-64, added Subsection 3.4.4.7.2 near middle of page where indicated.
- Page 3.4-65 thru 3.4-66, text flow changes.

Chapter 4

- No changes.

Chapter 5

- Page 5-4 thru 5-5, added paragraph at the end of Section 5 where indicated.
- Page 5.1.1-2, added bullet near the top of the page in Section 5.1.1 where indicated.
- Page 5.1.1-15, added text to the end of Table 5.1.1-1 where indicated.

Chapter 6

- Page 6-ii, 6-viii and 6-xix, updated Table of Contents to reflect changes in the chapter where indicated.
- Page 6-1, modified text near the end of the first paragraph in Section 6 where indicated.
- Page 6-2, added row to the bottom of the embedded table in Section 6 where indicated.
- Page 6.1-6 thru 6.1-7, added paragraph to the bottom of the page at the end of Section 6.1 where indicated.
- Page 6.2-1, added text near the end of the first paragraph where indicated.
- Page 6.7.7-1 thru 6.7.7-13, added new Section 6.7.7 where indicated.

Chapter 7

- Page 7-ii, updated Table of Contents to reflect changes in the chapter where indicated.
- Page 7.1-94 thru 7.1-98, added new Procedure 7.1.22.
- Page 7.2-18 thru 7.1-20, added new Procedure 7.2.9.

Chapter 8

- No changes.

Chapter 9

- No changes.

Enclosure 4

No. 71-9225 for NAC-LWT Cask

List of Drawing Changes

NAC-LWT SAR, Revision 24A

January 2024

List of Drawing Changes, NAC-LWT SAR, Revision 24A

315-40-188, LWT TRANSPORT CASK SHIPPING CONFIGURATION, LANL MOX, Rev 0P

Initial Issue

315-40-188, LWT TRANSPORT CASK SHIPPING CONFIGURATION, LANL MOX, Rev 1P

[redacted]

315-40-188, LWT TRANSPORT CASK SHIPPING CONFIGURATION, LANL MOX, Rev 0NP

Initial Issue

315-40-189, TRANSFER TUBE DETAILS, LANL MOX, Rev 0P

Initial Issue

315-40-189, TRANSFER TUBE DETAILS, LANL MOX, Rev 1P

[redacted]

315-40-189, TRANSFER TUBE DETAILS, LANL MOX, Rev 0NP

Initial Issue

Enclosure 5

No. 71-9225 for NAC-LWT Cask

List of Effective pages and

NAC-LWT SAR, Revision 24A

January 2024

January 2024

Revision 24A

NAC-LWT

Legal Weight Truck Cask System

SAFETY ANALYSIS REPORT

Volume 1 of 3

NON-PROPRIETARY VERSION

Docket No. 71-9225

NAC INTERNATIONAL

Atlanta Corporate Headquarters: 3930 East Jones Bridge Road, Norcross, Georgia 30092 USA
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315-40-191		Rev 2P Rev 0NP	WESF Capsules Basket Assembly, Zeno
315-40-192		Rev 2P Rev 0NP	WESF Capsules Container Assembly, Zeno
315-40-193		Rev 1P Rev 0NP	LWT Lid Spacer, WESF Capsules, Zeno
315-40-195		Rev 1P Rev 0NP	LWT Transport Cask Shipping Configuration, BUP-500, Zeno
315-40-196		Rev 2P Rev 0NP	BUP-500 Basket Assembly, Zeno
315-40-197		Rev 1P Rev 0NP	BUP-500 Cavity Spacer, Zeno
315-40-188	Sheets 1 – 2	Rev 1P Rev 0NP	LWT Transport Cask Shipping Configuration, LANL MOX
315-40-189	Sheets 1 – 3	Rev 1P Rev 0NP	Transfer Tube Details, LANL MOX

1 GENERAL INFORMATION

This chapter of the NAC International, Legal Weight Truck spent fuel shipping cask (NAC-LWT) Safety Analysis Report (SAR) presents a general introduction to, and description of, the NAC-LWT cask. Terminology used throughout this report is presented in Table 1.1-1.

Shipment of the NAC-LWT cask by truck, ISO container, and/or by railcar, as a Type B(U)F-96 package, as defined in 10 CFR 71.4, is authorized for the following contents:

- PWR and BWR fuel assemblies[1];
- MTR fuel assemblies and plates;
- DIDO fuel assemblies;
- metallic fuel rods;
- 25 high burnup PWR and BWR fuel rods (including up to 14 fuel rods classified as damaged)[2];
- 16 PWR MOX fuel rods (or mixed load of up to 16 PWR MOX and UO_2 PWR fuel rods) and up to 9 burnable poison rods (BPRs);
- TRIGA fuel elements and TRIGA fuel cluster rods;
- General Atomics (GA) High-Temperature Gas-Cooled Reactor (HTGR) and Reduced-Enrichment Research and Test Reactor (RERTR) Irradiated Fuel Materials (IFM);
- up to 700 PULSTAR fuel elements;
- spiral fuel assemblies;
- MOATA plate bundles;
- up to eight (8) SLOWPOKE Fuel Canisters;
- up to eighteen (18) NRU or NRX Fuel Assemblies (or equivalent number of fuel rods);
- up to eighteen (18) NRU or NRX caddies loaded with EFN rods (Enriched Fast Neutron) rods, Booster rods and Mo-99 (“Moly Targets”);
- HEUNL;
- One SLOWPOKE fuel core;
- Up to eighteen (18) WESF capsules or up to two (2) BUP 500 capsules; and
- up to sixteen (16) transfer tubes filled with LANL MOX Fuel Rods

The authorized contents previously listed, except for HEUNL, include both irradiated and unirradiated forms of the materials.

Irradiated hardware is also authorized to be shipped in the NAC-LWT cask by truck, ISO container, and/or by railcar, as a Type B(U)F-96 package, as defined in 10 CFR 71.4. Irradiated hardware is defined as solid, irradiated and contaminated fuel assembly structural or reactor internal component hardware, which may include fissile material, provided the quantity of fissile

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[1] NAC-LWT casks containing PWR and BWR fuel assemblies are to be transported on an open trailer with a personnel barrier.

[2] PWR and BWR fuel rods may be transported in either a fuel assembly lattice (skeleton) or in a fuel rod insert. The fuel rod insert may contain PWR instrument/guide tubes and BWR water/inert rods in addition to the fuel rods.

material does not exceed a Type A quantity and does not exceed the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c).

Shipment of the NAC-LWT cask by truck, ISO container, and/or by railcar, as a Type B(M)-96 package, as defined in 10 CFR 71.4, is also authorized for the following contents:

- up to 300 Tritium Producing Burnable Absorber Rods (TPBARs), of which two can be prefailed; and
- up to 55 TPBARs segmented during post-irradiation examination (PIE), including segmentation debris.

In accordance with 10 CFR 71.59, the NAC-LWT cask is assigned a Criticality Safety Index (CSI) for criticality control of the approved contents as follows:

Approved Contents	**CSI**
PWR fuel assemblies	100
BWR fuel assemblies	5.0
MTR fuel elements	0.0
Metallic fuel rods	0.0
TRIGA fuel elements (in poisoned TRIGA fuel baskets)	0.0
TRIGA fuel elements (in nonpoisoned TRIGA fuel baskets)	12.5
TRIGA fuel cluster rods	0.0
High burnup PWR rods	0.0
High burnup BWR rods	0.0
PWR MOX rods	0.0
DIDO fuel elements	12.5
General Atomic Irradiated Fuel Material (GA IFM)	0.0
TPBARS and segmented TPBARS	0.0
Intact (uncanned) PULSTAR fuel	0.0
Canned PULSTAR fuel	33.4
ANSTO fuel	0.0
Solid irradiated hardware	0.0
ANSTO-DIDO fuel combination	0.0
SLOWPOKE Fuel Rods in Fuel Canisters	0.0
NRU / NRX Fuel Assemblies, EFN rods, Booster rods, and Moly targets	100
HEUNL containers	0.0
SLOWPOKE Fuel Core	100
SrF_2 (WESF or BUP) Capsules	0.0
LANL MOX Fuel Rods	25.0

TPBARs and SrF_2 capsules do not contain fissile material and criticality assessments are not required. Solid, irradiated and contaminated hardware contents could include fissile material not exceeding a Type A quantity and the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c). A CSI of 0 is assigned for these contents for documentation purposes.

The estimated Transport Index (TI) for shielding for the prior listed contents is shown in Table 5.1.1-1. The actual TI for individual shipments will be determined in accordance with 10 CFR 71.4 by the licensee.

Table 1.1-1 Terminology and Notation (cont'd)

	• up to sixteen (16) transfer tubes filled with LANL MOX Fuel Rods. Transfer Tubes must be loaded in the PWR/BWR Transport Can Assembly including the Divider Assembly. Transfer Tube Spacers are required at the top and bottom end of each tube. Transfer Tube Spacers may be used to separate contents but are not required. Empty Transfer Tubes without spacers may be loaded. Different LANL MOX fuel types may be loaded in the same package but only one fuel type may be loaded into any Transfer Tube. Also, only one (1) Transfer Tube containing one (1) 530-000 type rod may be included in the cask payload. See Table 1.2-20 for additional limitations.
Impact Limiters	Aluminum honeycomb energy absorbers located at the ends of the cask.
Intact LWR Fuel (Assembly or Rod)	Spent nuclear fuel that is not Damaged LWR Fuel, as defined herein. To be classified as intact, fuel must meet the criteria for both intact cladding and structural integrity. An intact fuel assembly can be handled using normal handling methods, and any missing fuel rods have been replaced by solid filler rods that displace a volume equal to, or greater than, that of the original fuel rod.
Damaged LWR Fuel (Assembly or Rod)	Spent nuclear fuel that includes any of the following conditions that result in either compromise of cladding confinement integrity or recognition of fuel assembly geometry. 1. The fuel contains known or suspected cladding defects greater than a pinhole leak or a hairline crack that have the potential for release of significant amounts of fuel particles. 2. The fuel assembly: i. is damaged in such a manner as to impair its structural integrity; ii. has missing or displaced structural components such as grid spacers; iii. is missing fuel pins that have not been replaced by filler rods that displace a volume equal to, or greater than, that of the original fuel rod; iv. cannot be handled using normal handling methods. 3. The fuel is no longer in the form of an intact fuel assembly and consists of, or contains, debris such as loose pellets, rod segments, etc.

Table 1.1-1 Terminology and Notation (cont'd)

Damaged Fuel (TRIGA)	TRIGA fuel (elements and cluster rods) with known or suspected clad breach (i.e., cladding defects that permit the release of gas from the interior of the rod and/or allow water intrusion into the clad to fuel gap while submerged).
Fuel Debris (TRIGA)	TRIGA damaged fuel that does not maintain its structural integrity, including fuel particles, fuel debris, and broken fuel rods.
Degraded ANSTO Fuel	ANSTO fuel elements (Mark II MOATA, Mark III Spiral, and Mark IV DIDO fuel) that have corrosion, destructive examination and/or mechanical damage to the fuel plates, but are structurally acceptable for transport (i.e., will not result in appreciable fuel debris formation under transport conditions). Fuel elements may be disassembled and plates may contain significant corrosion or mechanical damage in nonfueled plate areas; fuel elements may have sections of the fueled plate removed for examination; or fuel elements may have fuel core exposure due to through-clad corrosion or mechanical damage. The fuel (core material) area exposed may not exceed 5% of the total fueled cross-sectional area of the element.
Undamaged Aluminum-Based Fuel	Aluminum-based reactor fuel plates/elements that are structurally sound, but may have fuel core exposure due to corrosion or mechanical damage of the clad. Through-clad corrosion and/or mechanical damage is limited to 5% of the fueled surface area of the element.
TPBAR	Tritium Producing Burnable Absorber Rod
Irradiated Fuel Material (IFM)	High-Temperature Gas-Cooled Reactor (HTGR/IFM) and Reduced-Enrichment Research and Test Reactor (RERTR/IFM) type TRIGA fuel entities produced by General Atomics.
PULSTAR Fuel Element	PULSTAR fuel rod. May be contained in either assembly, rod holder or can form for shipment. PULSTAR fuel elements may be intact or damaged.
Damaged PULSTAR Fuel Element	PULSTAR fuel rods having cladding failures greater than hairline cracks or pinhole leaks. The damaged fuel definition for PULSTAR fuel elements includes fuel debris. Damaged PULSTAR fuel elements may also be referred to as failed and must be transported in either of two types of PULSTAR cans.

Table 1.1-1 Terminology and Notation (cont'd)

Undamaged SLOWPOKE Fuel Rods in the	SLOWPOKE fuel rods that are structurally sound, but may have fuel core exposure due to corrosion or mechanical damaged of the clad
SLOWPOKE Fuel Core	SLOWPOKE fuel rods that are "Undamaged Aluminum-Based Fuel" therefore limiting through-clad corrosions and/or mechanical damage of the clad to 5% of the fuel surface area of the element.
SrF_2 Capsules	SrF_2 (Strontium Fluoride) capsules are separated into two forms, the WESF capsules, and the BUP-500 capsules. The WESF capsules consist of Sr-90 byproduct material sealed within an inner and an outer capsule. The BUP-500 capsules are the heat source assembly from the BUP-500 Radioisotope Thermoelectric Generator (RTG).
LANL MOX Fuel Rods	Mixed oxide fuel rod variants including those described as PNNL, Exxon, UO_2, ROD1063, 530-000, NIS5, characterized in Table 1.2-20.

- up to 25 TPBARs (of which two can be prefailed) in a rod holder;
- up to 55 TPBARs segmented during post-irradiation examination (PIE), including segmentation debris;
- up to 700 PULSTAR fuel elements (intact or damaged);
- up to 42 spiral fuel assemblies;
- up to 42 MOATA plate bundles;
- up to 800 SLOWPOKE undamaged and/or damaged fuel rods contained in up to eight (8) SLOWPOKE fuel canisters (up to 100 fuel rods each);
- up to 18 NRU or NRX undamaged or damaged fuel assemblies (one per flow tube) or the equivalent number of loose rods as an assembly per basket tube (12 rods for NRU or 7 rods for NRX);
- up to eighteen (18) NRU/NRX caddies loaded with EFN rods, Booster rods, or Moly targets;
- 4 HEUNL containers (empty or filled such that a minimum under filled cavity void of one gallon exists);
- One SLOWPOKE fuel core containing up to 298 undamaged SLOWPOKE fuel rods;
- up to 18 WESF capsules, or up to 2 BUP-500 capsules;
- up to 4,000 lbs of solid, irradiated and contaminated hardware, which may include fissile material less than a Type A quantity and meeting the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c). Total allowed mass includes the weight of spacers, shoring and dunnage; or
- up to sixteen (16) transfer tubes filled with LANL MOX Fuel Rods.

PWR or BWR fuel rods may be placed in a fuel rod insert (also referred to as a rod holder) or in a fuel assembly lattice. The fuel rod holder is composed of a 4×4 or a 5×5 rod array. An alternate 5×5 rod holder is designed to contain an oversize nonfuel-bearing component (e.g., CE guide tube or BWR water rod). The alternative configuration reduces fuel-bearing capacity to a maximum of 21 fuel rods. The lattice may be irradiated or unirradiated. Up to 14 of the fuel rods may be classified as damaged. Damaged fuel rods must be placed in a rod holder. Damaged fuel rods or rod sections may be encapsulated to facilitate handling prior to placement in the rod holder. PWR rods may include Integral Fuel Burnable Absorber (IFBA) rods.

PWR MOX fuel rods (or a combination of PWR MOX and UO_2 PWR fuel rods) are required to be loaded in a screened or free flow PWR/BWR Rod Transport Canister with a 5×5 insert. PWR MOX/UO_2 rods may include Integral Fuel Burnable Absorber (IFBA) rods.

Damaged TRIGA fuel elements, cluster rods and fuel debris are required to be loaded in a sealed damaged fuel canister (DFC).

PULSTAR fuel elements may be configured as intact fuel assemblies, may be placed into a fuel rod insert, i.e., a 4×4 rod holder (intact elements only), or may be loaded into one of two can designs, designated as the PULSTAR screened fuel can or the PULSTAR failed fuel can. Damaged PULSTAR fuel elements and nonfuel components of PULSTAR fuel assemblies must be loaded into cans. PULSTAR fuel cans may only be loaded into the top or base module of the shall be limited to that defined for the authorized PWR content condition as described in Chapter 5.

The NAC-LWT cask provides a testable containment for the contents during both normal operations and hypothetical accident conditions, satisfying the requirements of 10 CFR 71.51. Any number of NAC-LWT casks may be shipped at one time, each on its own vehicle.

The NAC-LWT has two leaktight configurations as defined by ANSI N14.5. The standard configuration is provided by a closure lid with a metal containment seal and alternate vent and drain port covers provided with Viton® containment O-rings. The second configuration is provided by a closure lid with a metal containment seal and Alternate B vent and drain port covers provided with metal seals. The metal port cover seal containment configuration is required to be utilized for all TPBAR contents and may be used for other contents. The NAC-LWT standard, Viton® O-ring containment configuration is not authorized for TPBAR contents.

NAC-LWT casks may be shipped in a closed International Shipping Organization (ISO) container when containing all fuel contents other than PWR and BWR fuel assemblies. NAC-LWT casks containing PWR and BWR fuel assemblies are to be transported on an open trailer with a personnel barrier.

The terminology of MTR, DIDO and TRIGA fuel elements will be used independent of whether the element contains low, medium or high enriched uranium (i.e., LEU, MEU or HEU), except when required for analysis or loading purposes.

TPBAR contents may be placed into a consolidation canister, waste container or 5×5 rod insert (also referred to as a rod holder) in a PWR/BWR Rod Transport Canister. Segmented TPBARs are only permitted within the waste container. The three TPBAR shipping configurations are individually placed within one of the two TPBAR basket assemblies (one with a 7-inch bottom spacer and the alternative TPBAR basket assembly with a 6.5-inch alternative bottom spacer), depending on container configuration.

LANL MOX Fuel Rods must be loaded in the PWR/BWR transport can assembly including the Divider Assembly. Four (4) transfer tubes may be loaded into each of the four (4) openings created by the Divider Assembly for a maximum of sixteen (16) transfer tubes. A Transfer Tube spacer is required at the top and bottom end of the tube. Transfer Tube spacers may be used to separate contents but are not required. The PWR/BWR Transport Can Assembly may be used with any of the lids and corresponding PWR insert and basket assembly. Different LANL MOX fuel types may be loaded in the same package but only one fuel type may be loaded into any Transfer Tube. Table 1.2-20 provides additional limitations on the number of LANL MOX Fuel Rods allowed in a given transfer tube, along with the maximum number of transfer tubes with a given type of fuel rod allowed in a single package.

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

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

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

1.2.3 Contents of Packaging

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

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

1. The maximum contents weight shall not exceed 4,000 pounds.
2. The limits specified in Table 1.2-1 through Table 1.2-13 for the fuel and other radioactive contents shall not be exceeded.
3. Any number of casks may be shipped at one time, one cask per tractor/trailer vehicle.
4. The maximum decay heat shall not exceed the following: 2.5 kW for PWR fuel assemblies; 2.2 kW for BWR fuel assemblies; 2.3 kW for 25 high burnup PWR fuel rods; 2.1 kW for 25 high burnup BWR fuel rods; 2.3 kW for 16 PWR MOX/UO_2 fuel rods; 1.26 kW for MTR fuel; 1.05 kW for DIDO fuel assemblies with top spacer and 0.756 kW without top spacer; 1.05 kW for TRIGA fuel elements or fuel cluster rods; 13.05 W for GA IFM packages; 0.693 kW for 300 TPBARs; 0.127 kW for TPBAR segments; 0.058 kW for 25 TPBARs; 0.84 kW for the PULSTAR fuel contents; 0.659 kW for spiral fuel assemblies (0.109 kW per basket); 0.126 kW for MOATA plate bundles (21 W per basket); 5.0 W for SLOWPOKE fuel rods; 640 W for NRU/NRX fuel assemblies; 144W for EFN rods (8 W per caddy), 101 W for EFN/Moly mixed basket (8W per caddy for EFN rods and 0.8 W per caddy for Moly targets), 4W for Booster rods (0.2 W per caddy), 4.65 W for HEUNL; 45 W for the SLOWPOKE fuel core; 2.4kW for WESF (0.4kW per container assembly), 2.2kW for BUP-500; 1.26 kW for solid, nonfissile, irradiated hardware, and 25W for LANL MOX Fuel Rods.
5. Radiation levels shall meet the requirements delineated in 10 CFR 71.47 or 49 CFR 173.441. The neutron shield tank may be drained for shipment of metallic fuel rods.
6. Surface contamination levels shall meet the requirements of 10 CFR 71.87(i) or 49 CFR 173.443.
7. Damaged TRIGA fuel elements and fuel debris (up to two equivalent elements) will be shipped in a sealed damaged fuel canister.
8. Damaged TRIGA cluster rod and fuel debris will be transported in a sealed damaged fuel canister (maximum of up to six equivalent fuel cluster rods).

21. Any combination of undamaged or damaged SLOWPOKE Fuel Rods contained in 5 x 5 or 4 x 4 rod insert assemblies loaded into screened aluminum Fuel Canisters (four rod insert assemblies per fuel canister) with a maximum of four (4) SLOWPOKE Canisters per MTR-28 top and upper intermediate basket module (maximum of eight canisters per NAC-LWT cask). Cell block spacers will be installed in the center three fuel cells for the loaded basket modules.
22. Maximum 18 NRU or NRX fuel assemblies or the equivalent number of loose rods. NRX assemblies or rods must be placed into a fuel rod caddy assembly for handling and geometry constraint. NRU fuel rods may be placed in a caddy. Note, the use of the caddy plug is not required for NRU or NRX shipments. Only a single fuel type (NRU or NRX) shall be loaded in a single NRU/NRX fuel basket assembly.
23. Maximum 18 NRU/NRX caddies containing EFN rods, Booster rods, or Moly targets. NRUX/NRX caddies are limited to 36 EFN rods, 16 Booster rods, 20 Short Moly Targets, or 36 double length Moly targets or the equivalent number in rod/target segments or fragments. Rods/targets or segments/fragments thereof smaller than 6 inches in length require the use of the caddy plug. All materials must be placed in a caddy and only a single type is permitted in a caddy. EFN rod and Moly targets caddies may be placed into the same package (EFN rods are limited to exterior basket tubes). Booster rod caddies may not be mixed with EFN rod or Moly target caddies in a single package.
24. Four HEUNL containers. Containers shall be empty or filled with HEUNL material such that a minimum under filled cavity void of one gallon exists.
25. One SLOWPOKE fuel core containing up to 298 undamaged SLOWPOKE fuel rods. The SLOWPOKE fuel core is packaged in the SLOWPOKE fuel core basket.
26. Maximum 18 WESF capsules, in WESF baskets with one WESF capsule per capsule container assembly opening (three capsules per container, six containers per basket).
27. Maximum 2 BUP-500 capsules with spacers on either side. A single BUP-500 capsule may be loaded with a short spacer installed in place of the second BUP-500 capsule.
28. Up to sixteen (16) transfer tubes filled with LANL MOX Fuel Rods subject to the limitations provided in Table 1.2-20. Different LANL MOX fuel types may be loaded in the same package but only one fuel type may be loaded into any Transfer Tube.

1.2.3.1 TRIGA Fuel and Basket Description

Two basic types of TRIGA fuel are to be transported in the NAC-LWT cask: TRIGA fuel elements and smaller fuel rods from TRIGA fuel cluster assemblies. TRIGA fuel elements are approximately 1-1/2 inches in diameter and are described in Section 1.2.3.1.1. TRIGA fuel cluster rods are smaller; approximately 1/2-inch in diameter and are also described in Section 1.2.3.1.1.

Up to 140 TRIGA fuel elements in the form of: a) standard fuel elements – either aluminum clad or stainless steel clad; b) instrumented fuel elements – similar to standard fuel elements (aluminum clad or stainless steel clad), but containing thermocouple instrumentation; and c) fuel follower control rod elements (aluminum or stainless steel clad) – poison rods with a fuel follower in a single tube may be shipped in the NAC-LWT cask. Up to 560 TRIGA fuel cluster rods may be shipped.

Up to six equivalent TRIGA fuel cluster rods may be loaded and transported in a sealed damaged fuel can (DFC). Up to the equivalent of two TRIGA damaged fuel elements and debris may be loaded and shipped in a sealed DFC. The TRIGA transport baskets and DFCs are described in Section 1.2.3.1.2.

1.2.3.1.1 TRIGA Fuel

TRIGA Fuel Elements

The characteristics of the design basis TRIGA fuel element are presented in Table 1.2-4 and in Table 1.2-1 for the poisoned basket and in Table 1.2-2 for the nonpoisoned basket.

The fuel material in a TRIGA fuel element is a solid, homogeneous mixture of uranium-zirconium hydride alloy, i.e., a metal alloy fuel. Both the aluminum-clad and the stainless steel-clad TRIGA fuel elements are approximately 1.5-inch diameter rods by approximately 30 inches long. The fuel follower control rod elements range in length from 45 inches to 66.5 inches and are cut, as required, to fit the basket length. Instrumented fuel elements are identical to standard fuel elements with the exception of thermocouples and wires and lead-out tubing. The lead-out tubing needs to be detached prior to shipment in order for the instrumented fuel elements to fit into the standard element height envelope. The aluminum-clad TRIGA fuel element and instrumented fuel element, the stainless steel-clad TRIGA fuel element and instrumented fuel element, and the standard fuel follower control rod element are shown in Figure 1.2.3-1 through Figure 1.2.3-5, respectively.

TRIGA Fuel Cluster Rods

The fuel material in TRIGA fuel cluster rods is a solid, homogeneous mixture of uranium-zirconium-erbium hydride alloy, i.e., a metal alloy fuel. Erbium is a burnable neutron poison that is used in the fuel to enhance the flux profile along the length of the fuel rod, and conservatively ignored in the nuclear evaluations. The rods have a nominal diameter of 0.54 inch and are approximately 31 inches long. The rod cladding is Incoloy 800 material and is 0.015-inch thick, minimum. Instrumented rods are identical to the standard rods, with the exception of thermocouples and wires. A diagram of the TRIGA fuel cluster rods, and the individual fuel pin (cluster rod) making up the cluster, is shown in Figure 1.2.3-6.

The active fuel region of a TRIGA fuel cluster rod is a maximum of 0.53 inch in diameter, 22.5 inches in length, and has an initial uranium enrichment of up to 95 percent for HEU material and 20percent for LEU material. A compression spring is utilized to fill the space in the plenum region of the rod, and top and bottom plugs are used to seal the fuel within the rod. The design-basis TRIGA fuel cluster rod characteristics are summarized in Table 1.2-3, Table 1.2-4, and Tables 5.1.1-1, 5.1.1-2, 6.2.6-1 and 6.2.6-2. Axial fuel spacers, as shown on Drawing 315-40-085, may be used to axially position the TRIGA fuel elements, fuel inserts and DFCs. The axial spacers do not provide a safety function and are dunnage used to position the fuel elements to facilitate fuel handling. The total weight per basket module cell for the TRIGA fuel elements or cluster rods, inserts, spacer(s) and fuel cans, as applicable, shall be limited to a maximum of 80 pounds.

TRIGA Fuel Classification

The TRIGA fuel contents are divided into three categories based on fuel condition for evaluation, loading configuration and transport in the NAC-LWT:

1. Intact fuel (i.e., no cladding breach) is loaded directly into the TRIGA fuel basket modules (Section 1.2.3.1.2) with a maximum of four TRIGA fuel elements per loading position. Certain high ^{235}U content, LEU and HEU intact stainless steel TRIGA fuel elements, as defined in Table 1.2-2, are restricted to a maximum loading of three fuel elements per basket module cell in a top or bottom basket module only. To ensure that four fuel elements are not loaded into a cell containing high ^{235}U content fuel elements, a dummy TRIGA spacer tube is preinstalled in the basket prior to loading. Up to 16 intact cluster rods are loaded into fuel rod inserts (Drawing 315-40-096) that are inserted into the TRIGA fuel basket module cell openings. Intact TRIGA fuel elements and cluster rods may be loaded into a sealed DFC, if length permits.
2. Damaged TRIGA fuel elements and TRIGA fuel debris (up to the equivalent of two fuel elements) shall be loaded into a sealed DFC (Section 1.2.3.1.2), and then loaded into a top or base basket module.
3. Damaged TRIGA cluster rods and cluster rod fuel debris (up to the equivalent of six cluster rods) shall be loaded into a sealed DFC and then loaded into a top or base basket module.

1.2.3.1.2 TRIGA Fuel Baskets and Damaged Fuel Cans

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

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

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

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

1.2.3.2 MTR and DIDO Fuel and Basket Description

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

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

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. The total weight per basket module cell for the fuel element, spacer(s) and fuel plate canister, as applicable, shall be limited to a maximum of 80 pounds.

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.

1.2.3.16 SLOWPOKE Fuel Core

One SLOWPOKE fuel core containing up to 298 undamaged SLOWPOKE fuel rods may be transported in the NAC-LWT. The SLOWPOKE fuel core is packaged in the SLOWPOKE fuel core basket. A spacer is attached to the SLOWPOKE fuel core basket lid locating the fuel core at the bottom of the basket. The basket is transported with empty intermediate and bottom MTR-42 basket modules to provide axial spacing. The SLOWPOKE fuel core basket is therefore located next to the NAC-LWT cask lid.

The SLOWPOKE fuel core primary components are up to 298 undamaged SLOWPOKE fuel rods, a center tube, and upper and lower plates. SLOWPOKE fuel rods are composed of highly enriched uranium-aluminum alloy fuel meat within aluminum cladding. As discussed in Section 1.2.3.12, criticality in a SLOWPOKE core during reactor operations is achieved by the use of a thick beryllium neutron reflector surrounding the core. The beryllium reflector is not part of the packaged contents. A sketch of a SLOWPOKE fuel rod is provided in Figure 1.2.3-19. Key physical, radiation protection and thermal characteristics of the SLOWPOKE fuel core, i.e., parameters documented in the analytical chapters to be safely transported, are listed in Table 1.2-17.

1.2.3.17 SrF_2 Capsules

There are two types of SrF2 capsules, the WESF capsules, and the BUP-500 capsules. The WESF capsules must be loaded into the WESF capsule container assemblies prior to being loaded into the WESF basket assembly within the NAC-LWT cavity. The WESF LWT lid spacer and all six (6) WESF capsule container assemblies must be installed. A sketch of the WESF capsules is provided in Figure 1.2.3-23. The WESF capsule basket assembly design is presented in NAC drawing 315-40-191. The BUP-500 capsules must be loaded into the BUP-500 basket assembly within the NAC-LWT cavity. One spacer must be installed on either side of a capsule. A single BUP-500 capsule may be loaded with a short spacer installed in place of the second BUP-500 capsule. A sketch of the BUP-500 capsule is provided in Figure 1.2.3-24. The BUP-500 basket assembly design is presented in NAC drawing 315-40-196.

Key physical, radiation protection, and thermal characteristics of the SrF2 capsules are listed in Table 1.2-19.

1.2.3.18 LANL MOX Fuel Rods

The NAC-LWT cask is analyzed and evaluated for the transport of up to 16 Transfer Tubes. Transfer Tubes must be loaded in the PWR/BWR transport can assembly including the Divider Assembly. The evaluated characteristics for the authorized LANL MOX Fuel Rods are provided in Table 1.2-20. Different LANL MOX fuel types may be loaded in the same package, subject to the limitations provided in Table 1.2-19, but only one fuel type may be loaded into any single Transfer Tube. A sketch of a generic LANL MOX Fuel Rod is provided in Figure 1.2.3-25.

Figure 1.2.3-25 LANL MOX Fuel Rod Generic Rod Components

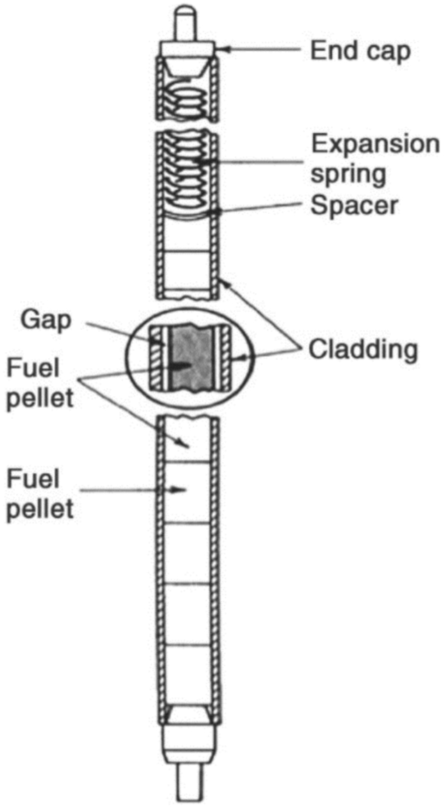

Table 1.2-1 Characteristics of Design Basis TRIGA Fuel Elements Acceptable for Loading in the Poisoned TRIGA Basket

	TRIGA HEU (Notes 1, 2, 6 & 7)	**TRIGA LEU (Notes 1, 2, 6 & 7)**	**TRIGA LEU (Notes 1, 2, 6 & 7)**
Fuel Form	Clad U-ZrH rod	Clad U-ZrH rod	Clad U-ZrH rod
Maximum Element Weight, lbs	13.2	13.2	13.2
Maximum Element Length, in	47.74	47.74	47.74
Element Cladding	Stainless Steel	Stainless Steel	Aluminum
Clad Thickness, in	0.02	0.02	0.03
Active Fuel Length, in	15	15	14-15 (Note 4)
Element Diameter, in	1.478 max.	1.478 max.	1.47 max.
Fuel Diameter, in	1.435 max.	1.435 max.	1.41 max.
Maximum Initial U Content/Element, kilograms	0.196	0.845	0.205
Maximum Initial ^{235}U Mass, grams	137	169	41
Maximum Initial ^{235}U Enrichment, weight percent	70	20	20
Zirconium Mass, grams (Note 5)	2060	1886-2300	2300
Hydrogen to Zirconium Ratio, max. (Note 5)	1.6	1.7	1.0
Maximum Average Burnup, MWd/MTU	460,000 (80% ^{235}U)	151,100 (80% ^{235}U)	151,100 (80% ^{235}U)
Minimum Cooling Time	90 days (Note 3)	90 days (Note 3)	90 days (Note 3)

Notes:

1. Mixed TRIGA LEU and HEU contents authorized.
2. TRIGA Standard, instrumented and fuel follower control rod type elements authorized.
3. Maximum decay heat of any element is 7.5 watts.
4. Aluminum clad fuel with 14-inch active fuel is solid and has no central hole with a zirconium rod.
5. Zirconium mass and H/Zr ratio apply to the fuel material (U-Zr-H_x) and do not include the center zirconium rod.
6. Listed TRIGA fuel elements have a 0.225-inch diameter zirconium rod in the center.
7. Dimensions listed are as-fabricated (unirradiated) nominal values.

Table 1.2-2 Characteristics of Design Basis TRIGA Fuel Elements Acceptable for Loading in the Nonpoisoned TRIGA Basket

	TRIGA HEU (Notes 1, 2, 6)		TRIGA LEU (Notes 1, 2, 6)		TRIGA LEU (Notes 1, 2, 6)
Fuel Form	Clad U-ZrH rod (Note 4)		Clad U-ZrH rod (Note 4)		Clad U-ZrH rod (Note 4)
Maximum Element Weight, lbs	13.2		13.2		13.2
Maximum Element Length, in	47.74		47.74		47.74
Element Cladding	Stainless Steel		Stainless Steel		Aluminum
Minimum Clad Thickness, in	0.01		0.01		0.01
Active Fuel Length, in	(Note 5)		(Note 5)		(Note 5)
Maximum Element Diameter, in	1.5 max.		1.5 max.		1.5 max.
Fuel Diameter, in	(Note 5)		(Note 5)		(Note 5)
Maximum Initial U Content/Element, kilograms	0.198	0.186	0.845	1.447	0.205
Maximum Initial ^{235}U Mass, grams	138	175 (Notes 7, 8)	169	275 (Notes 7, 8)	41
Maximum Initial ^{235}U Enrichment, weight percent	71	95 (Notes 7, 8)	25	25 (Notes7, 8)	25
Zirconium Mass, grams	(Note 5)		(Note 5)		(Note 5)
Hydrogen to Zirconium Ratio, max.	(Note 5)		(Note 5)		(Note 5)
Maximum Average Burnup, MWd/MTU	460,000 (80% ^{235}U)	583,000	151,100 (80% ^{235}U)		151,100 (80% ^{235}U)
Minimum Cooling Time	90 days (Note 3)		90 days (Note 3)		90 days (Note 3)

Notes:

1. Mixed LEU and HEU TRIGA fuel element, and LEU and HEU TRIGA fuel cluster rod, as defined in Table 1.2-3, contents authorized.
2. TRIGA Standard, instrumented and fuel follower control rod type elements authorized.
3. Maximum decay heat of any element is 7.5 watts.
4. Element may contain zirconium rod in the center.
5. See criticality analyses in Chapter 6, Section 6.4.5.6, for the evaluations determining critical fuel characteristics.
6. Dimensions listed are as-fabricated (unirradiated) nominal values.
7. Elements limited to loading in top and bottom basket module only.
8. Elements limited to a maximum of three per basket module cell.

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

Element Type	TRIGA Fuel Cluster Rod
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
Max. Rod Weight (kg)	0.65
Min. U in U-ZrH (wt %)	43.0 (LEU) or 9.5 (HEU)[1]
Max. ^{235}U in U (wt %)	19.9 to 93.3
^{235}U Mass (g)	55.0 (LEU) or 46.5 (HEU)
Max. H to Zr Ratio	1.7

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[1] Equivalent to a maximum zirconium mass of 357 g for LEU fuel and 457 g for HEU fuel material. Lower weight percents are permitted, provided the maximum zirconium mass limits are not exceeded.

Table 1.2-4 Fuel Characteristics

Parameter	PWR Fuel Assembly	BWR Fuel Assembly	PWR Rods	High Burnup PWR Rods	PWR MOX Fuel Rods[6]	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	16 rods	25 rods	25 rods
Maximum Overall Weight, lbs	1650	750	N/A	N/A	N/A	N/A	N/A
Maximum Overall Length, in	178.25	176.1	162	162	162	176.1	176.1
Maximum Active Fuel Length, in	150	150	150	150	153.5	150	150
Fuel Rod Cladding	Zirc	Zirc	Zirc	Zirc	Zirc	Zirc	Zirc
Maximum Uranium, kg U	475	198	58.2	65.6	41.6[7]	198	198
Maximum Initial ^{235}U, wt %	*See below*[3]	4.0	5.0	5.0	7.0 max/2.0 min, fissile Pu[8]	5.0	5.0
Maximum Burnup, MWd/MTU	35,000	30,000	60,000[4]	80,000	62,500	60,000 - 80,000	80,000
Maximum Unit Decay Heat, kW	2.5	1.1	0.564	0.92	0.143	0.84	0.84
Maximum Cask Decay Heat, kW	2.5	2.2	1.41	2.3	2.3	2.1	2.1
Minimum Cool Time, yr	2	2	150 days	150 days	90 days	210 - 270 days[5]	150 days

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[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 7×7 rods is determined by extent of burnup. See Section 5.3.8 and Table 5.3.8-23.

[6] Up to 16 PWR MOX fuel rods or a combination of up to 16 MOX PWR and UO_2 PWR fuel rods can be loaded.

[7] Maximum fuel mass is 2.6 kg HM/rod.

[8] Maximum 5.0 wt % ^{235}U for UO_2 rods.

Table 1.2-4 Fuel Characteristics (Continued)

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

---

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

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

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

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

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

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

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

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

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

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

Table 1.2-4 Fuel Characteristics (Continued)

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

---

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

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

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

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

Table 1.2-5 PWR Fuel Characteristics

Fuel Type	No. of Fuel Rods	Max. Assembly Length (in.)	Max. Assembly Weight (lb)	Max. Enrich. (wt %)	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 x 7	49	0	175.9	678.9	0.1923	0.738	0.563	0.037	0.477	146
GE 8 x 8-1	63	1	175.9	681.0	0.1880	0.640	0.493	0.034	0.416	146
GE 8 x 8-2	62	2	175.9	681.0	0.1847	0.640	0.483	0.032	0.410	150[1]
GE 8 x 8-4	60	4	176.1	665.0	0.1787	0.640	0.484	0.032	0.410	150[1,2]
GE 9 x 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 x 7	49	0	171.3	619.1	0.1960	0.738	0.570	0.036	0.490	144
Ex/ANF 8 x 8-1	63	1	171.3	562.3	0.1764	0.641	0.484	0.036	0.4045	145.2
Ex/ANF 8 x 8-2	62	2	176.1	587.8	0.1793	0.641	0.484	0.036	0.4045	150
Ex/ANF 9 x 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

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[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

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[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

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[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[1]
Max total weight of ^{235}U (g)	160 (total per assembly)
Maximum enrichment (wt % ^{235}U)	95
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[2]
Max. assembly weight (lb)	18[3]
Assembly maximum heat load (W)	15.7[4]
Burnup/cool time limit	Variable[5]

---

[1] Cropped to fit within ANSTO fuel basket module nominal height of 28.3 inches.

[2] Criticality evaluations reduced inner and outer shell thickness to 0.01 cm to provide additional moderator within the assembly.

[3] Typical assembly weight is 7.9 pounds. Bounding structural analysis weight is listed. Bounding weight includes DFC and fuel plates.

[4] Thermal and shielding evaluation employed 18 W per element. Based on cool time constraint, 15.7 W represents maximum heat load. Spiral fuel elements with degraded cladding loaded into aluminum DFCs shall be limited to a maximum decay heat of 10 W per element.

[5] 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.

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

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[1] Typical assembly weight is 13.6 pounds. Bounding structural analysis weight is listed. Bounding weight includes DFC and fuel plates.

[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.

Table 1.2-13 Solid, Irradiated Hardware Characteristics[1]

Parameter	Value
Maximum Content Weight Maximum Content Length	4,000 pounds [2] 171.5 inches [3]
Hardware Material	Solid, irradiated and contaminated fuel assembly structural or reactor internal component hardware [4]
Maximum Cask Heat Load	1.0 KW
Maximum Activity per Cask, Ci	6.0 x 10E+6
Maximum Source Term, gamma/sec	6.0 x 10E+15
Maximum Source Term, MeV/sec	1.0 x 10E+15

---

[1] Maximum content weight includes any spacers, containers or dunnage loaded in the cavity with the irradiated hardware.

[2] Length of cavity is limited to 171.5 inches by the installation and use of an irradiated hardware spacer bolted to the underside of the closure lid.

[3] Appropriate secondary containers will be used to prevent any contact and cross-contamination between the carbon steel contents and the stainless steel internals of the cask cavity.

[4] The irradiated hardware contents may contain fissile material, provided the quantity of fissile material does not exceed a Type A quantity and does not exceed the mass limits of 10 CFR 71.53.

Table 1.2-14 SLOWPOKE Fuel Rods

Parameter	Value
Maximum Cask Heat Load	5 W
Maximum Canister Heat Load	0.625W
Payload Limit (lb/canister)	25
Maximum ^{235}U per rod (g)	2.800
Maximum U per rod (g)	3.111
Minimum Cool Time	14 yr
Maximum Burnup (GWd/MTU or wt% ^{235}U Depletion)	30 GWd/MTU 4.5 wt% ^{235}U

Notes:

1.) Heat load limit established by thermal analysis.
2.) Fissile material (^{235}U) mass limit established by criticality analysis.
3.) Fuel (U) mass, cool time, burnup/depletion limit established by shielding analysis.
4.) Payload weight limit established by structural analysis and includes both fuel and canister weight.

Table 1.2-15 NRX / NRU Fuel Assemblies / Rods

Parameter	NRU (HEU)	NRU (LEU)	NRX
Maximum Cask Heat Load	640 W		
Maximum Per Tube Heat Load	35.6 W		
Payload Limit (lb/tube)	20		
Maximum ^{235}U per rod (g)	43.24	43.68	79.05
Maximum U per rod (g)	48.0	230	87.0
Minimum Cool Time (yr)	19	3	18
Maximum Burnup (MWd)	364	363	375
Maximum^{235}U Depletion (%)	87.4	83.6	85.1

Notes:

1.) Heat load limit established by thermal analysis.
2.) Fissile material (^{235}U) mass limit established by criticality analysis.
3.) Fuel (U) mass, cool time, burnup/depletion limit established by shielding analysis.
4.) Payload weight limit established by structural analysis and includes both fuel, caddy weight and dunnage.

Table 1.2-16 HEUNL Characteristics

Parameter	Value
Maximum HEUNL payload per Container	15.35 gal
Maximum Cask Heat Load	4.65 W
Maximum Per Container Heat Load	1.16 W
Maximum HEUNL Heat Load	0.02 W/L
Maximum Curie Content (gamma emitters) [1]	9.0 Ci/L
Maximum ^{235}U content[2]	7.4 g ^{235}U/L
Maximum ^{235}U enrichment [2]	93.4 wt%

---

[1] Maximum Curie content defined by source term and shielding evaluations.

[2] Maximum ^{235}U content and enrichment defined by criticality evaluation.

Table 1.2-17 SLOWPOKE Fuel Core

Parameter	Value
Maximum Cask Heat Load (W)	45
Payload Limit (lb)	15
Maximum Number of Rods per Core	298
Maximum Initial ^{235}U per rod (g)	2.83
Maximum Initial Enrichment (wt % ^{235}U)	95.3
Maximum Initial ^{235}U per core (g)	837
Minimum Initial Enrichment (wt% ^{235}U)	90
Minimum Cool Time	2 weeks
Maximum Core Average Depletion (%^{235}U)	2.1%

Notes:

[1] Heat load limit established by thermal analysis.

[2] Maximum number of rods per core, fissile material (^{235}U) initial mass per rod limit, and maximum initial enrichment established by criticality analysis.

[3] Fissile material (^{235}U) initial mass per fuel core, minimum initial enrichment, depletion percentage, and cool time established by shielding analysis.

[4] Payload weight limit established by structural analysis.

Table 1.2-18 EFN Rods, Booster Rods, and Moly Targets

Parameter	Short Moly	Double Length Moly	EFN	Boosters
Maximum Per Caddy Heat Load (W)	0.3	0.8	8	0.2
Payload Limit (lb/tube)	20			
# Rod/Targets (Equivalent)	20	36	36	16
Maximum ^{235}U per rod (g)	1.1	2.41	13	18.1
Minimum Cool Time (yr)	38	8	23	37
Maximum ^{235}U Depletion (%)	94.8	30.4	87.4	2.9
Maximum Initial Enrichment (wt% ^{235}U)	94			

Notes:

1.) Fissile material (^{235}U) mass limit established by criticality and shielding analysis.

2.) Cool time, burnup/depletion limit established by shielding analysis.

3.) Payload weight limit established by structural analysis and includes both fuel, caddy/caddy plug weight and dunnage.

4.) Depletion percentage may be generated on a per assembly basis for EFN rods and Booster rods and on a rod basis for the Moly Targets. Assemblies are disassembled into rods/rods segments prior to loading into caddy. Moly rods are disassembled into the component targets.

Table 1.2-19 SrF_2 Capsules

Parameter	WESF Capsules	BUP-500 Capsules
Maximum Cask Heat Load (W)	2400	2200
Maximum Per Capsule Heat Load (W)	400	1100
Maximum Activity per Cask (Ci ^{90}Sr)	1.062E+06	3.52E+05
Payload Limit (lb)	396	300

Table 1.2-20 LANL MOX Fuel Rod Characteristics

Parameter	PNNL	EXXON	UO_2	ROD 1063	530-000	NIS5
Max. rod OD (inch)	0.565	0.451	0.229	0.55	0.63	0.5
Min. wall thick. (inch)	0.035	0.035	0.015	0.015	0.015	0.015
Rod material	Zr Alloy	Zr Alloy	SS304	Zr Alloy	Zr Alloy	SS316
Max. active length (inch)	35.6	70	36.1	47.913	18	13.5
Max. pellet OD (inch)	0.486	0.372	0.1988	0.48	0.56	0.31
Max. # of rods per transfer tube	4	2	8	3	1	3
Max. # of tubes per cask	16	16	16	12	1	16
Fuel form	Oxide	Oxide	Oxide	Oxide	Oxide or Carbide	Carbide
^{235}U wt%	0.712	0.712	94	0	0	94
^{240}Pu wt%	16	16	0	10	10	4
Pu wt%	5.36	6.31	0	100	100	20
U-235 (g/rod)	6.76	7.71	159.9	0	0	159.58
U (g/rod)	949.85	1083.44	170.11	0	0	169.76
Pu (g/rod)	56.29	76.35	0	1378.77	922.01	42.38
Total U/Pu (g/rod)	1006.14	1159.79	170.11	1378.77	922.01	212.14

Note:

1.) Fissile Pu-239 and Pu-241 comprise the remaining plutonium. A 9 to 1 ratio of Pu-239 to Pu-241 bounds the range of Pu-240 weight fractions analyzed herein.

January 2024

Revision 24A

NAC-LWT

Legal Weight Truck Cask System

SAFETY ANALYSIS REPORT

Volume 2 of 3

NON-PROPRIETARY VERSION

Docket No. 71-9225

NAC INTERNATIONAL

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Table 2.2.1-1 Weights of the NAC-LWT Cask Major Components (cont.)

Component	Weight (pounds)	Axial Center of Gravity Location (inches)
HEUNL Container & Spacer[7]	1,446	104
HEUNL Payload	704	98
SLOWPOKE Fuel Core Basket & Five MTR Baskets	1,160	108
SLOWPOKE Fuel Core Payload	15	164
WESF Basket, Lid Spacer & Container[8]	1,972	99
WESF Payload	396	99
BUP-500 Basket	1,694	97
BUP-500 Payload & Spacers[9]	408	98
LANL MOX Payload	1,479	95

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[7] Includes 4 HEUNL Containers, Container Guide and Container Spacer.

[8] Includes 1 Lid Spacer and 6 WESF Containers.

[9] Two BUP-500 canisters (150 lbs each) are loaded with three spacers (36 lbs each) to maintain axial position. The C.G. is presented in the loaded configuration.

Table 2.2.1-2 Weights and Center of Gravity Locations for the NAC-LWT Cask Shipping Configurations (cont'd)

Component	Weight (pounds)	Axial Center of Gravity Location (inches)
Package - Loaded for Shipment TPBARs in the PWR/BWR Rod Transport Canister	49,109	99.2
Package - Empty for Shipment (TPBAR Basket for PWR/BWR Rod Transport Canister)	47,783	99.1
Package - Loaded for Shipment (SLOWPOKE Fuel, Four Unit Basket) [1]	49,030	99.1
Package - Empty for Shipment (SLOWOKE Fuel, Four Unit Basket)	48,190	98.9
Package – Loaded for Shipment (NRU/NRX Basket with Fuel Assemblies and Caddy containing rods/targets)	41,111	97.0
Package – Empty for Shipment (NRU/NRX Basket)	40,751	96.8
Package – Empty for Shipment (HEUNL)	48,656	99.2
Package – Loaded for Shipment (HEUNL)	49,360	99.2
Package – Loaded for Shipment (SLOWPOKE Fuel Core, Basket, Five MTR Baskets)[2]	48,400	99.3
Package – Empty for Shipment (SLOWPOKE Fuel Core Basket, Five MTR Baskets)[2]	48,400	99.3
Package – Empty for Shipment (WESF)	49,180	99.1
Package – Loaded for Shipment (WESF)	49,576	99.1
Package – Empty for Shipment (BUP-500)	48,902	99.0
Package – Loaded for Shipment (BUP-500)	49,310	99.0
Package – Loaded for Shipment (LANL MOX Fuel Rods)	49,561	99.2
Package – Empty for Shipment (LANL MOX Fuel Rods)	49,366	99.2
Package - Design for Shipment	52,000	98.93

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[1] A fuel weight of 30 lbs/assembly is used to compute the weight for this table as compared to the maximum weight for the SLOWPOKE canister of 25 pounds.

[2] Weight rounded up to nearest 100 pounds.

provided for the cask drain tube. The drain tube is connected to a fitting on the cask body, and is used to drain or fill the cask during cask loading or unloading operations.

For the shipment of up to 25 PWR or BWR rods, or up to 16 PWR MOX rods (or mixed MOX and UO_2 rods), a canister with insert will be utilized to position the fuel rod contents within the PWR basket. Similarly, LANL MOX Fuel Rods may be loaded in up to 16 transfer tubes, positioned using a divider assembly, in the canister within the PWR basket. The canister for the fuel rods will be fabricated from Type 304 stainless steel (minimum thickness 0.12 inch) and will be designed to allow positive handling of the canister during loading and unloading operations. The size, shape, closure design and capacity of the canister will vary depending on the requirements of the shipping and/or receiving facilities. A spacer fabricated from stainless steel will be utilized, as required, to position the PWR/BWR rod canister longitudinally within the NAC-LWT cask cavity. A PWR insert fabricated from 6061-T651 aluminum is used to laterally position the rod canister within the PWR basket. The total weight of the fuel rods, canister and basket insert will be less than the maximum PWR fuel assembly payload weight of 1,650 pounds. Therefore, the up to 25 fuel rods content condition is bounded by the current PWR basket analyses.

2.6.12.3 PWR Basket Analysis

The minimum ambient temperature during normal transport, -40°F, combined with the maximum decay heat load produces an average inner wall temperature of 151°F. The 6061-T6 aluminum alloy expands approximately 1.5 times more per degree Fahrenheit than stainless steel. Assuming that both the cask and basket respond linearly, the maximum as-designed gap between the basket and the cavity, when the basket is centered in the cavity, is 0.094 in. Since aluminum expands faster than stainless steel, any increase in temperature will serve to decrease the basket-cavity gap. Since the gap is small, it is assumed that there is no relative motion between the basket and cask, and that the basket is in contact bearing on the inner shell during a side drop. The basket bearing loads are transmitted to the inner shell and cask structure.

2.6.12.3.1 Bearing Stress Calculation

The bearing stress is calculated using Case 6 (Roark, page 320), which models the cylindrical basket in a circular groove. The maximum compressive stress is calculated using:

2.6.12.18 LANL MOX Fuel Transfer Tubes and Divider Plates

The LWT Transport Cask LANL MOX shipping configuration (drawing 315-40-188) consists of the LWT cask body assembly, the PWR basket assembly, PWR insert and the rod transport canister assembly, containing 16 transfer tubes (drawing 315-40-189) loaded with the LANL MOX Fuel Rods. A divider assembly (drawing 315-40-189) is used to maintain the position of the transfer tubes (four in each quadrant) inside the rod transport canister. Note that LANL MOX shipping configuration utilizes the same rod transport can assembly and supporting cask internal structures used to ship high burnup rods within a 4×4 or 5×5 insert. In the LANL MOX configuration, the insert (4×4 or 5×5) is replaced by 16 transfer tubes and a divider assembly and the content weight for the rod transport canister is 141 pounds less than that for the high burnup configuration. The rod transport canister assembly is evaluated in Section 2.6.7.10 and Section 2.7.1.7 for normal and accident conditions, respectively, for the transport of high burnup rod configuration. The content weight and material property temperatures used in the evaluation of the rod transport canister bound those of the LANL MOX configuration. Therefore, the rod transport canister assembly evaluations (as documented in Sections 2.6.7.10 and 2.7.1.7) are bounding and applicable to the same rod transport canister assembly with LANL MOX content. No further evaluation is required for the rod transport canister assembly or other cask internal structures.

The following sections present the evaluation of the transfer tubes and the divider plates for the end drop and side drop of normal conditions of transport. Note that the maximum heat load for LANL MOX fuel is 25 Watts per cask. Material properties and allowable stresses used in the evaluation are determined at a conservative temperature of 300°F since the maximum temperature for the LANL MOX configuration is less than 300°F during normal conditions of transport.

2.6.12.18.1 Transfer Tube and Divider Plate – End Drop

In the end drop condition, the transfer tube and the divider plate are subjected to inertia load due to self-weight (W_t) with an normal condition end drop acceleration (g_{end}) of 15.8g per Table 2.6.7-32. The transfer tube and divider plate are evaluated for membrane stresses (σ_m) as shown in the following table. Design Stress Intensity (S_m) is used as the allowable stress limit for primary membrane stresses per Table 2.1.2-2. The transfer tubes and the divider plate are made of Type 304 stainless steel. S_m is 20.0 ksi for Type 304 stainless steel at 300°F. As shown in the following table, the margins of safety are Large.

[redacted]

Transfer tube spacer may be used between the LANL MOX Fuel Rods inside the transfer tube. The membrane stress for the tube spacer is calculated to be 0.74 ksi using a bounding weight of 12.2 lb. for the transfer tube content (with the end drop acceleration of 15.8g), a cross-sectional area of 0.26 in^2. The margin of safety is also Large based on a design stress intensity of 14.9 ksi (S_m for Type 433 stainless steel at 300°F).

The shear stress in the optional fillet weld between the transfer tube wall and the end cap is evaluated. In the end drop, the weld is subjected to the inertia load of the transfer tube wall (43.9 lb.) only. The shear stress in the weld is calculated to be 1.13 ksi based on the effective area of the fillet weld (0.039 in^2). The margin of safety is +2.7 based on the allowable stress of $0.6S_m$ for shear stress and a weld quality factor of 0.35 (ASME B&PV Code, Section III, Subsection NG, Table NG-3352-2). S_m is 20 ksi for the base metal (Type 304 stainless steel at 300°F).

2.6.12.18.2 Transfer Tubes and Divider Plates – Side Drop

The transfer tube geometry and material are identical to the 4×4 and 5×5 insert tubes used for the high burnup shipping configuration, which were evaluated for the side drop conditions of transport in Section 2.6.7.10. The temperature used to determine the material properties in Section 2.6.7.10 is significantly higher than the maximum temperature of the LANL MOX transfer tubes. The loaded tube weight used in evaluation in Section 2.6.7.10 is higher than the bounding weight of one loaded LANL MOX transfer tube weldment (15.0 lb.) Therefore, the tube side drop evaluations for the high burnup configuration are applicable and bounding for the LANL MOX transfer tubes and no additional side drop evaluations are required for the LANL MOX transfer tubes.

The divider assembly for the LANL MOX fuel transfer tubes consists of two divider plates welded together. For the side drop condition, the divider plates are evaluated using a finite element model as shown in Figure 2.6.12-22. The model is constructed using ANSYS BEAM188 elements for the plates. Two cases corresponding to different plate thicknesses (0.05

inch and 0.0625 inch) are considered. CONTA52 elements are used to represent the interface of the plates with the inner surface of the rod transport canister. Note that the total gap between the divider assembly and the inner surface of the canister is 0.07 inch. To maximize the plate displacement, a gap size of 0.07 inch is used for the contact elements on the left side of the model. The loading applied to the divider plates consists of nodal forces corresponding to the inertia load from two loaded transfer tubes using an acceleration of 24.3g for normal condition side drop (see Table 2.6.7-32). The material properties used in the model correspond to the material of Type 304 stainless steel at 300°F.

The analysis results are shown in the following table. The maximum primary membrane plus primary bending (P_m+P_b) stress intensities in the divider plates are evaluated using the allowable of $1.5S_m$ for normal conditions of transport. The minimum margin of safety is +0.52.

[redacted]

Note that the divider plates are welded using CJP weld. The maximum stress intensity at the weld locations is 11.47 ksi for the governing case with 0.05-inch plates. Using the allowable stress of $1.5S_m$ for Type 304 stainless steel (30 ksi) and a weld quality factor of 0.5 (ASME B&PV Code, Section III, Subsection NG, Table NG-3352-2), the minimum margin of safety is +0.31.

Figure 2.6.12-22 Finite Element Model for Divider Plates (LANL MOX Fuel)

[redacted]

2.6.12.19 Conclusion

[redacted]

[redacted]

2.7.7.20 LANL MOX Fuel Transfer Tube and Divider Plate

As discussed in Section 2.6.12.18, the LWT Transport Cask LANL MOX shipping configuration consists of the LWT cask body assembly, the PWR basket assembly, PWR insert and the rod transport canister assembly, containing 16 transfer tubes loaded with LANL MOX Fuel Rods. A divider assembly is used to maintain the position of the transfer tubes (four in each quadrant) inside the rod transport canister. The evaluation of the rod transport canister assembly in Section 2.7.1.7 for accident conditions of transport for the high burnup rod configuration are bounding and applicable to the same rod transport canister assembly with LANL MOX content. No further evaluation is required for the rod transport canister assembly or other cask internal structures. The following sections present the evaluation of the transfer tubes and the divider plates for the end drop and side drop of accident conditions of transport.

2.7.7.20.1 Transfer Tube and Divider Plate – End Drop

In the end drop condition, the transfer tube and the divider plate are subjected to inertia load due to self-weight (W_t) with an end drop acceleration (g_{end}) of 60g (bounding g-load for 30-foot end drop as shown in Table 2.6.7-33). The transfer tube and divider plate are evaluated for membrane stresses (σ_m) as shown in the following table. 0.7×Ultimate strength (S_u) is used as the allowable stress limit for primary membrane stresses for accident conditions per Table 2.1.2-2. The transfer tubes and the divider plate are made of Type 304 stainless steel. S_u is 66.2 ksi for Type 304 stainless steel at 300°F. As shown in the following table, the margins of safety are Large.

[redacted]

Transfer tube spacer may be used between the LANL MOX Fuel Rods inside the transfer tube. The membrane stress for the tube spacer is calculated to be 2.82 ksi using a bounding weight of 12.2 lb. for the transfer tube content (with the end drop acceleration of 60g), a cross-sectional area of 0.26 in^2. The margin of safety is also Large based on an allowable ($0.7S_u$) of 37.1 ksi (S_u is 53.0 ksi for Type 433 stainless steel at 300°F).

The shear stress in the optional fillet weld between the transfer tube wall and the end cap is evaluated. In the end drop, the weld is subjected to the inertia load of the transfer tube wall (43.9 lb.) only. The shear stress in the weld is calculated to be 4.28 ksi based on the effective area of the fillet weld (0.039 in^2). The margin of safety is +0.25 based on the allowable stress of 1.7 × 0.4 × Yield Strength (S_y) for shear stress (ASME B&PV Code, Appendix F, F-1337and NF-3324.5, Table NF-3324.5(a)-1) and a weld quality factor of 0.35 (ASME B&PV Code, Section III, Subsection NG, Table NG-3352-2). S_y is 22.4 ksi for the base metal (Type 304 stainless steel at 300°F).

2.7.7.20.2 Transfer Tubes and Divider Plates – Side Drop

Based on the discussed in Section 2.6.12.18 comparing the temperature and loaded tube weight between the tube evaluation for the high burnup shipping configuration and the LANL MOX fuel shipping configuration, the tube side drop evaluations for the accident conditions as presented in Section 2.7.1.7 for the high burnup configuration are applicable and bounding for the LANL MOX transfer tubes and no additional side drop evaluations are required for the LANL MOX transfer tubes.

For the accident condition, the divider plates are evaluated using the ANSYS finite element model as presented in Section 2.6.12.18. The same boundary conditions are used with the nodal forces corresponding to the inertia load from two loaded transfer tubes using an acceleration of 49.7g for accident condition side drop (see Table 2.6.7-33). The material properties used in the model correspond to the material of Type 304 stainless steel at 300°F.

The analysis results are shown in the following table. The maximum primary membrane plus primary bending (P_m+P_b) stress intensities in the divider plates are evaluated using the allowable of S_u (material ultimate strength) for accident conditions of transport. The minimum margin of safety is +1.07.

[redacted]

Note that the divider plates are welded using CJP weld. The maximum stress intensity at the weld locations is 19.07 ksi for the governing case with 0.05-inch plates. Using the allowable stress of S_u for Type 304 stainless steel (66 ksi) and a weld quality factor of 0.5, the minimum margin of safety is +0.73.

or a 5 × 5 insert as presented on the drawings provided in Section 1.4). The high burnup PWR and BWR rods may also be placed in a fuel assembly lattice. Damaged PWR/BWR fuel rods must be placed in a rod holder. The 16 PWR MOX fuel rods are required to be placed in a rod holder with a 5 × 5 insert. Along with the maximum 16 PWR MOX rod contents (or combination of PWR MOX and UO_2 PWR fuel rods), the remaining tubes may be loaded with burnable poison rods or other intact components with negligible heat loads (total additional heat load of less than 10 watts). Up to four (4) SLOWPOKE fuel canisters each containing up to 100 SLOWPOKE fuel rods with a maximum decay heat load of 0.625 Watts/canister can be loaded in a MTR basket module. For SLOWPOKE fuel contents, only the top and upper intermediate MTR-28 modules may be loaded. The empty intermediate basket modules and bottom basket modules are installed as axial spacers. The total package decay heat for SLOWPOKE fuel contents in the fuel canister is 5 Watts. In addition, a SLOWPOKE fuel core can be loaded in a SLOWPOKE fuel basket, which is placed on top of empty intermediate basket modules and a bottom MTR-42 fuel basket module. The maximum decay heat of the fuel core is 45 Watts.

LANL MOX Fuel Rods are loaded in up to sixteen (16) transfer tubes, which in turn are loaded in the PWR/BWR transport can assembly including the divider assembly. The total allowed heat load for this payload is 25 watts per cask.

An intact PWR fuel assembly with a maximum decay heat load of 2.5 kW is used in a majority of the thermal analyses. The failed fuel basket analysis in Section 3.6 uses a decay heat load of 30 Watts. The 42 MTR fuel assembly basket in Section 3.4.1.3 uses a decay heat load of 1.26 kW. A decay heat load of 1.05 kW is conservatively used for the TRIGA fuel basket analysis and a decay heat load of 0.693 kW is used for the TPBAR basket analysis. The maximum heat load for the PULSTAR fuel is 0.840 kW per cask. The maximum heat load for the maximum number of 16 PWR MOX fuel rods is 2.3 kW per cask (143 W per PWR MOX rod). The maximum heat load for the maximum number of (18) NRU or NRX fuel rod assemblies is 0.64 kW per cask. The maximum heat load for the damaged NRU or NRX fuels remains at 0.64 kW per cask, but 0.80 kW (0.64kW×1.25) per cask is used in thermal evaluation considering the concentration of the NRU/NRX rods. The NRU/NRX basket may also be loaded with EFN rods, Booster rods, or Moly targets and the maximum heat load for a basket slot having this content is less than 8 Watts per basket location. This is bounded by the 35.6 Watts per basket location (640 Watts per cask/18 tubes) for NRU or NRX fuels. The maximum heat load for four (4) HEUNL containers filled to capacity is 4.65 Watts per cask. As long as the decay heat load is within the design limit of 2.5 kW, any of the fuel types and other radioactive material that the NAC-LWT cask is analyzed to transport are bounded by the cask body thermal analyses of the design basis PWR assembly.

The primary heat rejection design criteria for the NAC-LWT cask are that:

1. Components important to safety shall not be subjected to temperatures outside their safe operating ranges.
2. Thermally induced stresses in the cask containment (in combination with pressure and various load condition stresses) shall not cause degradation of the cask containment capability.

The first criterion is fulfilled by thermal analysis results, which show that components important to safety are maintained within their safe operating ranges. In the event that the temperatures of the components important to safety fall outside the safe operating ranges, it is assumed that the component has failed. Temperatures of components important to safety may not fall outside the safe operating range during normal transport conditions. There are three important safety components that are subject to this thermal criterion – the tetrafluoroethylene (TFE), Viton®, and metallic O-ring seals; the lead gamma shield; and the 56 % ethylene glycol and water neutron shield.

An additional thermal consideration is associated with the liquid neutron shield tank – the reduction in neutron shielding capability caused by thermal contraction. An expansion tank is provided to ensure that the neutron shield tank remains full despite worst case contraction of the liquid in the tank during cooling. The method used by the expansion tank to keep the neutron shield tank full is described in Section 2.6.7.7.1.

The second criterion is fulfilled by the structural analysis of Chapter 2, which shows that combined load stresses (including thermally induced stresses) are less than the limits stated in Section 2.1.2.

The thermal analyses were performed for a 0.25-inch thick neutron shield tank shell, while the actual fabricated thickness is only 0.24 inches (6mm). The shell thickness difference of 0.01 inches equates to only a 0.009°F ΔT; therefore, the analyses reported in this chapter are valid.

3.4.4.7 Maximum Internal Pressure for 16 PWR MOX/UO_2 Fuel Rods or 16 LANL MOX Fuel Rods in Transfer Tubes

3.4.4.7.1 Maximum Internal Pressure for 16 PWR MOX/UO2 Fuel Rods in a Rod Holder

Based on the allowable loading of up to 16 PWR MOX/UO_2 fuel rods, cask internal pressures are calculated. Bounding cask free volume, gas temperatures, and rod backfill pressure are directly obtained from the BWR high burnup rod evaluations in Section 3.4.4.3.

Variable	Unit	Value
Cask Free Volume (PWR Basket with Insert/Canister/Rod Holder)	in^3	5908
Normal Condition Cask Average Gas Temperature	ºF	600
Normal Condition Cask Backfill Partial Pressure (at temperature)	psia	29.3
PWR Fuel Rod Backfill Pressure	psia	565

These values are combined with a conservative 2.9 in^3 fuel rod free volume and SAS2H calculated fission and actinide gas inventories to determine system pressure. The 2.9 in^3 free rod volume applied here is larger than the UO_2 rod volume previously employed (2.5 in^3) to account for additional volume designed into the MOX rods to counter any potential increase in fission gas release from the PuO_2 / UO_2 MOX fuel mixture.

The ideal gas law and Dalton's law of partial pressures are used to calculate internal pressures by combining cask backfill, rod backfill, and fission/actinide gases. Fill temperature applied to the rod gases is 22ºC (standard temperature). Maximum fission and actinide gas inventories were obtained from 80 GWd/MTHM fuel rod, 3% enriched ^{235}U or 3 wt % fissile Pu, SAS2H output sets. The fuel rod corresponds to the maximum fissile mass defined in the shielding source term calculations. SAS2H runs produced a total gas inventory of 0.29 moles per rod (99+% fission gas), with bounding values obtained from the UO_2 rods (MOX rods produce approximately 98% of the UO_2 rod fission gas). Gas inventories increase as a function of reduced initial fissile material content. A 3% enrichment and/or 3% fissile Pu content is significantly below levels required to reach an 80 GWd/MTHM burnup level.

The resulting normal condition pressure for a failure fraction of 1/16 (bounds the 3% normal condition PWR rod failure fraction in the Standard Review Plan, NUREG-1617, Supplement 1) and 30% fission gas release is 17.2 psig (31.9 psia, or 2.2 atm).

Parametric studies are performed on the number of rods failing and the release fraction under normal conditions with an applied limit of 50 psig (normal condition structural analysis input value). Normal condition failure of up to 13 rods, at 100% gas release, remains below 50 psig. A similar analysis results in a maximum normal condition pressure of 48.5 psig for a normal condition failure of all 16 rods at a 75% fission gas release fraction (100% of backfill gas is released). Given that each of the rods is individually located within a support tube, no normal condition rod failures are expected during transport.

UO_2 or MOX rods included in the payload may be IFBA rods. As presented in Section 3.4.4.3, IFBA rods are expected to contribute in the range of 0.04 mole per rod to system pressure, assuming the absorber material is boron. As the MOX/UO_2 pressure calculations assumed a conservative 100% fission gas release of 0.29 mole per rod, a rod backfill of 0.075 mole, and a cask backfill of approximately 3.6 moles, the release of IFBA boron-generated gases would not significantly affect system pressure.

3.4.4.7.2 16 LANL MOX Fuel Rods in Transfer Tubes

LANL MOX Fuel Rods do not contain a significant heat source or fission gas quantity. Given the similarity in cask configuration to that of high burnup LWR MOX payload, which has both a significant fission gas quantity to release and a significant heat load, pressurization of the cask cavity will be bounded by that of the MOX rods.

3.4.4.8 Maximum Internal Pressure for Aluminum-Based Fuels

This section determines the bounding NAC-LWT transportation system internal pressure for the cask during normal conditions for aluminum-based research reactor fuel payloads (i.e., ANSTO, DIDO, MTR, and NRU/NRX fuels).

This analysis uses a combination of thermodynamic principles and dimensional analysis to calculate internal pressure. The basic functions employed are the Ideal Gas Law ($Pv = NRT$) and Dalton’s Law of Partial Pressure. For a given cask free gas volume, internal pressure is a function of fission gas and cask backfill gas. The aluminum-based plate element does not contain any backfill gases or free volume within the clad.

Volume, temperature and backfill inputs required for the system pressure evaluations are summarized in Table 3.4-23. Standard temperature (22.2ºC) is used for the cask backfill initial temperature. This is a reasonable assumption, as backfill gas will rapidly increase in temperature during cask fill operations. As the payload generates decay heat, the average temperature at sealing is expected to be significantly higher than the standard temperature. Minor changes in temperature, translated to absolute temperature for pressure calculations, would not affect the results of the calculation significantly.

NRU/NRX payloads are not evaluated for system pressure as inputs into the analysis outlined below; all indicate a conservative system pressure being obtained from the MTR payload:

- Total heat load and temperature are below that of the MTR payload. Furthermore, total fuel and fissile material mass (U-Al, or UAl-Si) in the 18 NRU/NRX assemblies is less than MTR fuel mass (2 elements maximum).

- MTR elements were evaluated at higher burnup levels than NRU/NRX and therefore, the NRX/NRU fuel will contain less fission gas.

The void space in the NRU/NRX cask cavity is higher than that of the fully loaded MTR system as the NRU/NRX bottom basket spacer occupies very little volume versus a loaded MTR basket and the NRU/NRX fuel assembly and basket cross section contains significant void areas.

3.4.4.8.1 Fuel Fission Gas Content

SAS2H source term calculations documented in Chapter 5 were used to generate fuel gamma and neutron sources. Included in this determination are gram quantities of light elements, fission products and actinides. Fission gas inventories are extracted from the ANSTO spiral fuel, DIDO LEU, MEU and HEU, and maximum fuel mass MTR LEU, MEU and HEU cases. Only the ANSTO spiral fuel is required as ANSTO DIDO fuel is bounded by the standard DIDO fuel definition, and ANSTO MOATA fuel is bounded by the generic MTR fuel definition. Minimum transport cool times are chosen for the analysis. None of the payloads generate significant quantities of actinide alpha decay gases, as plutonium generation is limited in the fuel elements modeled at 19% or greater ^{235}U enrichments. The negligible buildup of alpha decay gases makes the choice of cool time insignificant to the analysis results.

Fission product and actinide gas inventories in grams extracted from the SAS2H outputs are listed in Table 3.4-24. Fission gas inventories in grams are converted to inventories in moles using Avogadro's number and the atomic mass of each isotope. As illustrated in Table 3.4-25, the total molar quantity of fission gas does not vary significantly between various enrichment levels for a given fuel type. The MTR elements produce the bounding fission gas content. The majority of fission gases, ~85%, is comprised of Xenon isotopes. There is no significant quantity of helium or tritium.

3.4.4.8.2 Normal Condition Pressures

Using Dalton's Law of partial pressures, the NAC-LWT cask cavity pressure may be calculated by first determining the partial pressure of the released fission gases and adding it to the cask backfill gas. Gas available for release from the fuel elements depends on the fueled surface area exposed by clad-through damage.

Cask Backfill Gas

Based on the ideal gas law, the pressure of the cask backfill gas is simply the ratio of the backfill temperature at testing (assumed at standard temperature) to the operating condition temperature.

$$P_{\text{Cask Backfill}} = 14.7\ \text{psi} \times \frac{T_{\text{Operating Temperature}}}{T_{\text{Standard Conditions}}}$$

Partial pressures of the cask backfill at normal and accident conditions are 23.8 psi and 25.9 psi for ANSTO/DIDO and MTR payloads, respectively.

Fission Gas

The pressure of rod fission gas is calculated using release fraction (or surface area fraction assuming 100% release from the unclad fuel meat), the quantity of fission gas in the element, the cask cavity backfill temperature and the cask cavity gas temperature.

$$n = \text{Fission Gas Moles (Cask)} \times \text{Release Fraction}$$

$$P = \frac{\text{nRT}}{\text{V}}$$

For the MTR LEU fuel, a sample calculation based on a 50% surface area exposed with a 100% gas release from the exposed surface area is:

$$P_{\text{Fission Gas}} == \frac{0.455\,\frac{\text{moles}}{\text{element}} \times 42\,\frac{\text{elements}}{\text{cask}} \times 50\% \times 0.08206\,\frac{\text{liters}-\text{atm}}{\text{k}-\text{mole}} \times 470.2\text{K}}{229.3\,\text{liters}}$$

$$P_{\text{Fission Gas}} = 1.61\,\text{atm} = 23.7\text{ psi}$$

Normal Pressure

Normal and accident pressures can now be generated at the various release/surface area fractions. Only LEU MTR and DIDO elements are summarized as they produce the maximum MTR and DIDO fission gas quantities and, therefore, pressures. Results are summarized in Table 3.4-26 as partial pressure of the fission gas and total system pressure in psia and psig. To meet a 50 psig system structural analysis limit, a maximum 80% of the MTR and 100% of the DIDO/ANSTO gases can be assumed to escape from the plates. As MTR plates with significant through-clad damage will have released a portion of their gas inventory prior to transport (i.e., during in-core use, storage and cask vacuum drying), system pressure is expected to remain below 50 psig when considering all fission gas released from the MTR plates.

Note that experimental data summarized in WSRC-TR-98-00317, October 1998, “Bases for Containment Analysis for Transportation of Aluminum–Based Spent Nuclear Fuel,” Section 5.3.1, indicates no significant release of gases from exposed fuel material occurs at the temperature (200°C -300°C) of the NAC-LWT cask cavity and contents with aluminum-based fuel payload.

their respective minimum cool times of 18 and 19 years. NRU LEU fuel assemblies are found to be within regulatory compliance at a minimum cool time of 3 years.

A payload of 4 HEUNL containers is analyzed in Section 5.3.20. Source terms were calculated using an inventory of gamma-emitting radionuclides with the actinide and nitrate contents. The ORIGEN-S control module in SCALE 6.1 is used to calculate source spectra. A maximum payload of 64.3 L (17.0 gal) per container is conservatively applied for the source strength (due to void volume in the container that allows HEUNL thermal expansion, actual container capacity is less). Three-dimensional dose rates are calculated using the MCNP v1.60 code. The HEUNL payload is found to be within regulatory limits.

A payload of a SLOWPOKE core, up to 298 rods with 2.81 g ^{235}U per rod with a minimum enrichment of 90 wt% ^{235}U, is analyzed in Section 5.3.23. Source terms were calculated using TRITON in SCALE 6.1 with three-dimensional dose rates calculated using MCNP5 v1.6. The SLOWPOKE core is found to be within regulatory limits after a minimum cool time of 14 days.

A payload of Booster rods, EFN (Enriched Fast Neutron) rods, or Mo-99 (“Moly”) targets is analyzed in Section 5.3.24. Source terms were generated using TRITON in SCALE 6.1 for each of the payload types in the NRU/NRX basket and compared to those of the previously evaluated NRU-HEU payload. As demonstrated in Section 5.3.24, the sources and source density associated with the additional payloads are less than those previously evaluated. Dose rate results are therefore bounded by the NRU-HEU configuration.

A payload of two BUP-500 capsules or 18 WESF capsules is analyzed in Section 5.3.25. Source terms were generated using ORIGEN in SCALE6.2.4 with three-dimensional dose rates calculated using MCNP6.2. As demonstrated Section 5.3.25, the dose rates associated with the additional payloads are significantly less than those previously evaluated and are demonstrated to meet 10 CFR 71.47 and 10 CFR 71.51 limits. As maximum dose rates on the cask surface are less than 10 mrem/hr the transport index, TI, is less than 10 therefore exclusive use is not required based on shielding requirements.

A payload of 16 transfer tubes loaded with LANL MOX Fuel Rods (which include both MOX, i.e. plutonium as the primary fissile material, and enriched UO_2 based fuel material rods) are permitted for transportation. Shielding evaluations for the LANL MOX material are not required as the source associated with these rods is limited to decay radiation (primarily alpha) of the as-built fuel materials, not the fission product and higher actinides produces by burned/spent fuel material. The decay heat associated with these rods was estimated to be less than 1 watt per rod, with a limit set at 25 watts per cask. Section 5.3.17 demonstrates that a high burnup MOX rod payload with a heat load of 2.3 kW, with its associated fission product and higher actinide inventories, is acceptable for transport in the same basket and similar canister configuration as the LANL MOX

Fuel Rods; therefore, the LANL MOX Fuel Rods are acceptable for transport and will meet all regulatory requirements. Cask surface dose rates associated with LANL MOX Fuel Rods are estimated to be less than 1 mrem/hr. This estimate is based on a maximum surface dose rate of 110 mrem/hr reported for high burnup MOX materials in Section 5.3.17, a LANL MOX package maximum heat load of ~1% of the high burnup MOX materials, and most of the LANL MOX heat being associated with alpha decay which will not contribute significantly to cask dose rates

- up to 800 SLOWPOKE fuel elements contained in up to 8 SLOWPOKE fuel canisters,
- 1 SLOWPOKE fuel core containing up to 298 SLOWPOKE fuel elements in the SLOWPOKE fuel core basket,
- Up to 20 short Moly targets, 36 double length Moly targets, 36 EFN rods, or 16 Booster rod'
- Up to two BUP-500 capsules or 18 WESF capsules; or
- Up to 16 transfer tubes loaded with LANL MOX Fuel Rods.

The 25 high burnup PWR and BWR rods may be transported in three configurations: 1) a maximum of 25 intact fuel rods loaded in the rod holder; 2) a maximum of 25 fuel rods with up to 14 damaged fuel rods or rod fragments loaded in the rod holder; and 3) a maximum of 25 intact fuel rods housed in a fuel assembly lattice within the NAC-LWT PWR basket. The fuel assembly lattice may be irradiated up to an equivalent burnup of 80,000 MWd/MTU.

The metallic fuel consists of a single rod of uranium metal clad with aluminum. The intact metallic fuel rods are placed into a transport canister that will hold five intact rods. The cask can hold three transport canisters for a total of 15 intact metallic fuel rods. In the event the metallic fuel has failed or is suspected of having failed, each fuel rod is sealed in its own container. The failed metallic fuel is loaded into either one of the three holes in the metallic fuel basket or into one of the six openings in the failed metallic fuel basket.

MTR research reactor fuel elements are typically 33 to 57 inches long, including lower nozzle and upper handle. The fuel plates typically consist of U-Al, U_3O_8-Al, or USi-Al clad with aluminum. The fuel plates are held in a parallel arrangement with two thick aluminum slotted pieces to form a fuel element. Standard fuel elements have between 10 and 23 fuel plates. The active fuel region is typically 22.75 inches in height, and the fuel meat is typically 0.023-inch thick. The highly enriched uranium (HEU) fuel has been analyzed conservatively with an enrichment of 90 wt % ^{235}U and fuel loading per element up to 380 g ^{235}U, with a separate analysis performed to accommodate up to 460 g ^{235}U. The design basis fuel parameters are provided in Table 5.1.1-1. The fuel characteristics are presented in Table 5.1.1-2. The dose rates produced from the design basis 470 g ^{235}U and 640 g ^{235}U LEU and 380 g ^{235}U MEU MTR fuel are bounded by the HEU MTR design basis fuel. Therefore, a mixed loading of LEU, MEU and HEU MTR fuel elements are also bounded by a full HEU MTR fuel element loading.

The source term characteristics of the design basis PWR fuel assembly, BWR fuel assembly, metallic rods, 25 PWR rods, 16 PWR MOX rods, and MTR fuels are given in Table 5.1.1-3. The design basis PWR and BWR fuels require two years of cooling after discharge to meet the neutron and gamma source, and decay heat limits of the cask. The MOX rods require 90 days of cooling. The design basis metallic fuel requires one year cooling. The design basis MTR fuel

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

Fuel Type - Booster Rods
- 91.0 wt % minimum ^{235}U initial enrichment
- 2.9% maximum ^{235}U depletion
- 0.2 W/caddy maximum decay heat
- Minimum cool time 37 years

Fuel Form - Undamaged or collapsed/damaged
Quantity - Up to 16 rods per caddy; up to 18 caddies per Cask
Source of Fuel - Gentilly-1 reactor
Transport Index - 2.3

[redacted]

Fuel Type - LANL MOX Fuel Rods
- Maximum 25W per cask

Fuel Form - Rods
Quantity - Up to 16 transfer tubes
Transport Index - 1 (based on estimated cask surface dose rates)

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NAC-LWT

Legal Weight Truck Cask System

SAFETY ANALYSIS REPORT

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NON-PROPRIETARY VERSION

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6 CRITICALITY EVALUATION

The NAC-LWT cask is designed to transport either 1 pressurized water reactor (PWR) assembly; up to 25 intact PWR or BWR rods in a rod holder or fuel assembly lattice; up to 25 PWR or BWR fuel rods with a maximum of 14 of the rods classified as damaged in a rod holder; up to 16 PWR UO_2 or MOX rods in a rod holder; 2 boiling water reactor (BWR) assemblies; 15 sound metallic fuel rods; 6 failed metallic fuel rods; up to 42 high enriched uranium (HEU), medium enriched uranium (MEU) or low enriched uranium (LEU) Materials Test Reactor (MTR) fuel elements, or DIDO fuel assemblies; up to 140 TRIGA fuel elements; two packages of General Atomics Irradiated Fuel Material (GA IFM); up to 560 TRIGA fuel cluster rods; 1 consolidation canister with up to 300 TPBARs (including up to 2 damaged TPBARs); up to 700 PULSTAR fuel elements; up to 42 spiral fuel assemblies; up to 42 MOATA plate bundles; up to 800 SLOWPOKE rods; up to 18 NRU or NRX fuel assemblies; 4 HEUNL containers; one SLOWPOKE fuel core; or up to 18 NRU/NRX caddies loaded with EFN rods, Booster rods, or Moly targets; up to two BUP-500 capsules or 18 WESF capsules or up to 16 transfer tubes with LANL MOX Fuel Rods (which include both MOX, i.e. plutonium as the primary fissile material, and enriched UO2 based fuel material rods). This chapter illustrates that all packages meet the requirements of parts 71.55, 71.59 and 71.71 of 10 CFR 71.

In accordance with the requirements of 10 CFR 71.59 (b), the NAC-LWT cask is assigned a Criticality Safety Index (CSI) for criticality control for the authorized contents as follows:

Approved Contents	CSI
PWR fuel assemblies	100
BWR fuel assemblies	5.0
MTR fuel elements	0.0
Metallic fuel rods	0.0
TRIGA fuel elements (in poisoned TRIGA fuel baskets)	0.0
TRIGA fuel elements (in nonpoisoned TRIGA fuel baskets)	12.5
TRIGA fuel cluster rods	0.0
High burnup PWR (UO_2 or MOX) rods*	0.0
High burnup BWR rods*	0.0
DIDO fuel elements	12.5
General Atomic Irradiated Fuel Material (GA IFM)	0.0
TPBARS and segmented TPBARS	0.0
Intact (uncanned) PULSTAR fuel	0.0
Canned PULSTAR fuel	33.4
ANSTO fuel (spiral and/or MOATA)	0.0
Solid irradiated hardware	0.0
ANSTO-DIDO fuel combination	0.0
SLOWPOKE fuel rods (undamaged or damaged)	0.0
NRU and NRX; EFN Rods, Booster Rods, Moly Targets	100
HEUNL containers	0.0
SLOWPOKE Fuel Core	100
BUP-500 or WESF capsules	0.0
LANL MOX Fuel Rods	25

* up to 14 damaged rods

Section 6.7.6 present the methods and MCNP models used in the analyses. Section 6.7.3.3 presents the criticality analysis results of the NAC-LWT cask loaded with the NRU/NRX payload, with caddy results for EFN rods, Booster rods, or Moly targets in section 6.7.6.3. Criticality of the NAC-LWT cask with the most reactive configuration is evaluated. The fuel assemblies are assumed to be unburned. A single cask is analyzed. The results of the analysis show that the $k_{eff} + 2\sigma$ of the NAC-LWT cask with the most reactive configuration under normal and accident conditions is below the upper safety limit (USL) for highly enriched uranium (HEU) fuel.

Analyses are performed on the NAC-LWT with 4 HEUNL containers. The HEUNL material is permitted with up to 7.40 g/L ^{235}U at a maximum ^{235}U enrichment of 93.4 wt%. The evaluated payload considers a bounding container volume of 64.3 L (17.0 gal). Due to void volume in the container that allows HEUNL thermal expansion, actual container capacity is less. All evaluation detail, including input, method, and analysis results are included in Section 6.7.4. The criticality benchmark for this material is provided in Section 6.5.7. Criticality of the NAC-LWT cask with the most reactive configuration is evaluated. Considered in the most reactive configuration is the uranyl nitrate (other nitrates separated) at optimal H/U. The results show that the bias adjusted k_{eff} of an infinite array of NAC-LWT casks with the most reactive HEUNL configuration under normal and accident conditions is below the upper safety limit (USL) for highly enriched uranyl nitrates.

Analyses are performed on the NAC-LWT with one SLOWPOKE fuel core. The SLOWPOKE fuel core is permitted to contain up to 298 SLOWPOKE fuel rods with up to 95.3 wt % ^{235}U initial enrichment. The payload consists of undamaged fuel. All evaluation details, including input, method, and analysis results, are included in Section 6.7.5. The criticality benchmark analysis for this material is shown in Section 6.5.5. Included in Section 6.7.5 are the fuel core geometry and material description, the MCNP model used in the basket, and the criticality analysis results of the NAC-LWT loaded with one SLOWPOKE fuel core. The fuel is assumed to be fresh, i.e., no burnup credit. With the exception of the normal condition array, a single cask is analyzed. The fuel rod pitch is optimized. Variation of moderator density is considered. This includes preferential flooding evaluations of the basket that contains the fuel core. The results show that the bias adjusted k_{eff} of an NAC-LWT cask at maximum reactivity fuel rod pitch and at maximum reactivity interspersed moderation is below the upper safety limit (USL).

Criticality evaluations for the NAC-LWT loaded with SrF_2 capsules (BUP-500 or WESF capsules) are not required because the capsules do not contain fissile material and, therefore, cannot form a critical configuration.

Analyses are performed on the NAC-LWT with up to 16 transfer tubes with LANL MOX Fuel Rods. The payload consists of undamaged fuel rods (i.e., no gross fuel failure, hairline cracks or pinholes are allowed). All evaluation detail, including input, method, analysis results and critical benchmarks, are included in Section 6.7.7. Included are the fuel rod geometry and material description, the MCNP model used in the rod holder analyses, and the criticality analysis results of the NAC-LWT loaded with up to 16 transfer tubes. The fuel is assumed to be fresh, i.e., no burnup credit. Variation of moderator density inside and outside the cask is considered. Also included in the analysis are preferential flooding evaluations of the canister that contains the rod array. The results show that the bias adjusted k_{eff} of a 4-cask array of NAC-LWT casks at optimum fuel rod pitch and at optimum interspersed moderation is below the upper safety limit (USL) for MOX and UO_2 criticality benchmarks.

6.2 Package Fuel Loading

The NAC-LWT cask can safely transport 1 PWR assembly, up to 25 intact PWR or BWR rods in a rod holder or fuel assembly lattice, up to 25 PWR or BWR rods with up to 14 of the fuel rods classified as damaged in a rod holder, 2 BWR assemblies, 15 sound metallic fuel rods, 6 failed metallic fuel rods, up to 42 MTR fuel elements, up to 140 TRIGA fuel elements, up to 560 TRIGA fuel cluster rods, up to 42 DIDO fuel assemblies, two General Atomics Irradiated Fuel Material packages, up to 300 TPBARs (of which two can be damaged), up to 700 PULSTAR fuel elements, up to 42 spiral fuel assemblies, up to 42 MOATA plate bundles, up to 800 SLOWPOKE rods, up to 18 AECL NRU or NRX fuel assemblies, 18 NRU/NRX caddies loaded with EFN rods, Booster rods, or Moly targets, one SLOWPOKE fuel core, two BUP-500 capsules or 18 WESF capsules, or up to 16 transfer tubes with LANL MOX Fuel Rods. The characteristics for payloads containing fissile material are presented in the following sections. Fresh fuel is conservative because the fuel becomes less reactive as burnup increases. Burnable poisons, such as the gadolinium rods sometimes used in BWR assemblies, are ignored for conservatism.

TPBARs are stainless steel clad rods containing $LiA1O_2$ absorber pellets and nickel-plated Zircaloy getter tube or nickel-plated zirconium (NPZ) alloy spacer tubes with no absorber pellets. The TPBARs do not contain any fissile material.

[redacted]

6.7.7 LANL MOX Fuel Rods

This section includes input, analysis method, results, and criticality benchmark applicability evaluations for the NAC-LWT cask containing a payload of up to 16 transfer tubes loaded with LANL MOX Fuel Rods, see list in Table 1.2-20. The fuel rods may be composed of uranium oxide fuel pellets, plutonium oxide fuel pellets, mixed oxide fuel pellets, plutonium carbide fuel pellets, or mixed carbide fuel pellets.

6.7.7.1 Package Fuel Loading

The NAC-LWT cask may transport up to 16 transfer tubes with undamaged fuel rods. There are six unique rod types that bound the rods intended for shipment. Characteristics and quantity limits of the design basis fuel rods are presented in Table 1.2-20. Each of the rods is significantly shorter than the transfer tube array. The allowed number of rods per transfer tube shown in Table 1.2-20 are based on the number of rods that will physically fit into a transfer tube, except for fuel type 530-000, where only one rod is authorized per transfer tube, despite there being space for more than one.

6.7.7.2 Criticality Model Specifications

This section describes the models that are used in the criticality analyses for the NAC-LWT cask containing up to 16 transfer tubes loaded with LANL MOX Fuel Rods. The rods consist of natural uranium mixed with plutonium, highly enriched uranium with no plutonium, plutonium rods with no uranium, or highly enriched uranium with plutonium. The models are analyzed separately under normal conditions and hypothetical accident conditions to ensure that all possible configurations are subcritical.

The model uses the MCNP6.2 code package with the ENDF/B-VI cross-section set. No cross-section pre-processing is required prior to MCNP implementation. MCNP uses the Monte Carlo technique to calculate the k_{eff} of a system. In these analyses, approximately 1000 cycles with 10,000 neutron histories per cycle are tracked through the system. There are no statistical differences between MCNP6.2 and MCNP5, which was used for the UO_2 and MOX validations in Section 6.5.4.

Description of Calculational Models

The MCNP model of the NAC-LWT cask with up to 16 transfer tubes includes four 2x2 arrays of transfer tubes in the PWR insert and can weldment. The 2x2 arrays are separated by a divider plate. There are two divider options, denoted as thick and thin; both are analyzed. The cask is explicitly modeled and identical to the model shown in Figure 6.7.1-1.

The model of the NAC-LWT cask takes advantage of the universe structure of MCNP. Each universe defines an infinite space, bounded after its insertion into a containing cell. The “0” universe defines the cask universe. Other universes are defined for the basket, fuel rod array, transfer tube, and fuel rod. Each universe is developed independently as surfaces and cells. In the basket universe, the rod array is placed into a square (RPP) body that allows the moderator density outside the rod/tube array to be adjusted independently.

The modeled accident condition completely removes the neutron shielding, the neutron shield tank and the cask impact limiters. In the normal conditions model, the impact limiter diameter is modeled as identical to the neutron shield tank diameter. This allows for closer packing for the cask array than physically possible.

VISED sketches of the assembled geometry are shown in Figure 6.7.7-1 and Figure 6.7.7-2. Under normal conditions, the cask outer surface is surrounded by a rectangular body with reflecting boundary conditions. The boundary conditions are imposed on the sides, top and bottom, which simulates an infinite array of casks. Under accident conditions, a 4-cask array is modeled and surrounded by a full density water reflector. Therefore, the CSI is 25.

Package Regional Densities

Basket and cask composition densities (g/cc) and nuclide number densities (atm/b-cm) used in the subsequent criticality analyses are shown in Table 6.7.7-1. The various fuel compositions used are listed in Table 6.7.7-2.

Figure 6.7.7-1 VISED Sketch of LWT Radial View – Normal Conditions (Cask and Basket Detail)

[redacted]

Figure 6.7.7-2 VISED Sketch of LWT Axial View – Normal Conditions

[redacted]

Table 6.7.7-1 LANL MOX Fuel Rods Basket/Cask Compositions and Number Densities

[redacted]

Table 6.7.7-2 LANL MOX Fuel Rods Compositions and Number Densities

[redacted]

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[1] Shown for bounding carbide fuel form.

6.7.7.3 Criticality Calculations

This section presents the criticality analysis for the NAC-LWT cask with up to 16 transfer tubes loaded with LANL MOX Fuel Rods. As stated above, there are six rod types that bound the rods intended for shipment. The rods consist of natural uranium mixed with plutonium, highly enriched uranium with no plutonium, plutonium rods with no uranium, or highly enriched uranium with plutonium.

Criticality results are divided into individual sets of analyses.

- Evaluate the NAC-LWT accident configuration to determine the bounding fuel type(s), divider thickness, and rod pitch.
- Run the optimum moderator density evaluation.
- Evaluate normal condition and single cask “containment reflected” cases.

Rod Type Study

Each of the six rod types is evaluated to determine the bounding fuel type using the thin divider plate and the maximum pitch. Results are shown in Table 6.7.7-3, summarized as follows:

- Due to their high plutonium contents, the 530-000 and ROD1063 rods are significantly more reactive than the other rods. These rods are modeled with one and three rods axially per tube, respectively. The contents are limited to one 530-000 rod per tube (and one tube per cask) and three ROD1063 rods per tube (12 tubes per cask). Rod 530-000 is either oxide or carbide. The carbide form (denoted by the “-C” suffix) is significantly more reactive than the oxide form (denoted by the “-O” suffix).
- The NIS5 carbide rods are modeled with 3 rods axially per tube. These rods are subcritical ($k_{eff}+2\sigma < 0.49$).
- The UO_2 rods have a small area that allows for more than one rod in the x/y plane. Therefore, two and four rods per elevation are also considered. These rods are subcritical ($k_{eff}+2\sigma < 0.64$) with up to four rods per elevation (eight per tube).
- The PNNL and Exxon rods are natural uranium with a relatively small amount of plutonium. The PNNL rods are modeled with four axially per tube and the Exxon rods are modeled with two axially per tube. These rods are subcritical ($k_{eff}+2\sigma < 0.37$).

Based on these results, a mixed loading need not be considered. In particular, with the payload limited to a maximum of one 530-000 rod/tube per cask and three ROD1063 rods per tube (12 tubes per cask), 16 tubes of ROD1063 (48 rods per cask) represents a bounding reactivity configuration. ROD1063 is used for the studies that follow.

The next step varies the divider thickness and pitch (for ROD1063). Results are shown in Table 6.7.7-4. The thin divider tube at maximum pitch is the most reactive. This configuration maximizes the H/U-235 ratio. As noted in the structural evaluation, there is no permanent set to the basket as a result of HAC and only minimal elastic deformation (max ~0.1”) during the drop. Therefore, analysis of a pitch greater than the maximum need not be considered.

Optimum Moderator Density Evaluation

ROD1063 is evaluated at various internal and external moderator densities, including preferential flooding of the fuel region. For the preferential flooding scenarios, the square container containing the rod array is evaluated at a moderator density independent of that in the remainder of the cask cavity. Figure 6.7.7-3 contains the moderator density plot. The maximum reactivity is achieved by a preferentially flooded fuel region and void cavity and cask exterior. This result was to be expected as it provides maximum neutronic coupling within the reflective boundary (infinite array) model. Results are summarized in Table 6.7.7-5.

Single Cask Containment (Fully Reflected) and Normal Condition Array Evaluations

A single cask evaluation is performed to comply with 10 CFR 71.55(b)(3).

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 flooded and fully flooded cases are reevaluated by removing the lead and outer shells (including neutron shield), and reflecting the system by 20 cm water at full density on the X, Y, and Z faces. Single cask, containment fully reflected reactivities are summarized in Table 6.7.7-6.

A normal condition infinite cask array is also evaluated. As indicated by the evaluations of the accident conditions array, including the radial neutron shield reduces system reactivity by eliminating neutronic interaction between casks. Normal condition cask array results are summarized in Table 6.7.7-7.

Maximum Reactivities and Comparison to USL

The maximum $k_{eff}+2\sigma$ results for three primary analysis groups (single cask, normal array, and accident array) are summarized in Table 6.7.7-8. Two normal condition array cases are included as the cask remains dry through all operating conditions, while 10 CFR 71 requires a normal condition maximum reactivity moderator density case. The listed values represent the maximum system reactivity adjusted for Monte Carlo run uncertainty and are below the lower of the two system USLs.

No benchmarks for mixed heterogeneous UO_2 and MOX rod systems are publicly available. Therefore, individual benchmarks are established for UO_2 and MOX systems. The more limiting

USL is applied to the results. Per Section 6.5.4, the USL for an array of UO_2 rods is 0.9376 and 0.9331 for an array of MOX rods for a Δk of 0.0045 between the two fuel types. The evaluations demonstrated that MCNP, with its associated cross-sections, accurately predicts system reactivities containing either fuel rod type.

The focus of the evaluations is a wet (flooded) system, as no reasonable extrapolation of the data provided would indicate a safety concern for a dry system at the requested fissile material levels. While it is recognized that code performance and bias are potentially affected by the difference in the energy level of neutron causing fission, the benchmarks accounted for the basic phenomena, and the computer code is capable of tracking particles at their relevant energy levels.

Table 6.7.7-9 compares the rod/material combinations to the area of applicability for ROD1063. ROD1063 is PuO_2 only; therefore, the hypothetical configuration is significantly outside the area of applicability of the benchmark calculation. There is no statistically significant trend of reactivity versus energy and any relative changes in USL postulated from the extrapolation is not significant.

As the shipment includes uranium oxide rods, the maximum reactivity uranium oxide rod configuration characteristics are compared to its area of applicability in Table 6.7.7-10. Exceeding the area of applicability for enrichment, pellet diameter, rod diameter, and $H/^{235}U$ ratio in the UO_2 benchmark cases is acceptable as none of these variables has a trend that is statistically significant. Similarly, there is no statistically significant trend of reactivity versus energy and any relative changes in USL postulated from the extrapolation is not significant.

Table 1.2-20 lists the bounding characteristics for the fuel rods evaluated in this section.

Figure 6.7.7-3 LANL MOX Fuel Rods Moderator Density Study

[redacted]

Table 6.7.7-3 LANL MOX Fuel Rods
Reactivity as a Function of Rod Type

[redacted]

Table 6.7.7-4 LANL MOX Fuel Rods
Reactivity as a Function of Divider Thickness and Rod Pitch

[redacted]

**Table 6.7.7-5 LANL MOX Fuel Rods
Reactivity Summary for Accident Condition Array Cases**

[redacted]

**Table 6.7.7-6 LANL MOX Fuel Rods
Reactivity Summary for Single Cask Containment Fully Reflected Cases**

[redacted]

**Table 6.7.7-7 LANL MOX Fuel Rods
Reactivity Summary for Normal Condition Array Cases**

[redacted]

**Table 6.7.7-8 LANL MOX Fuel Rods
Summary of Maximum Reactivity Configurations**

[redacted]

Table 6.7.7-9 LANL MOX Fuel Rods MOX Comparison to Area of Applicability

[redacted]

Table 6.7.7-10 LANL MOX Fuel Rods UO_2 Comparison to Area of Applicability

[redacted]

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  a. If the dose rate is less than 2 mSv/h (200 mrem/hr) at all accessible points on the external surface of the package, and the TI is less than 10, the package meets the requirements of 10 CFR 71.47 (a).
  b. If the dose rate is greater than 2 mSv/h (200 mrem/hr), but is less than 10 mSv/h (1000 mrem/hr) at any point on the external surface of the package, or the TI is greater than 10, the package must be shipped as “exclusive use” and meet the requirements of 10 CFR 71.47 (b), (c) and (d). If the dose rate and shipping requirements of 10 CFR 71.47 (b), (1), (2), (3) and (4) cannot be met, the package cannot be shipped.
  c. If the dose rate is > 10 mSv/h (1000 mrem/hr) at any point on the external surface of the package, the package exceeds the limits of 10 CFR 71.47 and cannot be shipped.

40. Determine the appropriate Criticality Safety Index (CSI) assigned to the package contents in accordance with the CoC, and indicate the correct CSI on the Fissile Material label applied to the package per 49 CFR 172, Subpart E.
41. Complete the shipping documents, carrier instructions (as required), and apply appropriate placards and labels.

7.1.22 Procedure for the Dry Loading of LANL MOX Fuel Rods

This section describes the procedures for loading the NAC-LWT cask with LANL MOX Fuel Rods. The LANL MOX Fuel Rods are required to be loaded into Transfer Tubes prior to being loaded into the PWR/BWR Rod Transport Canister. The PWR Fuel Basket Assembly will contain the PWR insert, PWR/BWR Rod Transport Canister, Divider Plate, Transfer Tubes, Fuel Rods, and Transfer Tube spacers, as required. The PWR/BWR Rod Transport Canister, 315-40-098, Assembly 96, 97, 98 or 99 is used without the corresponding internal inserts, 315-40-098, items 7, 8 or 19. Any of the 315-40-098 assemblies may be used.

The maximum decay head load of a loaded Canister shall be ≤ 25 Watts.

The maximum content weight per basket shall be 1,479 lbs. See Table 2.2.1-1 for details.

LANL MOX Fuel Rods variants include the following rod types: PNNL, Exxon, UO2, ROD1063, 530-000, and NIS5. Fuel rods of different types may NOT be placed into a single Transfer Tube, however different rod types are allowed within the same package, subject to the limitations in Table 1.2-20. Only one 530-000 type fuel rod may be loaded in a given package, which can include other transfer tubes loaded with other fuel rod types.

The Transfer Tubes consist of the Transfer Tube weldment, tube bottom end spacer, specified LANL MOX fuel rod(s), Transfer Tube Spacer (as required), and final tube top end spacer. Transfer Tube Spacers are required at the top and bottom end of each tube except for Transfer Tubes being used as spacers, which may be completely empty. Spacers may be used to separate the contents but are not required. The Transfer Tubes shall be arranged up to a 16-tube configuration. Empty Transfer Tubes may be loaded to act as spacers if desired to obtain a full 16-tube complement for the shipment.

The PWR/BWR Transport Canister and Divider Plate will be preloaded into the NAC-LWT prior to loading of the loaded Transfer Tubes. The Transfer Tubes with LANL MOX Fuel Rods will be loaded with the required stack-up of Tube End Spacers, Fuel Rods, and Transfer Tube Spacers per the specific loading plan for the approved contents. The Transfer Tubes will then be placed into the NAC-LWT individually filling each section of the divider plate. Transfer Tubes may be loaded without fuel rods and considered spacers in the event of a partially loaded shipment.

The procedure for dry loading the Transfer Tubes is as follows:

1. Perform a receiving survey of the ISO and trailer and inspect for damage. The cask user shall verify by reference to the NAC provided Certificate(s) of Conformance that the identified NAC-LWT cask and associated lift yoke are within the allowable annual maintenance period specified on the certificate(s) prior to loading and release for transport.
2. Position the trailer in the designated cask unloading area. Level the trailer. Set the trailer brakes and chock the wheels to prevent unintended movement.
3. Licensees shall receive and survey the NAC-LWT cask for radiation and removable contamination (for both gross beta-gamma and alpha) per 10 CFR 20 and 49 CFR 173. Open the ISO container front and/or rear doors and record the survey results. If radiation or contamination levels exceed the limits of 49 CFR 173.441 or 173.443, respectively, the user/licensee shall notify the shipper, NAC, and ensure the appropriate notifications are completed.

   Note: Verify that the package nameplate displays the correct package identification number in accordance with the CoC.
4. Complete the radiation and contamination surveys of the cask as additional surfaces become accessible. Clean the cask surfaces, as required.
5. Remove the roof from the ISO container and cross members, if installed.
6. If installed, ensure the TIDs match the shipment documentation.
7. Remove any TIDs that may be present and remove the top impact limiter.
8. Remove the vent and drain port covers. Prior to reinstallation of the port covers, carefully inspect the port cover O-ring seals and, if the O-rings show any damage, replace them with approved spares. Ensure that the replacement O-rings are properly installed and seated. Visually inspect the vent and drain quick-disconnect nipples and replace them, if necessary.

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

9. Visually inspect the neutron shield tank fill, drain, and level inspection plugs for signs of neutron shield fluid leakage. If leakage is detected or suspected, verify shield tank fluid level and correct, as required.
10. Inspect the Horizontal Lid Removal Tool and hex head screws to ensure there is no damage. Replace any bolts that are damaged prior to attaching the Horizontal Lid Removal Tool to the LWT Lid.
11. Attach the rigging to the rear lift lug of the Horizontal Lid Removal Tool and position next to the NAC-LWT Lid.
12. Install the Horizontal Lid Removal Tool to the LWT Lid
13. Remove the rigging from the rear lift lug and attach the rigging to the Horizontal Lid Removal Tool center Lift Lug.
14. Loosen and remove all closure lid bolts.

    Note: Prior to installation, inspect the lid bolts and replace any that are damaged.
15. Remove the closure lid and set it on a support that is suitable for radiological control and for maintaining the cleanliness of the closure lid. Prior to installation, carefully inspect the Teflon O-ring seal in the underside of the closure lid. If the O-ring shows any damage, replace it. Remove the metallic O-ring from the groove and discard. Clean and visually inspect the groove and lid recess seating surfaces for cleanliness, damage, or degradation. If the groove and lid recess seating surfaces are acceptable, install a new metallic O-ring with an approved spare. Ensure the replacement O-rings are properly installed and seated.
16. Visually inspect the inner cavity for foreign material, free water, or damage. Note deficiencies and correct as required.
17. Remove any shipping dunnage as necessary.
18. Clean all accessible surfaces, including the lid sealing surface.
19. Verify the PWR Fuel Basket assembly, PWR Insert, PWR/BWR Rod Transport Canister, and Divider Plate are properly installed and no damaged occurred during transport.
20. Loosen all PWR/BWR Rod Transport Canister lid bolts and ensure disengagement from the rod canister.
21. Remove PWR/BWR Rod Transport Canister lid.
22. Ensure the specific loading configuration for the shipment and contents to be loaded comply with the NAC-LWT CoC.
23. Ensure the LANL MOX Fuel Rods are in their specified location within the Transfer Tubes prior to inserting them into the NAC-LWT.

    Note: Criticality requirements govern the proper configuration of Transfer Tubes in the NAC-LWT cask and fuel tubes within the Transfer Tubes. See Table 1.2-20 for limitations. Ensure the correct fuel rods, end spacers, and tube spacers are placed in the approved loading configuration.
24. Insert each Transfer Tube into the NAC-LWT per specific loading configuration one by one (up to16 Transfer Tubes). Either with fuel rods or without.
25. Install the rod canister lid and torque to 35 ± 5 in-lbs.

26. Install the closure lid onto the cask using the Horizontal Lid Removal Tool. Ensure the rigging is attached to the center Lift Lug of the Horizontal Lid Removal Tool prior to lifting
27. Visually verify that the lid is properly seated.
28. Install lid bolts hand tight.
29. Remove the rigging from the center Lift Lug and attach to the Rear Lift Lug prior to unbolting the Horizontal Lid Removal Tool.
30. Unbolt the Horizontal Lid Removal Tool and remove from the closure lid.
31. Tighten all 12 closure lid bolts to 260 ± 20 ft-lbs in three passes using the torque sequence indicated on the closure lid.
32. Connect the Vacuum Drying System (VDS) to the cask vent valve and evacuate the cask cavity by vacuum pump to less than or equal to 10 torr (13 mbar) and continue vacuum pumping for a minimum of 15 minutes.
33. At the end of the evacuation period, isolate the cask cavity from the vacuum pump and monitor the cask cavity pressure for a minimum of 10 minutes. If the pressure rise is less than 5 torr (6.7 mbar), the cavity is verified as dry of free water. If the pressure rise is greater than 5 torr (6.7 mbar), resume vacuum drying until the dryness verification results are satisfactory.
34. Backfill the cask cavity with helium to 0 psig (1 atmosphere, absolute), +1, -0 psi and disconnect the VDS from the vent valve.
35. Perform a helium leakage test of the closure lid containment O-ring using a Helium Mass Spectrometer Leak Detector (MSLD) in accordance with the requirements of SAR Section 8.1.3.1.
36. Install the vent and drain alternate port covers and torque the bolts to 100 ±10 inch-pounds.
37. If an alternate port cover containment O-ring seal was replaced, perform a helium leakage test on the affected port cover using a Helium MSLD in accordance with the requirements of SAR Section 8.1.3.2.2.
38. If the alternate port cover containment seal was inspected and accepted for reuse, perform a gas pressure drop leakage test on the affected port cover as follows.
    a. Install a pressure test fixture to the port cover test port, including a calibrated pressure gauge with a minimum sensitivity of 0.25 psi.
    b. Pressurize the port cover seal annulus to 15 psig, +1, -0 psi.
    c. Isolate the gas supply and observe the pressure gauge for a minimum of five minutes.
    d. The acceptance criterion for the test is no measurable drop in pressure during the minimum test time. An acceptable test assures that the minimum assembly verification leakage test sensitivity is achieved.
39. Survey the cask surface for removable contamination and radiation dose rates. Decontaminate the cask, if required.

    Note: Removable contamination levels and radiation levels shall comply with 49 CFR 173.443 and 173.441, respectively.

40. Verify the correct installation of the cask tie-down strap. Install the top impact limiter and verify the correct installation of the bottom impact limiter.
41. Install a TID to one of the top impact limiter ball lock pins. Record TID identification number on the loading/shipping documentation.
42. Install roof cross-members, if used and replace ISO container roof.
43. Complete a Health Physics survey on the external surfaces of the package and record the results. Complete dose rate measurements at the package surface, at 1 meter from the package surface, and at 2 meters from the vertical plane of the side of the transport vehicle. The maximum dose rate at 1 meter from the package is the transport index (TI). Ensure compliance with 10 CFR 71.87(i) and observe the following criteria.
    a. If the dose rate is less than 2 mSv/h (200 mrem/hr) at all accessible points on the external surface of the package, and the TI is less than 10, the package meets the requirements of 10 CFR 71.47 (a).
    b. If the dose rate is greater than 2 mSv/h (200 mrem/hr), but is less than 10 mSv/h (1000 mrem/hr) at any point on the external surface of the package, or the TI is greater than 10, the package must be shipped as "exclusive use" and meet the requirements of 10 CFR 71.47 (b), (c) and (d). If the dose rate and shipping requirements of 10 CFR 71.47 (b), (1), (2), (3) and (4) cannot be met, the package cannot be shipped.
    c. If the dose rate is > 10 mSv/h (1000 mrem/hr) at any point on the external surface of the package, the package exceeds the limits of 10 CFR 71.47 and cannot be shipped.
44. Determine the appropriate Criticality Safety Index (CSI) assigned to the package contents in accordance with the CoC, and indicate the correct CSI on the Fissile Material label applied to the package per 49 CFR 172, Subpart E.
45. Complete the shipping documents, carrier instructions (as required), and apply appropriate placards and labels.

7.2.9 Procedure for the Dry Unloading of LANL MOX Fuel Rods

This section describes the procedural steps required to unload the Transfer Tubes and prepare the empty NAC-LWT cask for transport. Up to sixteen (16) Transfer Tubes are to be unloaded from a NAC-LWT, configured as shown on Drawing No. 315-40-188, using a horizontal configuration. Empty Transfer Tubes may have been loaded as spacers. These Transfer Tubes may be left in the cask if present, and if they do not contain any fuel rods in preparation for a loaded or empty shipment.

Depending on facility capabilities and/or site restrictions, the fuel rods and spacers in the Transfer Tubes shall be removed and prepared for return transport horizontally in accordance with the operating procedures below. The Transfer Tubes may be reused and loaded back into the NAC-LWT for an empty shipment, as required.

1. Perform a receiving survey of the ISO container and trailer and inspect for damage.
2. Position the trailer in the designated cask unloading area. Set the trailer brakes and chock the wheels to prevent unintended movement. If necessary, the ISO container may be removed from the trailer and secured in the unloading area.
3. Licensees shall receive and survey the package for radiation and removable contamination per 10 CFR 20 and 49 CFR 173. Record the survey results. If radiation or contamination levels exceed the limits of 49 CFR 173.441 or 173.443, respectively, the licensee shall notify the shipper and ensure the appropriate notifications are completed.
4. Remove the roof from the ISO container and open the front and rear ISO doors. Remove the ISO roof cross members, if installed.
5. Verify the TID identification number on the top impact limiter to confirm tampering of the package did not occur.
6. Record TID number of package unloading report and remove TID.
7. Remove the top impact limiter.
8. Complete the radiation and contamination surveys of the package as additional surfaces become accessible. Clean the cask surfaces as required for entry into the dry unloading facility.

   Note: Steps 9 to 11 will be governed by site of facility requirements for venting/purging cavity gases. If venting of the NAC LWT is not required by the receiving site of facility, proceed to step 12.
9. Remove the vent port cover.
10. Connect the vent line with pressure gauge and isolation valve to the vent port quick disconnect coupling.

    Note: At the discretion of the receiving facility, a gas sample may be taken prior to cavity venting to determine if leakage from the fuel rods occurred during transport.

Note: The gases exiting from the cavity may be radioactive and at an elevated temperature and pressure. Cavity gases should be controlled and vented to radioactive gas treatment systems per site requirements.

11. Vent the cask cavity. Remove the vent line from the vent valves.
12. Inspect the Horizontal Lid Removal Tool and hex head screws to ensure there is no damage. Replace any bolts that are damaged prior to attaching the Horizontal Lid Removal Tool to the LWT Lid.
13. Attach the rigging to the rear lift lug of the Horizontal Lid Removal Tool and position next to the NAC-LWT Lid.
14. Install the Horizontal Lid Removal Tool to the LWT Lid.
15. Remove the rigging from the rear lift lug and attach the rigging to the Horizontal Lid Removal Tool center Lift Lug.
16. Loosen and remove all closure lid bolts.
17. Remove the closure lid and set it on a support that is suitable for radiological control and for maintaining the cleanliness of the closure lid.
18. Loosen all PWR/BWR Rod Transport Canister lid bolts and ensure disengagement from the rod canister.
19. Remove PWR/BWR Rod Transport Canister lid.
20. Unload the Transfer Tubes with fuel rods individually.
21. Inspect the outside of each Transfer Tube for damage.
22. Install the rod canister lid and torque to 35 ± 5 in-lbs.
23. Install the closure lid onto the cask using the Horizontal Lid Removal Tool. Ensure the rigging is attached to the center Lift Lug prior to lifting
24. Visually verify that the lid is properly seated.
25. Install lid bolts hand tight.
26. Remove the rigging from the center Lift Lug and attach to the Rear Lift Lug prior to unbolting the Horizontal Lid Removal Tool.
27. Unbolt the Horizontal Lid Removal Tool and remove from the closure lid.
28. Inspect, install and tighten all 12 closure lid bolts to 260 ± 20 ft-lbs in three passes using the torque sequence indicated on the closure lid.

    Note: Inspection or replacement of metallic seals is not required. New metallic seals will be installed and leak tested prior to the next loaded shipment, as required.
29. If port covers were removed, install the port covers on the vent and drain ports and torque the port cover bolts to 100 ± 10 inch-pounds for the alternate port covers or 285 ± 15 inch-pounds for the Alternate B port covers.
30. Decontaminate the cask. Survey the cask for surface contamination and radiation dose rates and decontaminate the cask, as required.

    Note: Removable contamination levels and radiation levels shall comply with 49 CFR 173.443 and 173.441, respectively.

31. Verify the correct installation of the cask tie-down strap. Install the top impact limiter and verify the correct installation of the bottom impact limiter.
32. Replace roof cross-members, close ISO container doors and install ISO container roof.
33. Complete a Health Physics survey on the external surface of the packaging and record the results.

    Note: Removable contamination levels and radiation levels shall comply with 49 CFR 173.443 and 173.441, respectively.
34. Complete the shipping documents and apply appropriate placards and labels.