January 2015

Revision 43

NAC-LWT

Legal Weight Truck Cask System

SAFETY ANALYSIS REPORT

Volume 1 of 3

NON-PROPRIETARY VERSION

Docket No. 71-9225

NAC INTERNATIONAL

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RECORD OF REVISIONS

Issue Date	Revision Number	Change	Description of Change
March 1988	0	N/A	Initial Release.
August 1988	1	2.10.8	Incorporate Drop Test Results.
July 1989	2	Throughout	General rewrite and reissue to incorporate NAC responses to NRC comments.
September 1989	3	Throughout	Provide revised stress tables. Clarify post-drop test revisions. Change from Fissile Class I to Fissile Class III. Vacuum drying required for PWR and BWR fuels.
November 1989	4	Throughout	Revise to Type B(U). Clarification of side and end drop analyses for the neutron shield and expansion tank. Correct containment calculations. Revise operating procedures.
June 1990	5		Deleted.
July 1990	6	2.10.14 and throughout	Incorporate failed metallic fuel as permissible contents of the packaging.
September 1990	6 (supplement)	7.1	Incorporate operational changes to 7/1990, Revision 6.

RECORD OF REVISIONS (continued)

Issue Date	Revision Number	Change	Description of Change
December 1990	7	2.10.13 and throughout	Renumber 2.10.14 as 2.10.13. Revise to include evaluation of three failed metallic fuel rods per canister.
August 1991	8	2.10.13	Revise to permit use of shipment of severely failed research reactor metallic fuel that has been accumulated in filters using failed fuel cans.
October 1991	9	1.0, 1.1, 1.2, 4.2, 4.4.3, 7.0, 7.1	Revise to incorporate response to NRC questions on Revision 8.
October 1994	10	1.4	Revise License Drawings to modify radiographic acceptance criteria.
November 1994	11	Throughout	Revise to permit shipment of MTR fuel.
January 1995	12	1.4	Revised License Drawings to incorporate new weld and inspection requirements.
March 1995	13	1.2, 2.2, 2.2.12.6, 5.1, 5.3.4, 6.4.4, 7.1.4	Submittal of consolidated SAR. Revised to incorporate responses to NRC questions on MTR fuel contents.
May 1995	14	1.4	Minor editorial corrections to consolidated SAR.

RECORD OF REVISIONS (continued)

Issue Date	Revision Number	Change	Description of Change
June 1995	15	Throughout	Revised to incorporate up to 25 individual PWR fuel rods as permissible contents.
August 1995	16	2.6.12.2	Revised to incorporate a description of the canister for individual intact PWR rods.
August 1995	17	2.6.12, 5.0, 5.1, 5.3, Table 6.2-1	Revised to incorporate shielding analysis for 25 PWR rods and editorial corrections.
October 1995	18	1,4,5 and 6	Revise to incorporate LEU MTR fuel elements as permissible contents.
December 1995	19	1.4	Submit revised MTR basket drawings incorporating additional fabrication details.
March 1996	20	1.2, 1.4, 7.1 and 7.2	Submit revised drawings for alternate drain configuration.
December 1997	21	1.2, 2.1.3, 2.4.3, 2.6, 2.7, 3.1, 3.4, 4.4, 5.0, 7.1.4, 7.1.5, 8.2, 9.0	Incorporates HEU MTR analysis for varying burnup and cool time. Incorporates note to clarify bolt thread chrome-plate requirements.
May 1998	22	1.0, 1.1, 1.2, 2.1, 2.6.12, 2.7.7, 2.9 (various), 3.1, 3.4, 3.5, 4.0 (all), 5.0, 5.1, 5.3, 6.0 (various), 7.0 (all), 8.1, 9.0	Incorporates 120 element TRIGA fuel analysis.
November 1998	23	1.0, 1.2.3, 2.7.1.6, 2.7.3, 2.7.5, 2.10.13.8, 3.2, 3.4, 3.5, 4.2, 4.3, 4.4, 5.1, 6 (all), 7.1, 8.1, 9.0	Incorporates changes for B(U)F-85 certification.

RECORD OF REVISIONS (continued)

Issue Date	Revision Number	Change	Description of Change
December 1998	24	1.2.3, 2.2.0, 2.3.0, 2.6.12, 2.7.7, 4.2, 4.3, 4.5.3, 5.1, 5.3.4, 6.4.3, 7.1, 7.2	Incorporates MTR-35 basket configuration, failed MTR fuel containment analysis, and various minor editorial changes.
February 1999	25	6.2.3 and 6.4.3	Added additional MTR configuration.
April 1999	26	1.0, 1.1, 1.2.2, 1.2.3, 2.6.12.7, 2.7.7.6, 2.7.7.9, 3.4.1.5, 3.4.1.6, 3.5.3.4, 4.2.1, 4.5.3, 5.0, 5.1, 5.3.6, 5.3.7, 6.0, 6.1, 6.2, 6.2.5, 6.2.6, 6.2.7, 6.3, 6.3.5, 6.4.5, 6.4.6, 6.6.5, 6.6.6, 7.0, 7.1.6, 8.1.7, 8.2	Incorporates TRIGA fuel cluster rod contents and TRIGA poisoned basket configuration.
June 1999	27	1.2.3.1.1.2 and 6.4.6.5	Incorporates increased fuel parameters for TRIGA fuel cluster rod contents.
December 1999	28	License drawings, 1.2, 2.3, 2.7, 2.10.8, 2.10.13, 3.2, 3.5, 5.4, 6.2, 6.4, 8.3, 9.0	Incorporates minor changes to numerous drawings to reflect changes facilitating fabrication and to increase the uranium loading of NISTR MTR fuel contents.
January 2000	29	Complete consolidation of SAR for CoC Renewal Application	Consolidated SAR, removed all shading and revision bars and numbered all pages to Revision 29.
		Chapter 7	Incorporated miscellaneous corrections and clarifications in the cask operating procedures based on cask operating experience.
		License Drawings 315-40-01, 02, and 03	Incorporated changes in Name Plate attachment and information (for corporate name and B(U)F-85 designation). Revised slot dimension on shield tank (Section G-G, sheet 4).

RECORD OF REVISIONS (continued)

Issue Date	Revision Number	Change	Description of Change
January 2000 (continued)	29	License drawings 315-40-05 and 06	Corrected material callout to 6061-T651 AL ALY for Items 10, 17, and 19 on 315-04-05 and Item 5 on 315-40-06.
July 2000	30	Throughout	Revised to incorporate high burnup PWR and BWR fuel rods and McMaster MTR fuel as authorized contents; to incorporate a revised specification for the Ball-Lok impact limiter attachment pins; and to incorporate an alternate fabrication method for the impact limiter shells.
		License Drawing 315-40-03	Corrected slot dimension for neutron shield gusset.
		License Drawings 315-40-01, -048, -052, -079, -084, and -094	Incorporated revised Ball-Lok pin specification.
		License Drawings 315-40-05 and –06	Incorporated alternate fabrication method for the impact limiter shells.
		License Drawings 315-40-098 through –105	Added to define the components used for shipment of high burnup fuel rods.
November 2000	31	Throughout Licensing Drawings 315-40-03, -04, -08, -099, -102, -105, and -106	Revised to incorporate drawing changes due to fabrication comments, as well as specific HEU-MTR fuel for Argentina research reactor.
January 2001	32	Throughout Licensing Drawings 315-40-05 and -06	Incorporated MEU-MTR fuel elements bounding MTR fuel element including tolerances for fabrication, enrichment, burnups and cool times. Incorporated revised dimensional tolerances for impact limiter shell dimensions and acceptance criteria for local scratches/gouges in the shells.

RECORD OF REVISIONS (continued)

Issue Date	Revision Number	Change	Description of Change
September 2001	33	Throughout; Licensing Drawings 315-40-02, -03, -04, -08, -10, -074, -108, -109, -110, -111, -113	Incorporated Alternate Port Cover design, alternate PWR fuel basket configuration and DIDO/Petten fuel
November 2002	34	Throughout	Incorporated 02A (LEU MTR) and 02B (MTR)
May 2004	35	Throughout	Incorporated 03A, 03C, 03D, 03F & 03G (GA IFM) and 03B, 03E & 03H (EPRI/Framatome)
December 2004	36	Complete consolidation of SAR for CoC renewal application. License drawings: 315-40-02 315-40-03 315-40-08 315-40-10 315-40-087 315-40-127 315-40-128	General update incorporating LWT-03I (TPBAR), LWT-04B (updated drawings for obsolete part numbers), LWT-04C (TPBAR RAI), LWT-04D (-96 changes), and LWT-04F (updates to TPBAR RAI for tritium release limits). Additional changes to the SAR have been incorporated in accordance with NRC/NAC discussions: Section 1.1, Page 1.1-1, clarified that fuel rod insert may also be referred to as a rod holder and that encapsulated fuel rods are not rod holders; Section 1.2.3, clarified that fuel rod capsules may be placed in a rod holder and added sketch of typical fuel rod capsule in Figure 1.2-11 to replace Framatome drawings; Section 1.2.3.1.2, added "intact" before "TRIGA fuel elements" in five places to clarify the TRIGA contents; Section 1.2.3.6, added "stainless steel" before "consolidation canister" in last paragraph to identify the TPBAR consolidation canister material; Figure 1.2-10 revised to eliminate unnecessary

RECORD OF REVISIONS (continued)

Issue Date	Revision Number	Change	Description of Change
December 2004 (continued)	36	Complete consolidation of SAR for CoC renewal application. License drawings: 315-40-02 315-40-03 315-40-08 315-40-10 315-40-087 315-40-127 315-40-128	detail; added drawing 315-40-03, revision 6, to cover LWT units 1 through 5 per CoC specification; revised drawing 315-40-128, per revision 1, to delete the reference to the Westinghouse TPBAR consolidation canister drawing; Figures 2.10.2-4a through –4d and Figure 2.10.2-5 renumbered with consecutive numbers; Table 5.1-1 simplified to only specify the Transport Index that is based on shielding per IAEA –96 regulations; Tables 5.3-3a through –3d, Table 5.3-6a, Table 5.3-7a and Table 5.3-9a renumbered consecutively; Section 5.3.6, moved Figures 5.3-9 through 5.3-15 and Figures 5.3-19 through 5.3-23 to the end of the section; Section 5.3.7.1, added references to Tables 5.3-26 and 5.3-27; Section 5.3.9, added reference to Figure 5.3-24; Figure 5.3-46, corrected MCNP input for 300 TPBARS at 30 days cool times. Files were updated to take advantage of automatic TOC, LOF, & LOT numbering, correct preface page numbers to chp# + pg number, delete extra section breaks, and except for Chapter 2 change page numbering to two levels. Pagination corrected, "x" changed to "x" in formulas, format for continued figures and tables made consistent, some footnotes put into true format and made consistent, and some automatic cross references set up.

RECORD OF REVISIONS (continued)

Issue Date	Revision Number	Change	Description of Change
June 2005	37	Incorporation of LWT-04E, LWT-05A, LWT-05B, LWT-05C, LWT-05D & LWT-05E License drawings: 315-40-01, Rev. 5; 315-40-086, Rev. 1; 315-40-098, Rev. 3; 315-40-100, Rev. 3; 315-40-104, Rev. 1; 315-40-129, Rev. 1; 315-40-130, Rev. 1; 315-40-133, Rev. 0; 315-40-134, Rev. 1; 315-40-135, Rev. 1	Added PULSTAR fuel, screened can option & TPBAR dunnage approved amendments to Revision 36.
November 2007	38	Incorporation of LWT-05F, LWT-06A, LWT-06B, LWT-06C, LWT-06E, LWT-06F, LWT-06G, LWT-07A, LWT-07B, LWT-07C, LWT-07D & LWT-07F License drawings: 315-40-01, Rev. 6; 315-40-02, Rev. 20; 315-40-03, Rev. 6; 315-40-03, Rev. 22; 315-40-08, Rev. 17; 315-40-048, Rev. 3; 315-40-052, Rev. 3; 315-40-079, Rev. 3; 315-40-084, Rev. 3; 315-40-085, Rev. 0; 315-40-094, Rev. 4; 315-40-104, Rev. 2; 315-40-111, Rev. 1; 315-40-124, Rev. 1; 315-40-125, Rev. 3; 315-40-127, Rev. 2; 315-40-128, Rev. 2; 315-40-133, Rev. 1; 315-40-139, Rev. 0; 315-40-140, Rev. 0; 315-40-141, Rev. 0; 315-40-142, Rev. 0; 315-40-145; Rev. 0 The following license drawings were deleted: 315-40-13, 315-40-14, 315-40-15, 315-40-17, 315-40-18 & 315-40-20	Added ANSTO, TPBAR, TRIGA & Petten approved amendments to Revision 37.

RECORD OF REVISIONS (continued)

Issue Date	Revision Number	Change	Description of Change
October 2008	39	Incorporation of LWT-07G, LWT-08A, LWT-08B, LWT-08C & LWT-08E	Added Romanian TRIGA fuel & MOX fuel approved amendments to Revision 38.
		License drawings: 315-40-01, Rev. 7; 315-40-02, Rev. 22; 315-40-70, Rev. 4; 315-40-71, Rev. 4; 315-40-72, Rev. 4; 315-40-79, Rev. 5; 315-40-084, Rev. 4; 315-40-096, Rev. 3; 315-40-104, Rev. 3	
		The following license drawings were deleted: 315-40-74, 315-40-75 & 315-40-76	
January 2010	40	Incorporation of LWT-08D, LWT-08F, LWT-08G, LWT-09A, LWT-09C, LWT-09D & LWT-09E	Added ANSTO HIFAR, TPBAR & Impact Limiter Gusset Weld Repair amendments to Revision 39.
		License drawings: 315-40-02, Rev. 24; 315-40-05, Rev. 10; 315-40-06, Rev. 10; 315-40-08, Rev. 18; 315-40-10, Rev. 8; 315-40-045, Rev. 6; 315-40-046, Rev. 6; 315-40-047, Rev. 6; 315-40-049, Rev. 6; 315-40-050, Rev. 6; 315-40-051, Rev. 6; 315-40-070, Rev. 6; 315-40-071, Rev. 6; 315-40-072, Rev. 6; 315-40-080, Rev. 4; 315-40-081, Rev. 4; 315-40-082, Rev. 4; 315-40-087, Rev. 6; 315-40-090, Rev. 4, 315-40-091, Rev. 4; 315-40-092, Rev. 4; 315-40-098, Rev. 6; 315-40-100, Rev. 4; 315-40-102, Rev. 2; 315-40-104, Rev. 5; 315-40-111, Rev. 2; 315-40-128, Rev. 3; 315-40-139, Rev. 1; 315-40-140, Rev. 1; 315-40-141, Rev. 1; 315-40-142, Rev. 1; 315-40-148, Rev. 0	

RECORD OF REVISIONS (continued)

Issue Date	Revision Number	Change	Description of Change
April 2010	41	Incorporation of LWT-10A, LWT-10B &LWT-10C	Added GA TRIGA fuel approved amendments to Revision 40.
		License drawings: 315-40-079, Rev. 6 & 315-40-085, Rev. 1	
November 2014	42	Consolidation of LWT-12A, 12B, 12C, 12D, 12D Supplement, 13A, 13A Supplement, 13C, 13C Supplement, 13D, 14A, 14C and 14C Supplement	Added SLOWPOKE, NRU/NRX, Basel MTR, and ANSTO Opal fuel to Rev. 41.
January 2015	43	Consolidation of LWT-12E, LWT-13B, LWT-14B, LWT-14D and LWT-14E	Added HEUNL to Rev 42.
		License drawings: 315-40-180, Rev. 3P and 0NP; 315-40-181, Rev. 5P and 0NP; 315-40-182, Rev. 2P and 0NP; & 315-40-183, Rev. 1P and 0NP	

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* Packaging Unit Nos. 1, 2, 3, 4 and 5 are constructed in accordance with this revision of drawing.

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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); and
- HEUNL.

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 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:

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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.

- 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	100
HEUNL containers	0.0

TPBARs 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

Cask Model	NAC-LWT
Package	The Packaging with its radioactive contents (payload), as presented for transportation (10 CFR 71.4). Within this report, the Package is denoted as the NAC-LWT cask or simply as the cask.
Packaging	The assembly of components necessary to ensure compliance with packaging requirements (10 CFR 71.4). Within this report, the Packaging is denoted as the NAC-LWT cask.
NAC-LWT Cask	This packaging consists of a spent-fuel shipping cask body and closure lid with energy absorbing impact limiters.
Contents (Payload)	• 1 PWR assembly • up to 2 BWR assemblies • up to 25 PWR or BWR rods (including high burnup fuel rods and up to 14 fuel rods classified as damaged)[1] • up to 16 PWR MOX fuel rods (or mixed contents of up to 16 PWR MOX and UO_2 PWR fuel rods) and up to 9 BPRs • up to 42 MTR fuel elements (including plates) • up to 42 DIDO fuel assemblies • up to 7 degraded clad DIDO fuel assemblies in damaged fuel cans (DFCs) in ANSTO top basket module • up to 15 sound (cladding intact) metallic fuel rods • up to 9 damaged metallic fuel rods or 3 severely damaged metallic fuel rods in filters • up to 140 intact or damaged TRIGA fuel elements/debris • up to 560 intact or damaged TRIGA fuel cluster rods • 2 GA IFM packages • up to 300 TPBARs (including up to 2 prefailed TPBARs) • up to 55 TPBARs segmented into individual segments and segmentation debris • up to 700 intact or damaged PULSTAR fuel elements in either assembly or element form, including fuel debris • up to 42 intact spiral fuel assemblies (also referred to as Mark III spiral fuel), including up to 7 degraded clad spiral fuel assemblies in DFCs. Spiral fuel assemblies may be cropped. • up to 42 intact MOATA plate bundles, including up to 7 MOATA plate bundles in DFCs

[1] 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.

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

	• any combination of individual ANSTO basket modules containing either spiral fuel assemblies or MOATA plate bundles up to a total of 42 assemblies/bundles, including up to 7 degraded clad DIDO, spiral or MOATA elements/ bundles in DFCs placed in an ANSTO top basket module • combination ANSTO-DIDO basket assembly (one ANSTO top module and five DIDO intermediate and base basket modules) containing up to 42 DIDO, spiral or MOATA elements/bundles with up to 7 degraded clad elements/bundles in the ANSTO top module in DFCs • up to eight (8) SLOWPOKE Fuel Canisters each containing up to 100 undamaged and/or damaged SLOWPOKE fuel rods • up to eighteen (18) NRU or NRX fuel assemblies. Fuel assemblies may be cropped. NRU fuel assemblies have the flow tube removed. NRX fuel assemblies/rods must be placed into the fuel rod caddy assembly as criticality analysis applied the fuel rod caddy as geometry constraints. Each basket tube is limited to the equivalent content of one assembly. One single fuel type may be loaded into one NRU/NRX basket assembly. NRU or NRX undamaged fuel assemblies/rods will be loaded into an 18 tube basket. • 4 HEUNL containers. Containers shall be empty or filled with HEUNL material, such that a minimum under filled cavity void of one gallon exists. • 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.
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.

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

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.
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.

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

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.
Irradiated Hardware	Solid, irradiated and contaminated fuel assembly structural or reactor internal component hardware, which may include fissile material, provided the quantity of fissile material does not exceed a Type A quantity and does not exceed the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c). Authorized quantity of irradiated hardware and components is limited to 4,000 lbs (including spacers, dunnage and containers) and a gamma source term as defined in Table 1.2-13.
MOX Fuel Rods	The term as used in this SAR is defined as irradiated or unirradiated mixed uranium-plutonium oxide (MOX) fuel rods. The MOX fuel rods can be made with plutonium having various compositions of plutonium isotopes. The evaluated mixes of the various grades of plutonium are defined in the shielding (Chapter 5) and criticality (Chapter 6) evaluations.

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

Damaged SLOWPOKE Fuel Rods	SLOWPOKE fuel rod with visible damage to the clad and fuel debris. Damage to the fuel rods may be the result of through-clad corrosion and/or mechanical damage. Damaged fuel may include any size fuel section, including fuel debris. All SLOWPOKE fuel rods, damaged or undamaged, and fuel debris must be placed into the SLOWPOKE fuel canister. The SLOWPOKE fuel canister maintains a boundary for gross release of fuel material.
Undamaged NRU or NRX Fuel Assembly	NRU HEU and NRX HEU contain uranium aluminum alloy fuel meat. NRU LEU fuel meat is U-Al-Si. Fuel assemblies may be cropped. NRU fuel assemblies have their flow channel removed. Loose rods, including rods with through clad damage, are considered to be undamaged provided they retain their structural integrity.
HEUNL Container	A stainless steel container for highly enriched uranyl nitrate liquid (HEUNL). The container is comprised of a welded lid, shell, bottom plate structure with lid penetrations for fill and drain operations. HEUNL is a solution containing uranyl nitrates, various other nitrates, and water.

1.1 Introduction

The NAC-LWT spent-fuel shipping cask has been developed by NAC International (NAC) as a safe means of transporting radioactive materials authorized as approved contents. The cask design is optimized for legal weight over the road transport, with a gross weight of less than 80,000 pounds. The cask provides maximum safety during the loading, transport, and unloading operations required for spent-fuel shipment. The NAC-LWT cask assembly is composed of a package that provides a containment vessel that prevents the release of radioactive material. The actual containment boundary provided by the package consists of a 4.0-inch thick bottom plate, a 0.75-inch thick, 13.375-inch inner diameter shell, an upper ring forging, and an 11.3-inch thick closure lid. The cask lid closure is accomplished using twelve, 1-inch diameter bolts. The cask has an outer shell, 1.20 inches thick, to protect the containment shell and also to enclose the 5.75-inch thick lead gamma shield. Neutron shielding is provided by a 5.0-inch thick neutron shield tank with a 0.24-inch (6mm) thick outer wall, containing a water/ethylene glycol mixture and 1.0 minimum weight percent (wt %) boron (58 wt % ethylene glycol; 39 wt % demineralized water; 3 wt % potassium tetraborate [$K_2B_4O_7$]). The neutron shield tank system includes an expansion tank to permit the expansion and contraction of the shield tank liquid without compromising the shielding or overstressing the shield tank structure. Aluminum honeycomb impact limiters are attached to each end of the cask to absorb kinetic energy developed during a cask drop, and limit the consequences of normal operations and hypothetical accident events.

The NAC-LWT is a legal weight truck cask designed to transport the following contents:

- 1 PWR assembly;
- up to 2 BWR assemblies;
- up to 15 sound metallic fuel rods;
- up to 42 MTR fuel elements;
- up to 42 DIDO fuel assemblies;
- up to 25 high burnup PWR fuel rods (including up to 14 rods classified as damaged)[1];
- up to 25 high burnup BWR fuel rods (including up to 14 rods classified as damaged)[1];
- up to 16 PWR MOX fuel rods (or a combination of 16 PWR MOX and UO_2 PWR rods) and up to 9 BPRs
- up to 9 damaged metallic fuel rods;
- up to 3 severely damaged metallic fuel rods in filters;
- up to 140 TRIGA intact or damaged fuel elements/fuel debris ("TRIGA" is a Trademark of General Atomics);
- up to 560 TRIGA intact or damaged fuel cluster rods/fuel debris;
- 2 GA IFM packages;
- up to 300 TPBARs (of which two can be prefailed) in a consolidation canister;

[1] 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.

- 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 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);
- 4 HEUNL containers (empty or filled such that a minimum under filled cavity void of one gallon exists); or
- 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.

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 28 MTR basket assembly. Intact PULSTAR fuel assemblies and intact PULSTAR fuel elements in a TRIGA fuel rod insert may be loaded in any basket module.

SLOWPOKE undamaged or damaged fuel rods will be loaded into 5 x 5 or 4 x 4 tube arrays with four (4) tube arrays placed in each screened SLOWPOKE Canister. A maximum of up to eight (8) SLOWPOKE Canisters may be loaded in two MTR-28 basket modules (top and top intermediate) with three (3) center row cells fitted with cell block spacers. Damaged fuel rods that cannot be accommodated in the 5 x 5 tube array will be loaded into the larger diameter 4 x 4 tube array. Empty lower intermediate and bottom MTR-28 basket modules will be installed as axial spacers for the two loaded basket modules.

NRU or NRX undamaged fuel assemblies/rods will be loaded into an 18 tube basket. Assemblies or loose fuel rods may be placed into an aluminum caddy which in turn is placed into the basket tube. NRX fuel assemblies/rods must be placed into the fuel rod caddy assembly as criticality analysis applied the fuel rod caddy as geometry constraints. The NRU/NRX basket is spaced to the top of the cask cavity.

Four HEUNL containers may be loaded directly into the NAC-LWT cask cavity. Each container may be filled to the point when material reaches the vent port during fill operations. Partially filled containers are permitted for transport. [redacted]

Irradiated hardware may be loaded directly into the NAC-LWT cavity or preloaded into a canister or cage. Stainless steel dunnage may be used to limit the movement of the irradiated hardware within the cask cavity. The maximum gamma source term of the irradiated hardware 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.

1.2 Package Description

This section presents a basic description of the NAC-LWT cask and the contents that may be transported. Drawings of the cask are presented within Section 1.4.

1.2.1 Packaging

1.2.1.1 Gross Weight

Gross shipping weight of the NAC-LWT spent-fuel shipping cask is approximately 52,000 pounds for the package. When mounted on the transport vehicle, the cask and vehicle weight is less than the 80,000-pound maximum for legal weight transport. A summary of overall component weights, detailed in Table 2.2.1-1, is listed below:

Component	Weight (pounds)
Cask Body	43,412
Closure Lid and Bolts	941
Payload and Basket	4,000 maximum
Impact Limiters	2,855
Total	51,208
SAR Analysis Weight	52,000

1.2.1.2 Materials of Construction, Dimensions, and Fabrication

The NAC-LWT cask body consists of Type 304 stainless steel forgings and closure lid with Type XM-19 stainless steel shells. Type XM-19 is a high strength stainless steel and is used in the inner and outer structural shells, which are more highly stressed than other cask components that use the more common Type 304 stainless steel. A lead gamma shield and a borated ethylene glycol/water solution neutron shield are utilized for radiation shielding. The cask provides the containment boundary for the payload and also acts as an environmental barrier. The cask is protected at each end by energy absorbing impact limiters, which consist of crushable aluminum honeycomb material with a thin aluminum shell. The impact limiters also provide thermal insulation, which protects the lid seals during the hypothetical fire transient event, although this thermal protection is conservatively neglected in this report. The cask is passively cooled because of its relatively low maximum heat loading of 2.5 kilowatts (kW). The overall arrangement of the NAC-LWT cask and design details are presented in the drawings within Section 1.4. The cask body, closure lid, and impact limiters are more fully described in the following sections.

1.2.1.2.1 Cask Body

The cask body is fabricated from Type 304 and Type XM-19 stainless steel. A poured lead gamma shield forms an annulus 5.75 inches thick and 174.9 inches long. The lead is enclosed between a 0.75-inch thick, 13.375-inch inner diameter Type XM-19 stainless steel inner shell and a 1.20-inch thick, 28.78-inch outer diameter Type XM-19 stainless steel outer shell. The Type 304 stainless steel bottom end forging of the cask is 4.0 inches thick, and the bottom also contains a 3.0-inch thick, 20.75-inch diameter lead disk enclosed by a 3.5-inch thick Type 304 stainless steel end cover.

As discussed in Chapter 8, installation of the lead into the cask is done in a carefully controlled manner. Temperatures of the inner and outer shells are continuously monitored and controlled during the lead pour and cooldown process. In addition, the welds connecting the inner and outer shells to the bottom end forging are not made until after the cooldown process is complete and the entire cask has reached a uniform temperature. Dimensional checks for straightness and ovality are also made before and after lead pour.

The upper ring forging is a Type 304 stainless steel ring 14.25 inches thick. This forging is machined to accept the closure lid and contains the penetrations to the cask cavity for the vent and fill/drain valves. Four lifting trunnions are welded to the forging to permit cask lifting and handling with a nonredundant or redundant lifting yoke.

Neutron shielding is provided by an ethylene glycol/water jacket that surrounds the 1.20-inch thick Type XM-19 stainless steel outer shell and is designed to axially blanket the active fuel length of the more common light water reactor fuels. The neutron shield region is 5.00 inches thick and 164.0 inches long. The external surface of the shield tank is a 0.24-inch thick Type 304 stainless steel shell with 0.50-inch thick end plates. An expansion tank for the neutron shield is provided to allow for thermal expansion and contraction of the liquid and is connected to the shield tank by a siphon tube. The liquid contains a solution of ethylene glycol/water and 1.0 wt % boron, which is added to reduce the secondary gamma radiation component.

The inner shell, end forgings, and the closure lid establish a cask cavity that is 177.9 inches long and 13.375 inches in diameter.

The weight of the cask body is approximately 43,412 pounds. The overall length of the cask body is 199.8 inches, and the maximum outside diameter is 44.24 inches at the neutron shield expansion tank.

1.2.1.2.2 Closure Lid

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

1.2.1.2.3 Impact Limiters

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

1.2.1.3 Valves and Testing

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

1.2.1.4 Heat Dissipation

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

1.2.1.5 Coolants

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

1.2.1.6 Protrusions

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

1.2.1.7 Lifting and Tiedown Devices

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

1.2.1.8 Shielding

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

1.2.2 Operational Features

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

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

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

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

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

1.2.3 Contents of Packaging

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

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

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

9. MTR fuel elements may consist of any combination of intact or damaged highly enriched uranium (HEU), medium enriched uranium (MEU) or low enriched uranium (LEU) fuel elements that are enveloped by the parameters listed in Table 1.2-4 as supported by information presented in Table 5.1.1-2, Table 6.4.3-21, Table 6.4.3-22, Table 6.4.3-25 and Table 6.4.3-28. MTR fuel elements will be transported in a leaktight configuration NAC-LWT cask.
10. High burnup PWR fuel rods will be shipped in either a sealed, free flow or screened can.
11. High burnup BWR fuel rods will be shipped in either a sealed, free flow or screened can.
12. Up to 25 high burnup PWR or BWR fuel rods in a fuel assembly lattice or rod holder. Up to 14 of the fuel rods in a rod holder may be classified as damaged. Damaged fuel rods or rod sections may be placed into fuel rod capsules prior to placing them in the fuel rod holder. Typical failed fuel rod capsule configuration is shown in Figure 1.2-11.
13. Production TPBARs will either be shipped in an open top consolidation canister as shown in Figure 1.2.3-10 and assembled in the cask as shown in Figure 1.2.3-12, or shipped in a PWR/BWR Rod Transport Canister in accordance with License Drawing No. 315-40-104.
14. Intact PULSTAR fuel elements may be loaded into a fuel rod insert or the PULSTAR screened or failed fuel can.
15. Damaged PULSTAR fuel elements and nonfuel components of PULSTAR fuel assemblies shall be loaded into either a PULSTAR failed fuel or screened fuel can, and placed into the top or base module of the 28 MTR fuel basket. Damaged fuel, including fuel debris, may be placed in an encapsulating rod prior to loading in a PULSTAR can.
16. Any combination of spiral fuel assemblies or MOATA plate bundles, each loaded into separate ANSTO basket modules containing up to a total of 42 assemblies/bundles.
17. Segmented TPBARs will be shipped in a sealed, dry Waste Container as shown in Figure 1.2.3-16 and assembled in the cask as shown in Figure 1.2.3-17.
18. Solid, irradiated and contaminated hardware containing less than a Type A quantity of fissile material and meeting the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c), loaded directly into the cask or contained in a secondary container or basket. The irradiated hardware spacer will be installed to limit the axial movement of the hardware above the lead shielded region of the cask body. As needed, additional secondary containers, dunnage and shoring may be used to limit the movement of the contents during normal and accident conditions of transport.
19. PWR MOX fuel rods (or a combination of PWR MOX and UO_2 PWR fuel rods) are required to be loaded in a screened or free flow PWR/BWR Rod Transport Canister provided with a 5 × 5 insert.
20. Any combination of up to 7 degraded clad DIDO, spiral or MOATA plate elements/ bundles loaded into an aluminum screened DFC as shown Figure 1.2.3-18 placed in an ANSTO top basket module, with remainder of either ANSTO basket modules containing MOATA plate bundles or spiral fuel elements or ANSTO-DIDO combination basket containing DIDO elements. Degraded aluminum-clad DIDO, spiral or MOATA plate elements/bundles will be transported in a leaktight configuration NAC-LWT cask.

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. Only a single fuel type (NRU or NRX) shall be loaded in a single NRU/NRX fuel basket assembly.
23. Four HEUNL containers. Containers shall be empty or filled with HEUNL material such that a minimum under filled cavity void of one gallon exists.

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.

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

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

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

pebbles. The fully-cured binding matrix is composed of carbonized graphite shim, coke, and graphite powder.

The RERTR IFM is comprised of 20 irradiated TRIGA fuel elements; 13 of the elements are intact and the remaining seven have been previously sectioned for examination purposes. Parameters characterizing the RERTR/TRIGA fuel elements are shown in Table 6.2.9-1. Three distinct mass loadings of uranium were used in the 20 TRIGA elements: 20, 30, and 45 wt % U; the average mass of the fueled portion of these elements is 551g with an enrichment of 19.7 wt % ^{235}U. The RERTR IFM consists of U-ZrH metal alloy fuel material and as a solid meets the requirement of 10 CFR 71.63.

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

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

1.2.3.4 PWR Fuel Assembly

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

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

1.2.3.5 BWR Fuel Assembly

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

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

1.2.3.6 TPBARs

The NAC-LWT cask is analyzed for the transport of three separate Tritium Producing Burnable Absorber Rod (TPBAR) content configurations. For the transport of production TPBARs from the reactor facility to the DOE processing facility, an open (i.e., unsealed) stainless steel

consolidation canister is utilized to contain up to 300 TPBARs, two of which can be prefailed. The characteristics of the production TPBARs are listed in Table 1.2-8. The consolidation canister assembly is shown in Figure 1.2.3-10. Up to 25 TPBARs may also be transported within the 5×5 rod holder located within the PWR/BWR Rod Transport Canister. For a TPBAR shipment, the transport canister is located within the TPBAR basket. Up to two of the 25 TPBARs located within the rod holder may be classified as prefailed.

The third transport configuration is for the shipment of segmented TPBARs, following post-irradiation examination (PIE), contained in a welded stainless steel waste container containing segments and debris from up to 55 TPBARs. The characteristics of the TPBAR PIE segments are provided in Table 1.2-12. The waste container and extension weldment assembly is shown in Figure 1.2.3-16.

TPBARs are similar in size and nuclear characteristics to standard, commercial PWR, stainless steel-clad burnable absorber rods. The exterior of a typical TPBAR is a stainless steel clad tube. The internal components of the TPBAR are designed and selected to produce and retain tritium. Internal configurations differ for various TPBAR designs (see DOE reports provided in the Chapter 1 Appendices). The internal components of a typical TPBAR include a plenum spacer tube (getter tube), a spring clip or a plenum (compression) spring, pellet stack assemblies (pencils), and a bottom spacer tube. A pencil consists of a zirconium alloy liner around which lithium aluminate absorber pellets are stacked and then confined in a getter tube as shown in Figure 1.2.3-9. The unclassified design details of the various TPBAR designs are provided in the unclassified DOE documents and drawings provided in the Chapter 1 Appendices.

The transport assembly arrangements for the consolidation canister and waste container TPBAR content configurations are identical and include a closure lid spacer assembly, a TPBAR basket and Alternate B port covers with bolting installed. The detailed requirements for the NAC-LWT assembly are provided in license drawing 315-40-128 in Section 1.4. The overall payload arrangement for the NAC-LWT with the consolidation canister and waste container are shown in Figure 1.2.3-12 and Figure 1.2.3-17, respectively. For the transport of fewer than 300 TPBARs in the consolidation canister, stainless steel dunnage may be used to align and protect the contents. The weight and volume of the dunnage and the reduced TPBAR contents of the consolidation canister must be less than, or equal to, the weight and volume of 300 TPBARs. Up to 25 TPBPAR rods may also be transported in a PWR/BWR Rod Transport Canister in a NAC-LWT assembly as shown in License Drawing No. 315-40-104 (assembly 95).

The TPBAR content conditions are analyzed and evaluated for compliance with structural, thermal, containment and shielding conditions of the NAC-LWT in the appropriate SAR chapters. TPBARs do not contain fissile material and, therefore, criticality evaluations have not

been performed. The operating procedures for the wet and dry loading and dry unloading of the TPBAR contents are provided in Chapter 7. The special leakage and pressure testing requirements for NAC-LWT casks intended for the transport of TPBAR contents are provided in Chapter 8.

1.2.3.7 PWR/BWR Fuel Rods

PWR and BWR fuel rods are transported within the fuel lattice (skeleton) or 4×4 or 5×5 inserts (rod holder). The rod holder is located within a free flow, screened or sealed PWR/BWR transport canister. (The rod holder may also contain a nonfuel-bearing irradiated hardware component [e.g., BWR water rod, PWR instrument/guide tube].)

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

1.2.3.8 PULSTAR Fuel Element and Transport Configuration Description

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

PULSTAR fuel elements may be loaded into the module cells in one of four configurations: a) intact PULSTAR fuel assemblies b) intact PULSTAR fuel elements loaded into the 4×4 TRIGA fuel rod insert (Dwg. 315-40-096); c) intact or damaged PULSTAR fuel elements, fuel debris and nonfuel-bearing components of PULSTAR fuel assemblies in the PULSTAR screened can (Dwg. 315-40-135); or d) intact or damaged PULSTAR fuel elements, fuel debris and nonfuel-bearing components of PULSTAR fuel assemblies in the PULSTAR sealed can (Dwg. 315-40-130). The contents of either can type are restricted to a quantity of fissile material and a total volume of material equivalent to 25 PULSTAR fuel elements. The sealed cask contents are restricted to the displaced volume of 25 intact PULSTAR fuel elements. The total cask payload shall not exceed 700 PULSTAR fuel elements. Loading of modules with mixed PULSTAR payload configurations is allowed, but PULSTAR cans, either screened or sealed, are restricted to loading in the base and top modules.

PULSTAR fuel elements are low enriched (< 7 wt %) uranium oxide rods, with zirconium alloy cladding. During reactor operation, 25 PULSTAR fuel elements are arranged in a rectangular 5×5 lattice, surrounded by a zirconium alloy box, and capped by top- and bottom-end fittings to form a PULSTAR fuel assembly. The nonfuel components of a PULSTAR fuel assembly are primarily aluminum and zirconium alloy and do not contain a significant activation source. A

sketch of a PULSTAR fuel assembly is provided in Figure 1.2.3-13. Key physical, radiation protection and thermal characteristics of the PULSTAR fuel assembly/elements are listed in Table 1.2-9.

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

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

1.2.3.9 ANSTO Basket and Payload Description

Three basic fuel types are to be transported in the ANSTO baskets within the NAC-LWT cask: spiral fuel assemblies, MOATA plate bundles and DIDO elements. Spiral fuel assemblies are composed of cylindrical aluminum inner and outer shells connected by curved metallic fuel plates. Further detail on the spiral fuel assemblies is provided in Section 1.2.3.9.1. MOATA plate bundles are comprised of up to 14 MTR fuel plates. Further detail on the plate bundles is provided in Section 1.2.3.9.2. DIDO elements are described in Section 1.2.3.2. The spiral fuel assemblies, MOATA plate bundles and DIDO elements may be intact or may have degraded cladding and be disassembled. Note that spiral assemblies may be cropped by removing nonfuel-bearing hardware to fit within the basket tubes. Cropped spiral fuel assemblies are classified as intact fuel. Spiral, MOATA and DIDO having degraded cladding or disassembled may be placed in aluminum DFCs as shown on Figure 1.2.3-18 prior to loading into the top ANSTO basket module or assembly to facilitate handling during loading and unloading operations. DFCs containing fuel elements shall be limited to loading in the 7 cells of the top ANSTO basket module of a standard six-module ANSTO basket assembly or in the top ANSTO basket module

of the ANSTO-DIDO combination basket assembly. The ANSTO-DIDO combination basket is an assembly of a top ANSTO module, four intermediate DIDO modules and one base DIDO module. As the interfaces, weight and overall dimensions of the ANSTO and DIDO basket modules are essentially identical, the combination basket assembly is bounded by the structural, thermal and criticality analyses for the separate DIDO and ANSTO basket assemblies.

Up to 42 spiral fuel assemblies or 42 MOATA plate bundles may be loaded in an ANSTO basket assembly. Up to 7 intact DIDO, spiral or MOATA plate elements/bundles and/or degraded clad DIDO, spiral or MOATA plate elements/bundles in DFCs may be loaded in an ANSTO top module in either the standard ANSTO basket assembly or in the ANSTO-DIDO combination basket assembly. DIDO fuel elements loaded into an ANSTO top module in either the ANSTO basket assembly or the ANSTO-DIDO combination basket assembly will be limited to a maximum decay heat load of 10 W per element whether with or without a DFC. Spiral fuel elements loaded into DFCs shall be limited to a maximum decay heat load of 10 W per element. MOATA plate bundles loaded into DFCs shall be limited to a maximum decay heat of 1 W per bundle. The remaining 35 cells of the ANSTO-DIDO combination basket may be loaded with up to 35 intact DIDO fuel elements.

A full cask load of either the ANSTO basket assembly or the ANSTO-DIDO combination basket assembly contains 6 baskets of up to 7 fuel assemblies or plate bundles per basket. The mixed loading of ANSTO and ANSTO-DIDO combination basket assemblies as described previously containing spiral fuel assemblies, MOATA plate bundles or DIDO elements is authorized.

1.2.3.9.1 Spiral Fuel Assemblies

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

1.2.3.9.2 MOATA Plate Bundles

The design basis characteristics of MOATA plate bundles are presented in Table 1.2-4. The fuel material in the plate bundle is a solid, homogeneous mixture of uranium-aluminum alloy, i.e., a metal alloy fuel. Each plate is clad in aluminum. A plate bundle is comprised of up to 14 fuel

plates. Two thick (0.635 cm) aluminum nonfuel side plates support the fuel plate stack from two sides, making a possible total of 16 plates per bundle. At each axial end, the plates in the stack are connected by a pin. Spacing between plates is maintained by disk spacers placed onto the top and bottom pins between each fuel plate and the aluminum side plates. A sketch of a typical MOATA plate bundle is provided in Figure 1.2.3-15.

1.2.3.10 Solid, Irradiated and Contaminated Hardware

The design basis characteristics of the solid, irradiated and contaminated hardware are provided in Table 1.2-13. As described in the content definition, the solid, irradiated and contaminated hardware may contain small quantities of fissile materials. Fissile materials in the irradiated hardware contents are acceptable if the quantity of fissile material does not exceed a Type A quantity and does not exceed the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c).

The irradiated hardware may be directly loaded into the NAC-LWT cask cavity, or may be contained in a secondary container or basket. As needed, appropriate component spacers, dunnage and shoring may be used to limit the movement of the contents during normal and accident conditions of transport.

To ensure that the movement of the irradiated hardware contents above the lead shielded length of the NAC-LWT cask body (i.e., the approximately upper 6.25 inches of the cavity length) is precluded, an Irradiated Hardware Lid Spacer as shown on Drawing No. 315-40-145 shall be installed for all irradiated hardware content configurations. The total installed height of the spacer is 6.5 inches. Therefore, the available cavity length for the irradiated hardware is approximately 171 inches. The NAC-LWT cask shall be assembled for transport as shown on NAC Drawing No. 315-40-01 with the irradiated hardware spacer installed on the lid.

A comparative shielding evaluation for a conservatively selected irradiated hardware transport configuration (i.e., a single line source with no self-shielding) or consideration of the additional shielding provided by additional spacers, dunnage, inserts or secondary containers is presented in Chapter 5. The evaluations show that the regulatory dose rate requirements per 10 CFR 71.47 for normal conditions of transport, or 10 CFR 71.51(b) under hypothetical accident conditions, are not exceeded.

1.2.3.11 PWR MOX Fuel Rods

The NAC-LWT cask is analyzed and evaluated for the transport of up to 16 PWR MOX fuel rods (or a combination of up to 16 PWR MOX and UO_2 fuel rods) loaded into a 5 × 5 insert placed in a screened or free flow PWR/BWR Rod Transport Canister. The authorized characteristics of the evaluated PWR MOX fuel rods are provided in Table 1.2-4. For mixed PWR MOX and UO_2

PWR fuel rod combinations, the UO_2 PWR fuel rods may have the identical heat load, burnup and cool time characteristics as the PWR MOX fuel rods.

In addition to the 16 PWR MOX fuel rods (or a combination of PWR MOX and UO_2 PWR fuel rods), up to 9 burnable poison rods (BPRs) may be loaded in the remaining openings in the 5 × 5 insert in the PWR/BWR Rod Transport Canister.

1.2.3.12 SLOWPOKE Fuel Rods

SLOWPOKE fuel rods are transported in the NAC-LWT in the 28 MTR fuel basket assembly, which consists of four modules with seven cells per module. The basket assembly is composed of a top module, a base module, and two intermediate modules. Fuel load is limited to a maximum of four loaded cells per basket module, with fuel only loaded in the top and top intermediate modules. The lower intermediate and bottom modules are used as axial spacers and are not loaded. The center row of three cells within the basket modules containing fuel are not loaded and contain a blocking device in each opening to prevent inadvertent loading. Therefore, a cask load for SLOWPOKE fuel rods is limited to eight loaded cells per cask.

SLOWPOKE fuel rods must be loaded into a canister. The canister is a screened boundary providing gross particle control for damaged fuel material. Damaged and undamaged fuel may be mixed when loaded into the canister. Canister content is composed of 4x4 or 5x5 aluminum tube arrays that are stacked four high within the canister. Mixed load of 4x4 and 5x5 tube arrays are permitted in a canister. Based on the 5x5 tube arrays and four tube arrays per canister, the maximum content per canister is 100 SLOWPOKE fuel rods (or the equivalent quantity of damaged material).

SLOWPOKE fuel rods are composed of highly enriched (> 90 wt %) uranium-aluminum alloy fuel meat within aluminum cladding. During reactor operation ~300 rods form a reactor core. Criticality in a SLOWPOKE core is achieved by the use of a thick beryllium neutron reflector surrounding the core. 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 rods are listed in Table 1.2-14.

The SLOWPOKE canister is constructed primarily of aluminum. A limited quantity of stainless steel is located within the canister lid structure. The canister is designed to: a) minimize the dispersal of gross fuel particles that may escape from damaged fuel rod cladding and/or fuel debris (note that metallic fuel is not expected to release significant gross particulate even with severe clad damaged); b) facilitate retrieval of the contents from the transportation cask; and, c) confine damaged fuel and/or debris within a known volume to facilitate criticality control, maintain dose limits, and control thermal loads within the cask. SLOWPOKE fuel pieces and debris may be placed into an aluminum tube structure located within the canister. The aluminum

tubes provide structural support for individual fuel rods/pieces during transport in the NAC-LWT but are not required within the analysis to maintain safety limits.

1.2.3.13 NRU/NRX Fuel Assemblies or Fuel Rods

NRU/NRX fuel assemblies and fuel rods are transported in the NAC-LWT in an 18 tube basket. The basket assembly is composed of 18 fuel tubes arranged in two concentric rings. The basket is spaced towards the top of the cask cavity by a bottom basket spacer.

NRX fuel assemblies or loose fuel rods must be loaded into a fuel rod caddy assembly. Loose NRU fuel rods may be loaded into a caddy. Mixed loading of NRU and NRX assemblies in a basket is not permitted. NRX assemblies are composed of (7) fuel rods and the NRU assemblies are composed of (12) fuel rods.

NRU/NRX HEU fuel rods are composed of highly enriched (> 90 wt%) uranium-aluminum alloy fuel meat within aluminum cladding. NRU LEU fuel meat is composed of <20% wt% ^{235}U enriched material composed of uranium-aluminum-silicon. NRU and NRX rods have a fin structure attached to the clad. The NRX rods have spiral fins to retain rod spacing. NRU assemblies in addition to the fins have a set of spacer disks assuring that rod pitch is maintained. A sketch of both NRU and NRX fuel assemblies is provided in Figure 1.2.3-20. Key physical, radiation protection and thermal characteristics of the NRU and NRX fuel assemblies are listed in Table 1.2-15.

The NRU/NRX caddy is constructed of aluminum. The aluminum caddy provides geometry constraint to fuel rod movement. Due to the increased reactivity of NRX fuel relative to high enriched NRU fuel, only NRX criticality evaluations credited this constraint.

1.2.3.14 HEUNL Containers

HEUNL material packaged in HEUNL containers may be directly loaded into the NAC-LWT cavity. Four containers must be packaged in the NAC-LWT for transport. The containers may be partially filled. [redacted] A sketch of the HEUNL container is provided in Figure 1.2.3-21. The container design is presented in NAC drawing 315-40-181. All hardware indicated on drawing 315-40-181 has been determined to be "Important to Safety" and has been evaluated, characterized and will be controlled in accordance with NAC's QA Program as described in Section 1.3.

[redacted]

HEUNL material consists of a solution of uranyl nitrate, various other nitrates (primarily aluminum nitrate), and water. The solution may contain uranyl nitrates with up to 7.40 g/L ^{235}U. Key physical, radiation protection, and thermal characteristics of the HEUNL material are provided in Table 1.2.3-16.

Figure 1.2.3-1 Aluminum Clad TRIGA Fuel Element

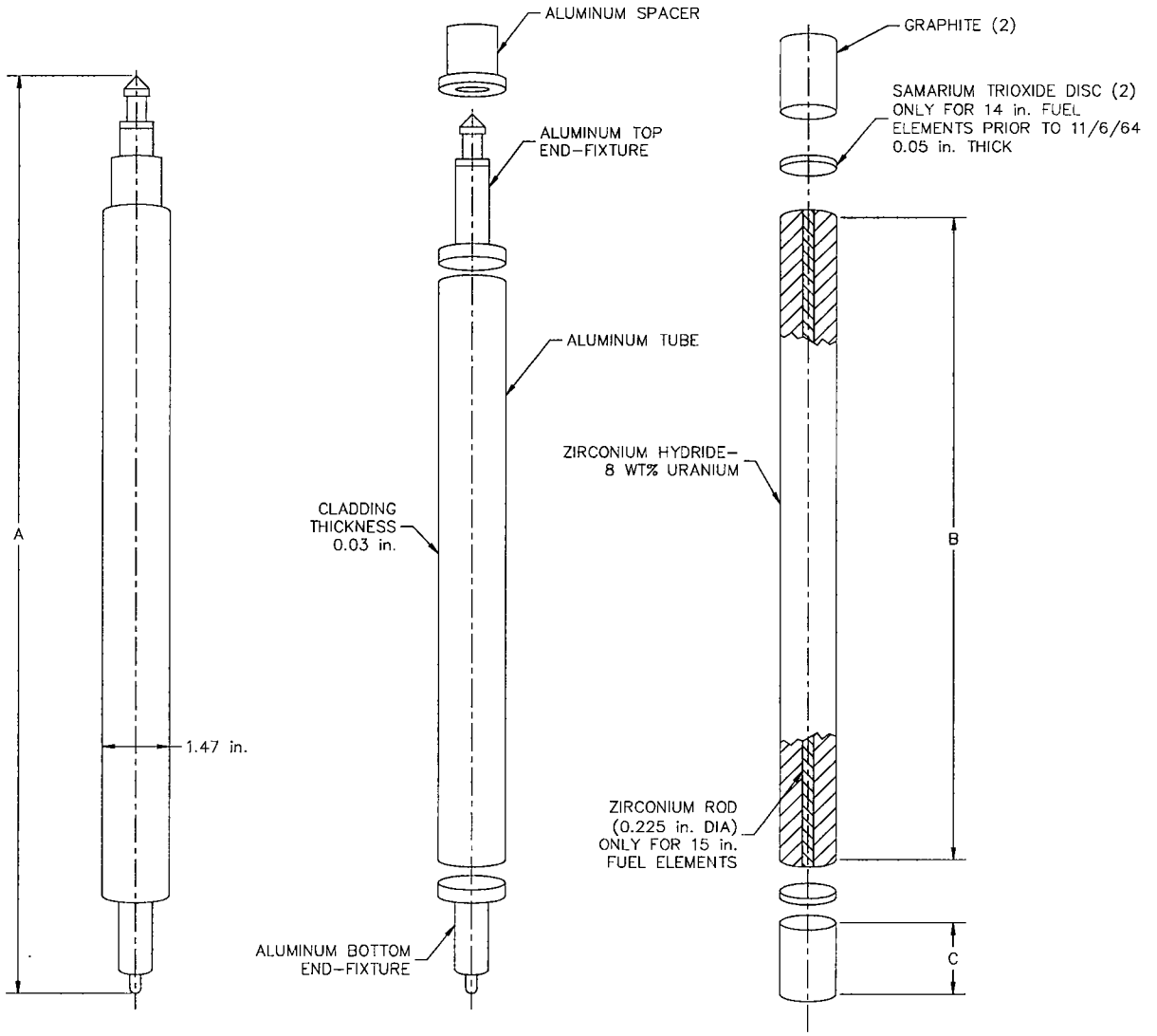


Figure 1.2.3-2 Aluminum Clad Instrumented Fuel Element

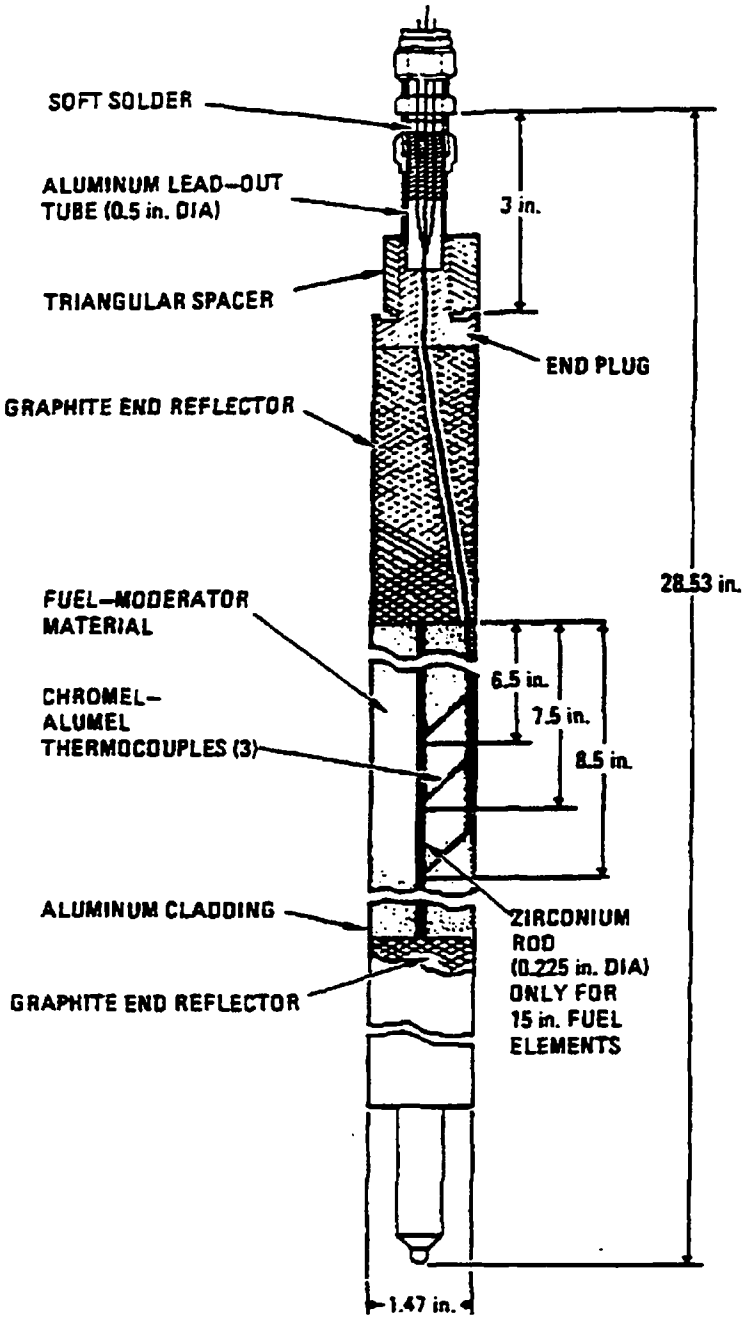


Figure 1.2.3-3 Stainless Steel Clad TRIGA Fuel Element

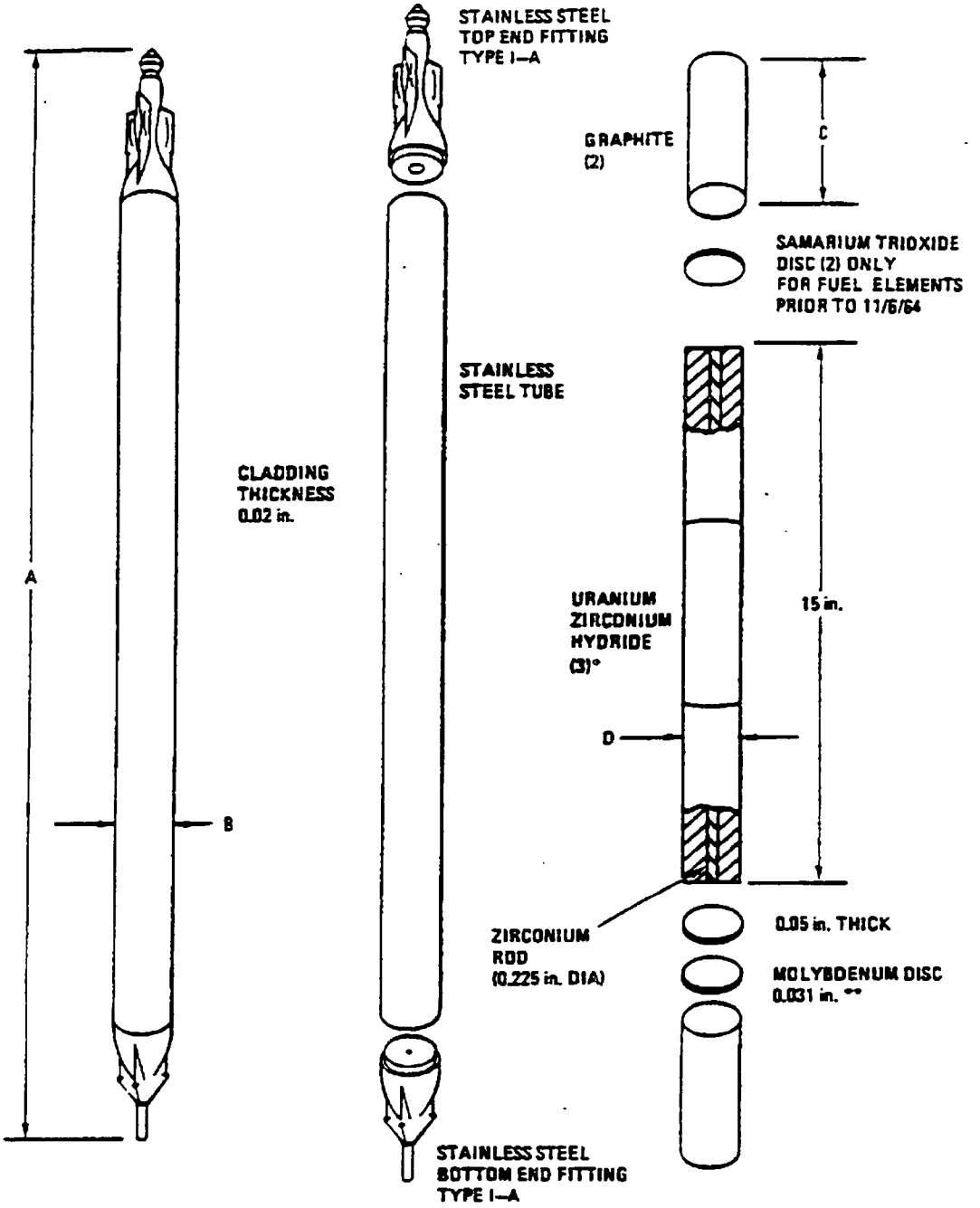


Figure 1.2.3-4 Stainless Steel Clad Instrumented Fuel Element

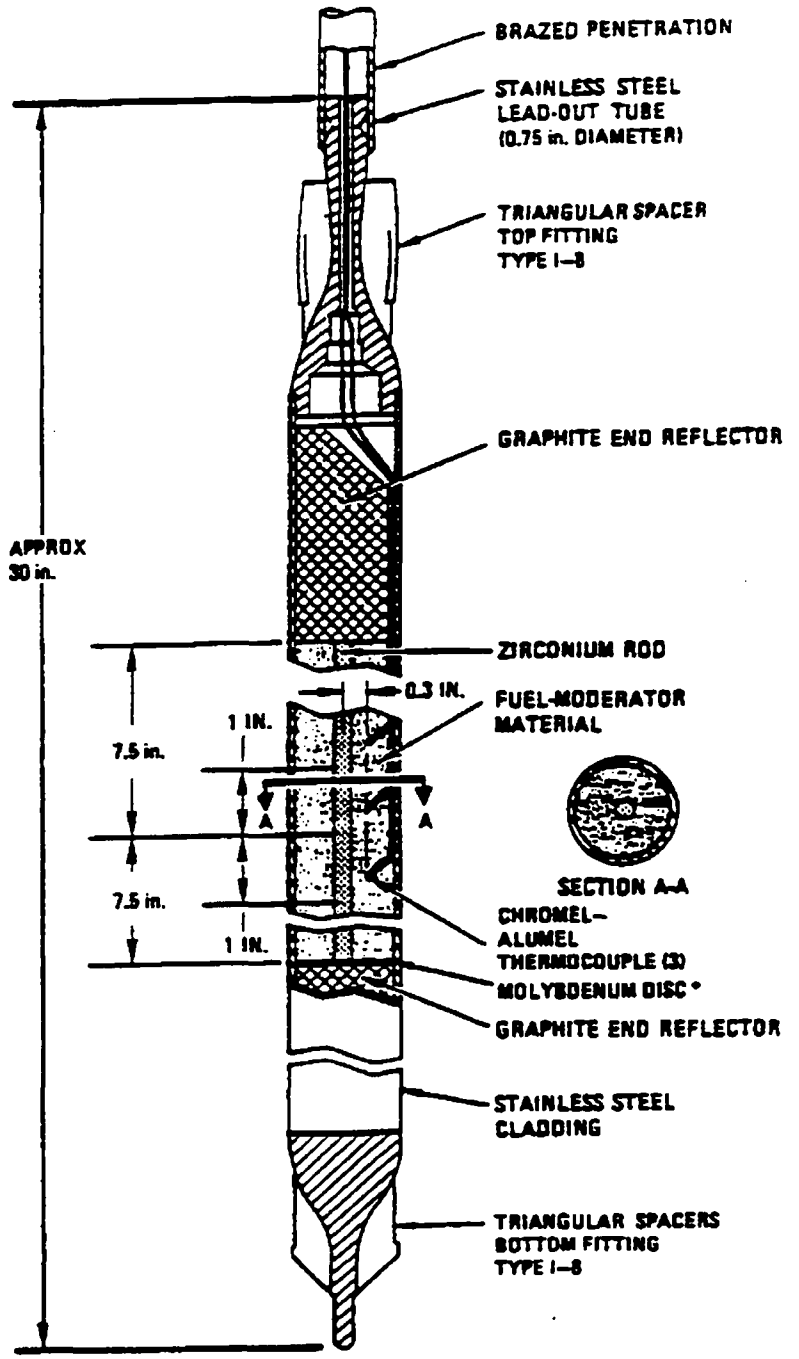


Figure 1.2.3-5 Standard Fuel Follower Control Rod Element

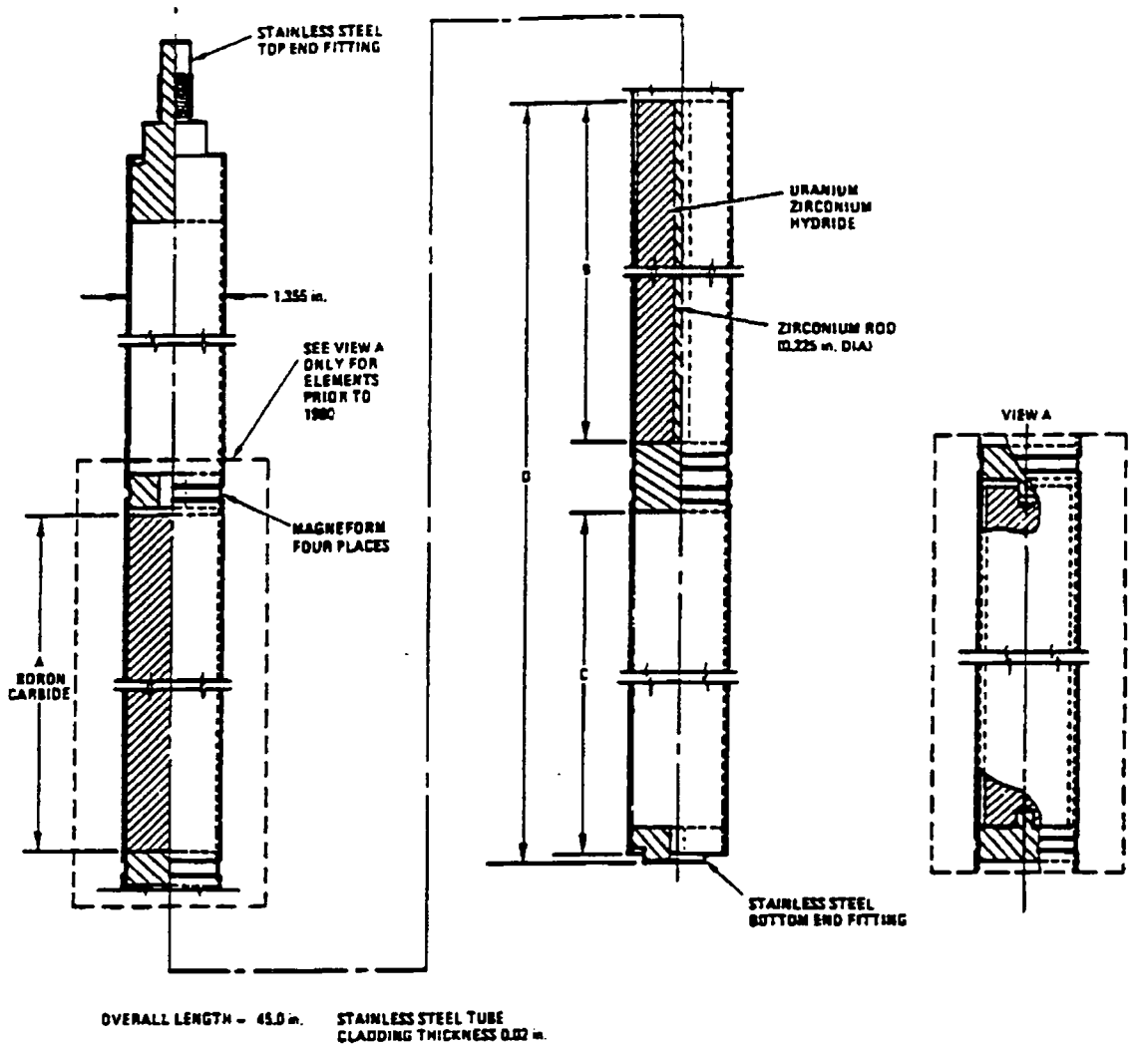
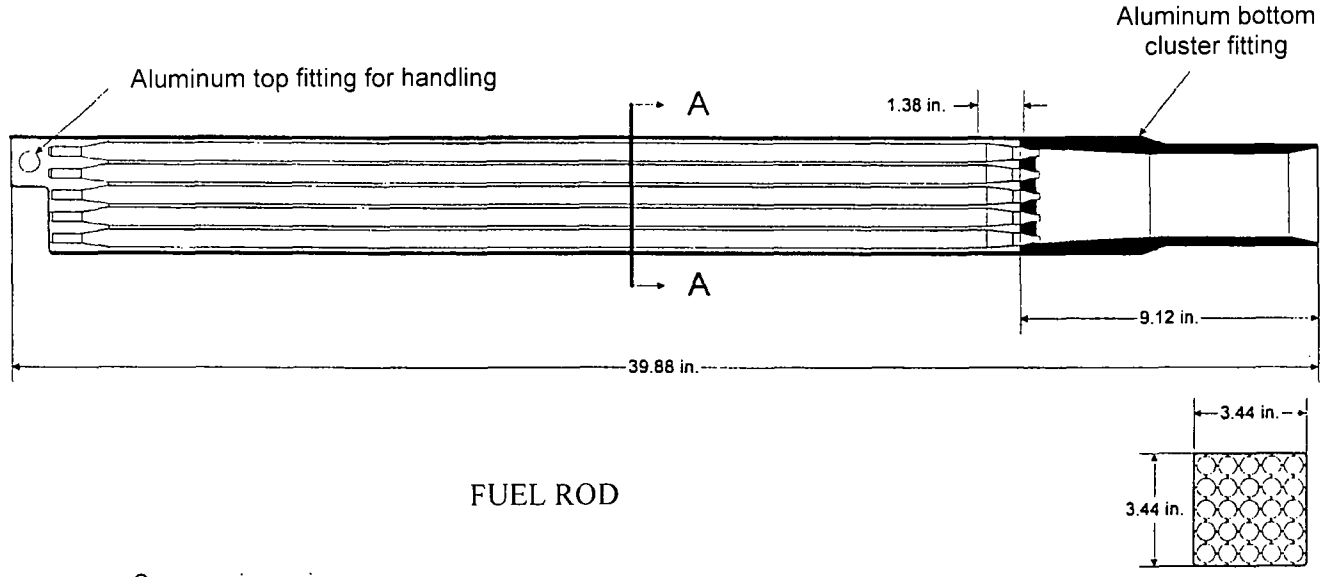


Figure 1.2.3-6 TRIGA Fuel Cluster and Rod Details

TRIGA *FUEL CLUSTER*



Fuel bundle and fuel element

Figure 1.2.3-7 HTGR Fuel Handling Unit

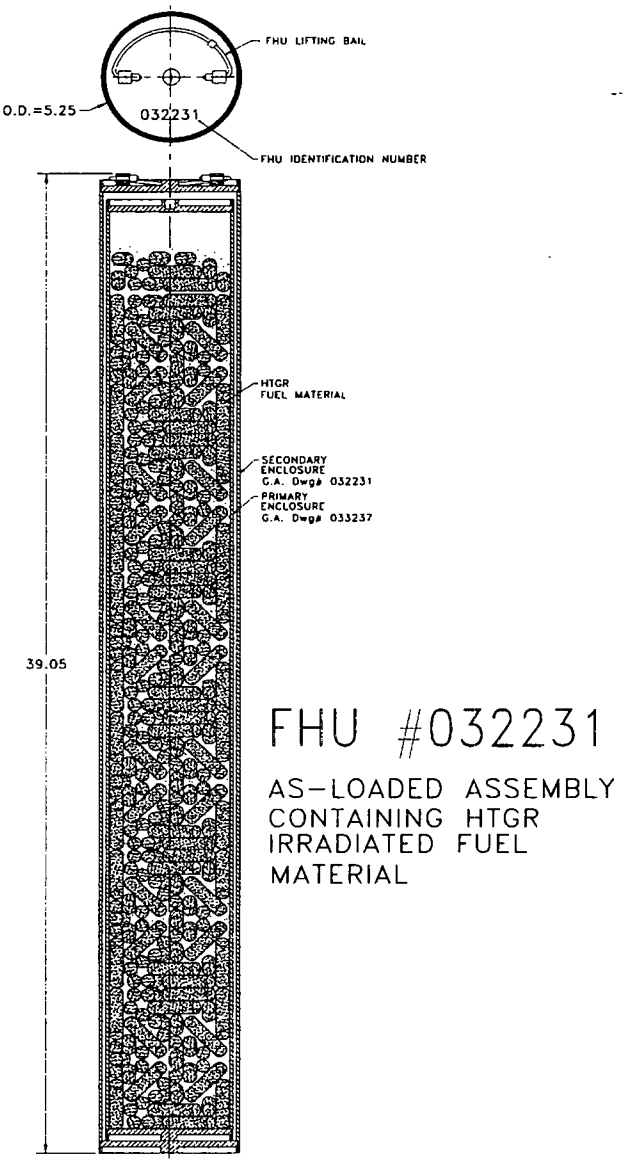


Figure 1.2.3-8 RERTR Fuel Handling Unit

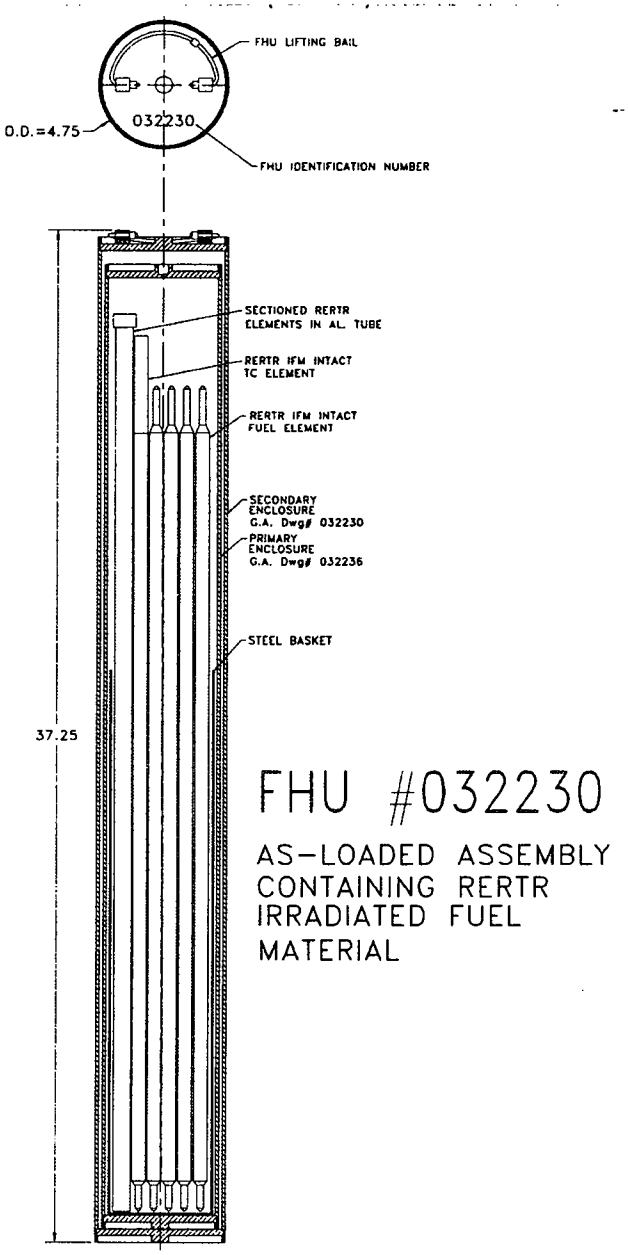


Figure 1.2.3-9 Typical TPBAR Assembly

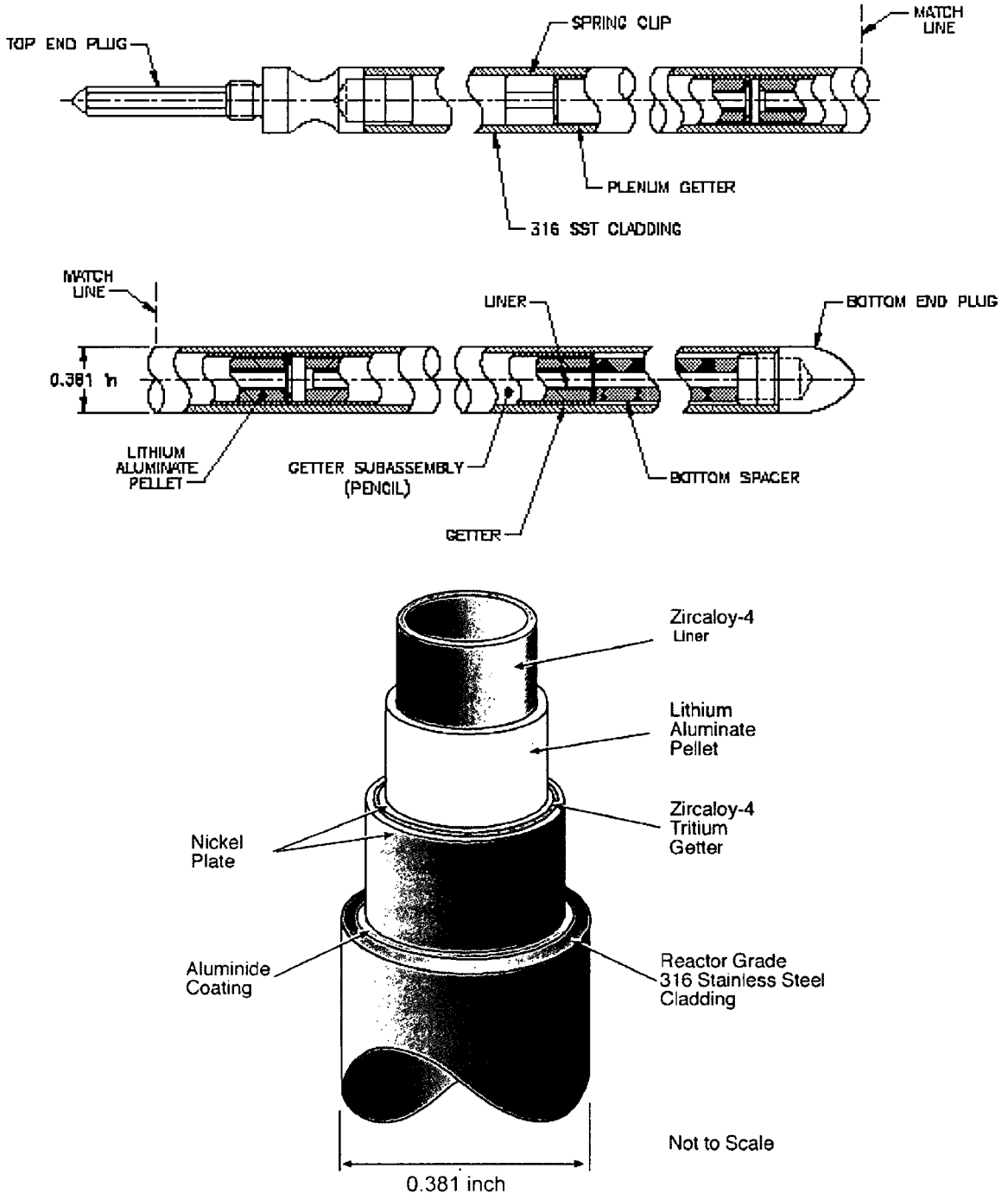
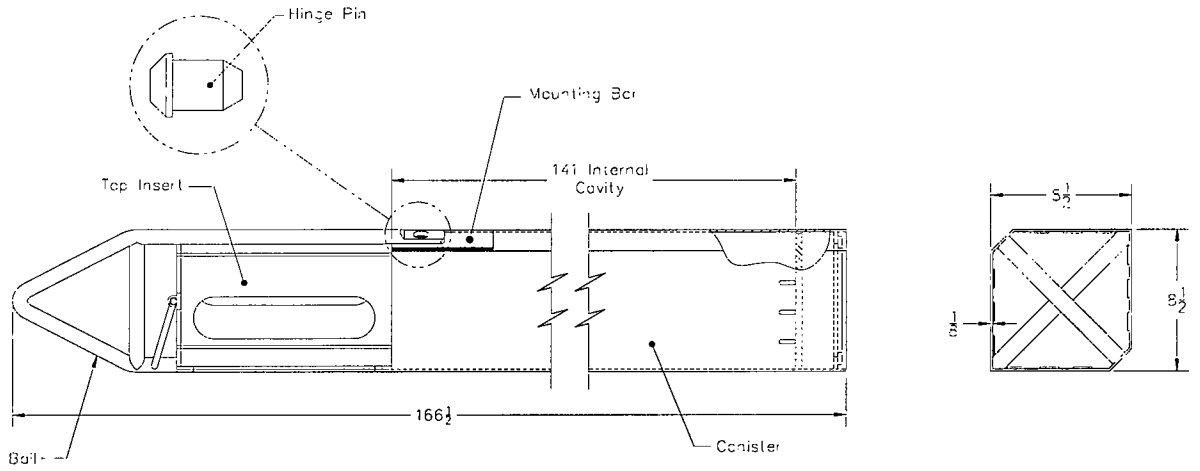


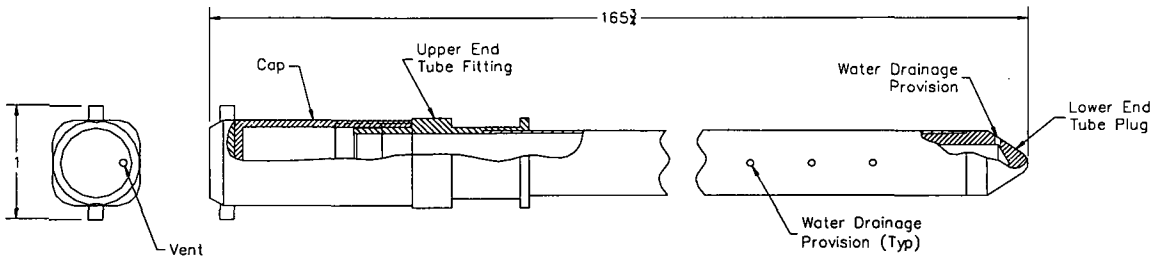
Figure 1.2.3-10 TPBAR Consolidation Canister Sketch



Conceptual Layout with Approximate Dimensions

Note: Material of construction is stainless steel.

Figure 1.2.3-11 Failed PWR/BWR Fuel Rod Capsule



Failed Fuel Rod Capsule Conceptual Layout

All Dimensions Approximate

Note: Material of construction is stainless steel.

Figure 1.2.3-12 NAC-LWT with TPBAR Consolidation Canister Payload

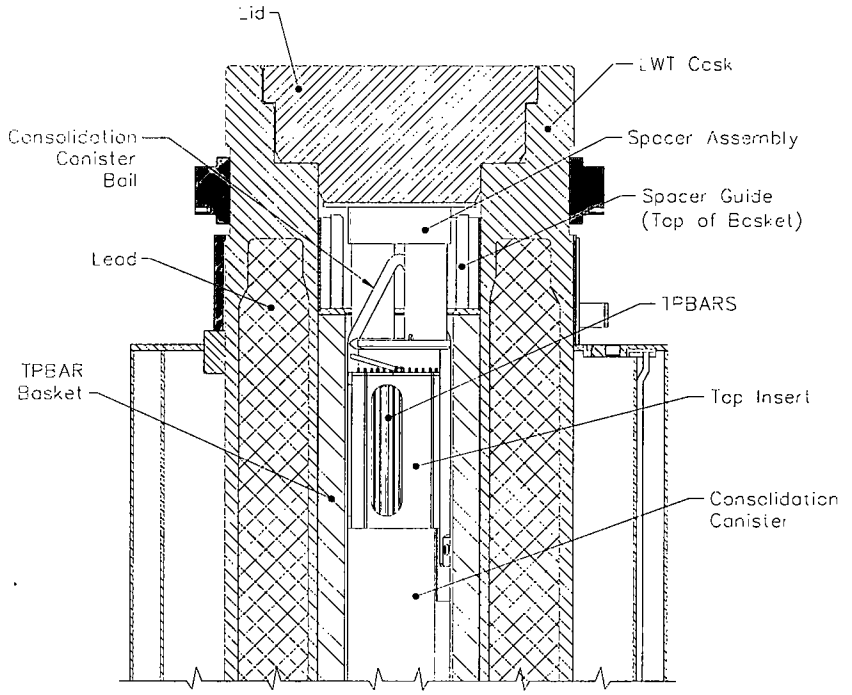


Figure 1.2.3-13 PULSTAR Fuel Assembly

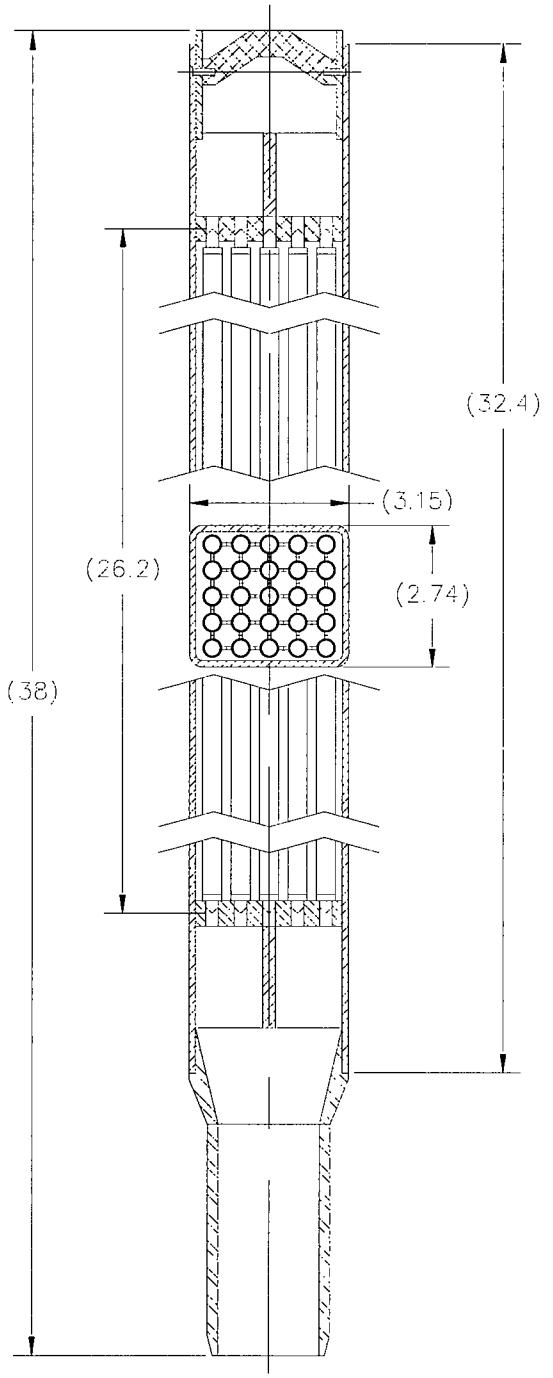
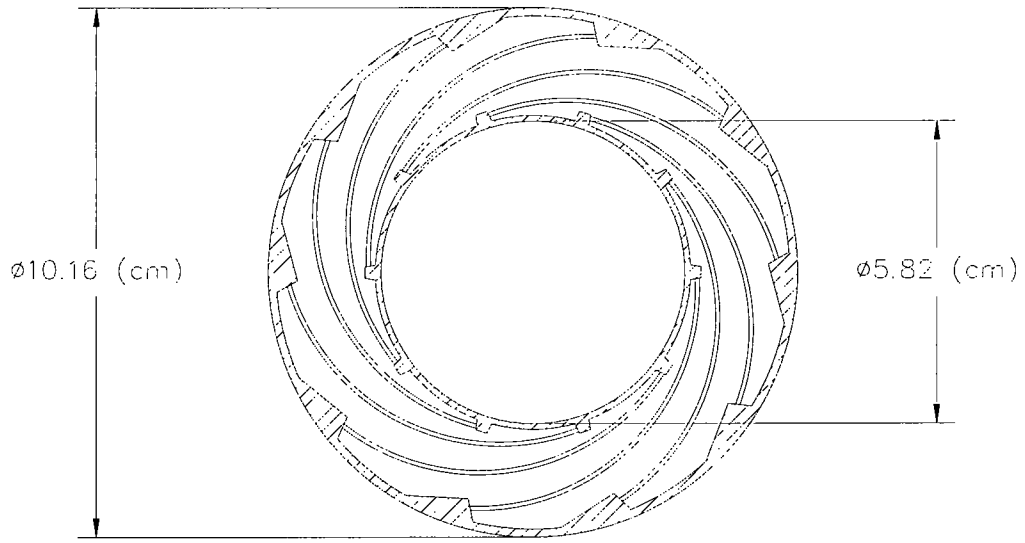
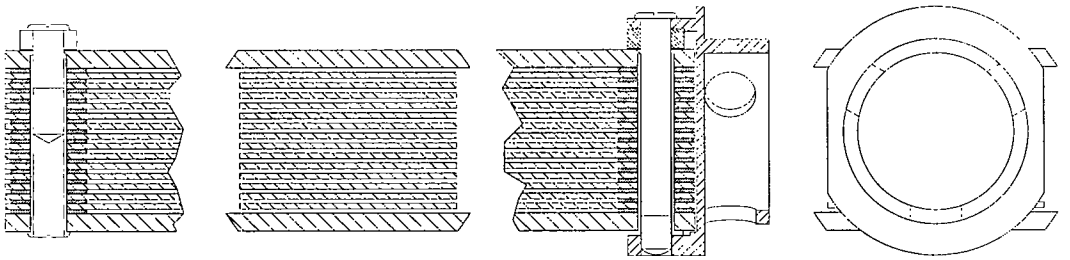


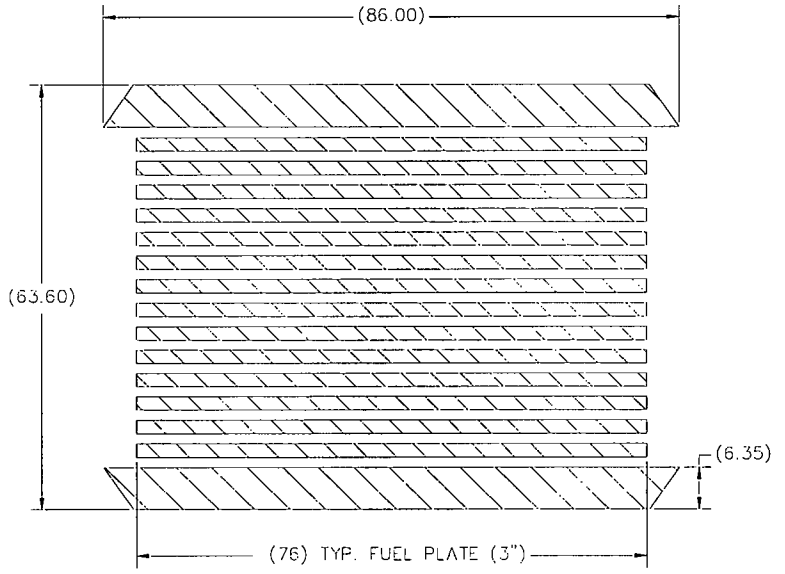
Figure 1.2.3-14 Spiral Fuel Assembly Cross-Section Sketch



Note: Nominal dimensions

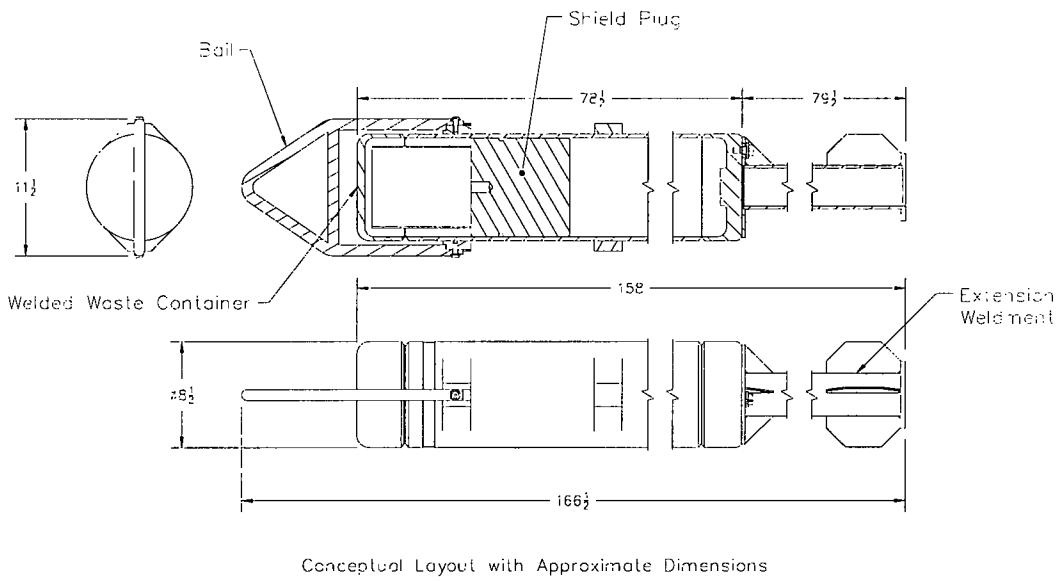
Figure 1.2.3-15 MOATA Plate Bundle Sketches





Note: 14-plate bundle configuration. Dimensions are reference values. Bundles with a reduced number of plates retain the plate pitch and compensate by wider side plates and outside spacers to retain overall bundle dimensions.

Figure 1.2.3-16 TPBAR Waste Container and Extension Weldment Sketch



Note: Material of construction is stainless steel.

Figure 1.2.3-17 NAC-LWT with TPBAR Waste Container Payload

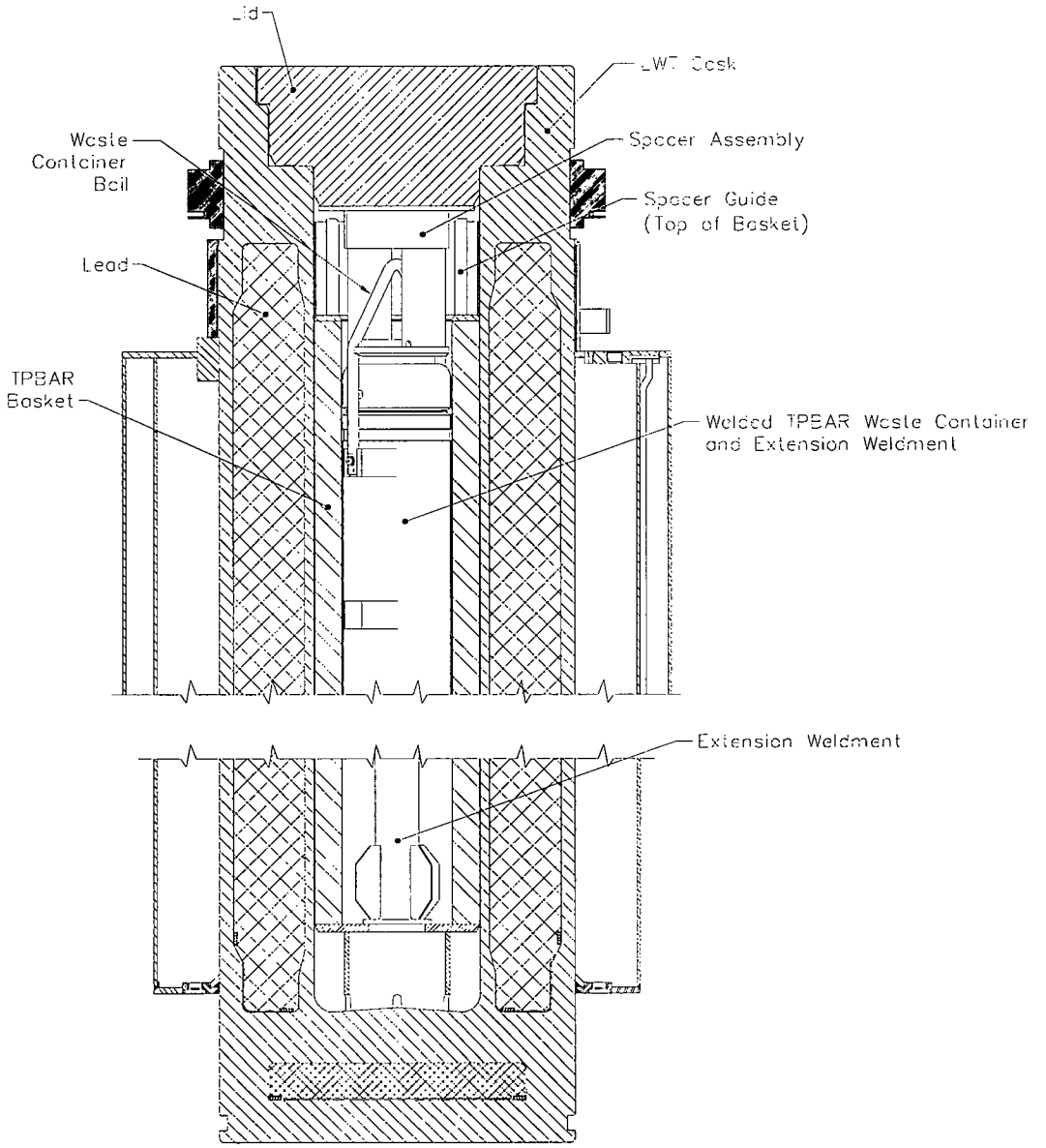
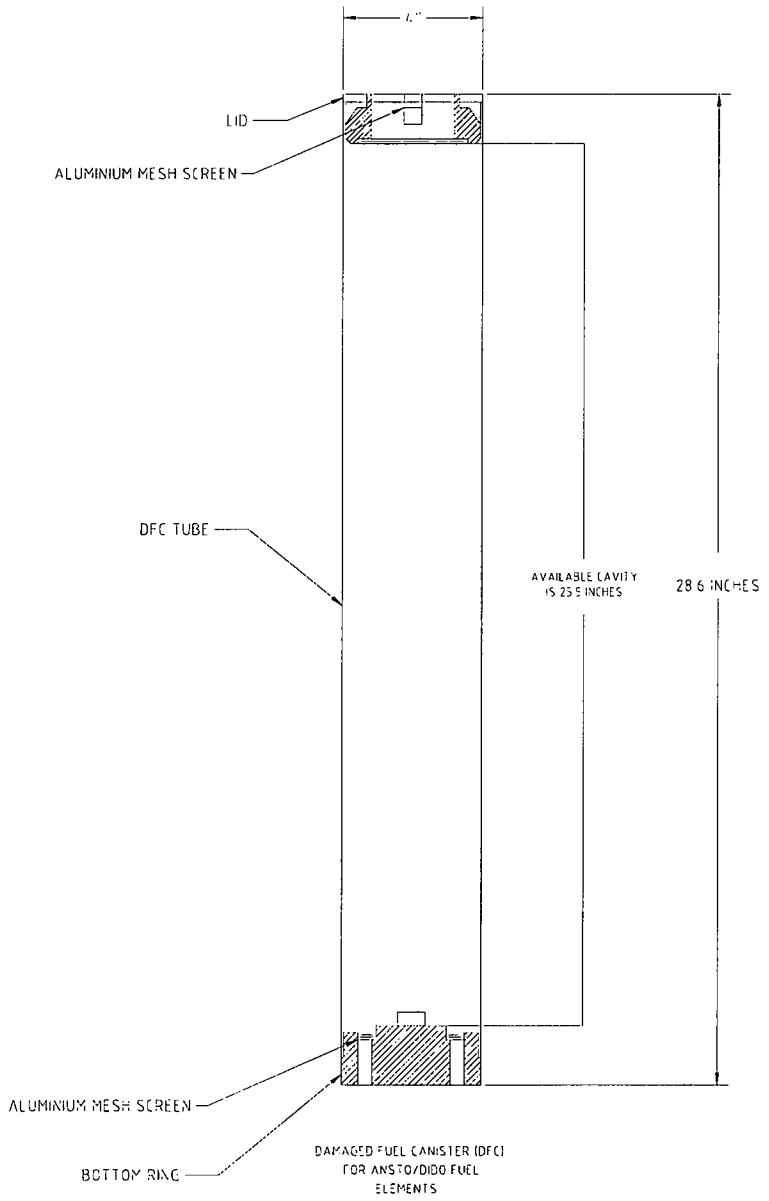


Figure 1.2.3-18 ANSTO Damaged Fuel Can (DFC)



NOTES:
1 DFC MATERIAL - 6061 ALUMINIUM
2 DIMENSIONS NOMINAL

Figure 1.2.3-19 SLOWPOKE Fuel Element

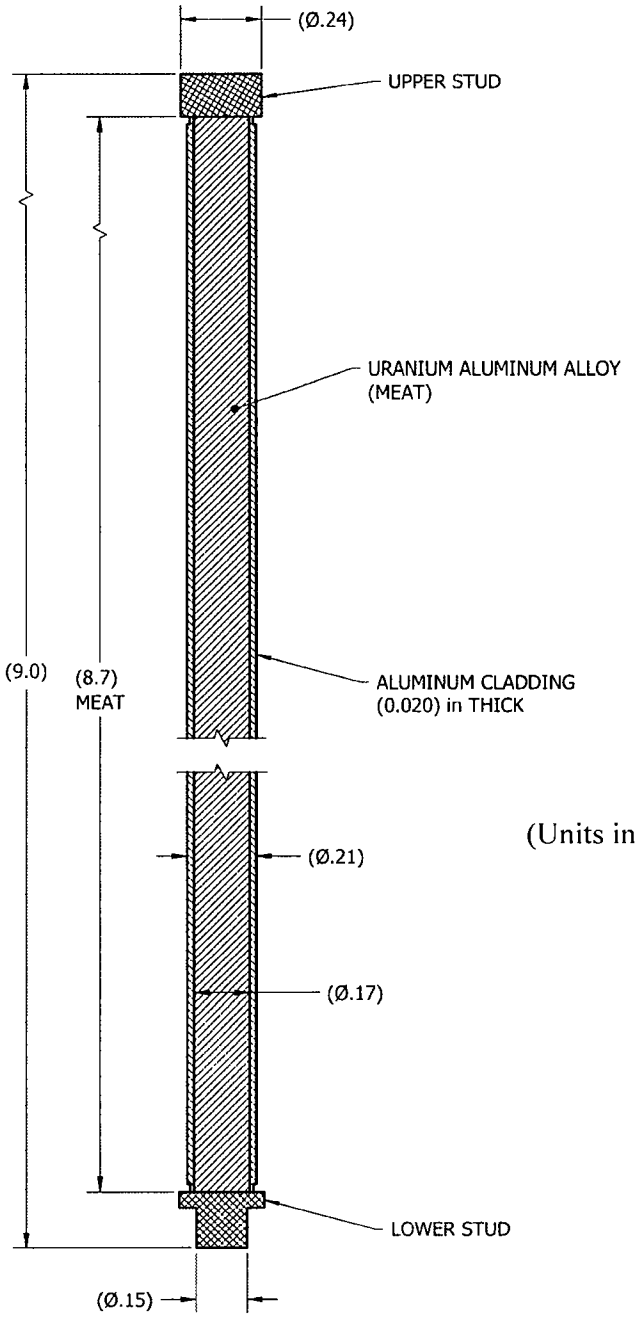
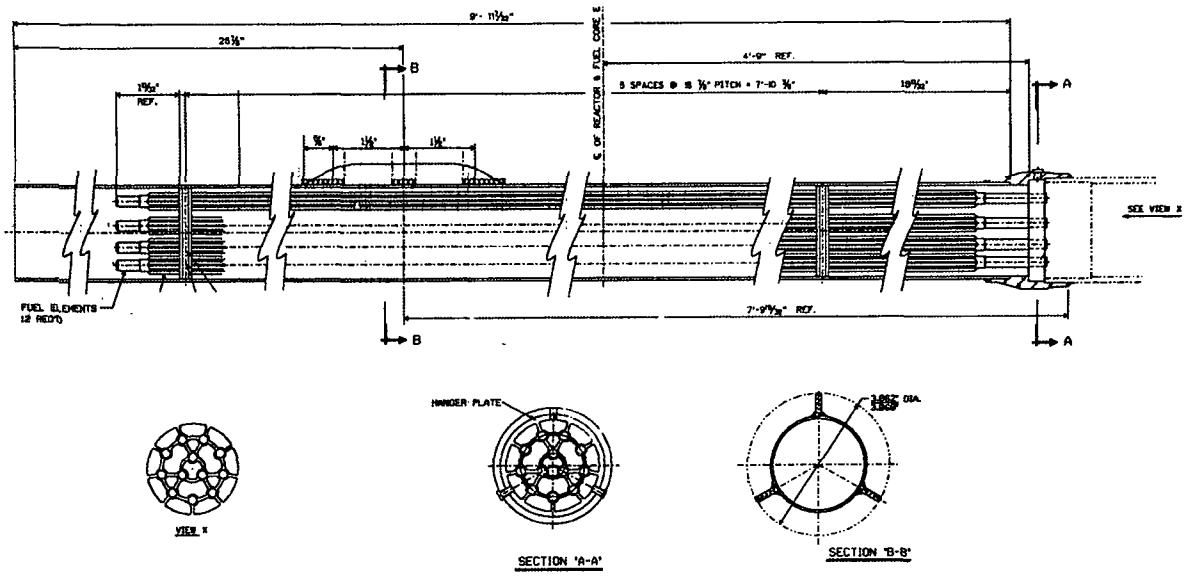
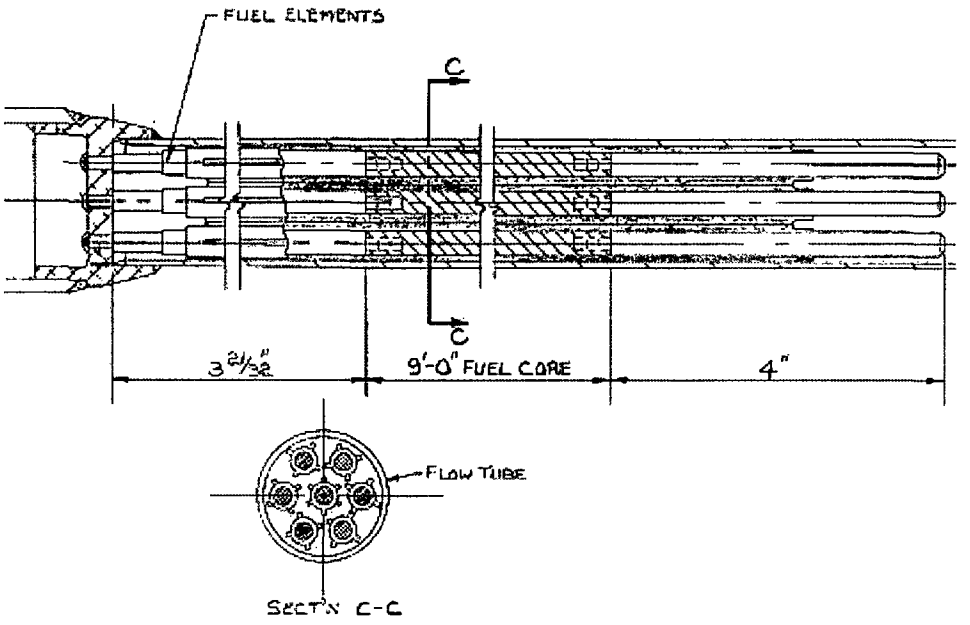


**Figure 1.2.3-20 NRU and NRX Fuel Assemblies
(Before Cropping and Potential Removal of Flow Tube)**

NRU



NRX



(Units in inches)

Figure 1.2.3-21 HEUNL Container

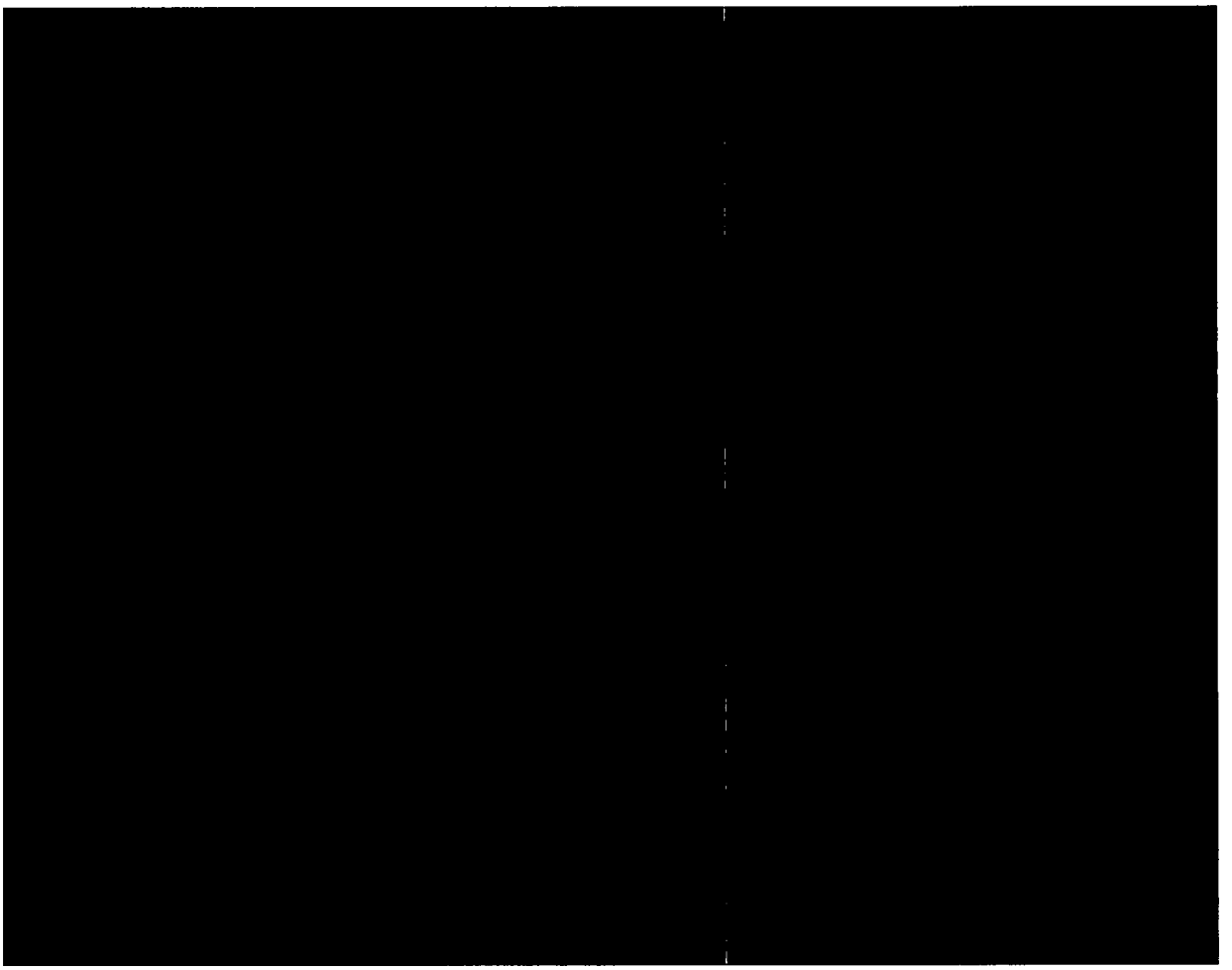


Table 1.2-1 Characteristics of Design Basis TRIGA Fuel Elements Acceptable for Loading in the Poisoned TRIGA Basket

	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	583,000 (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 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

[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

[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

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

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

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

Table 1.2-8 Typical Production TPBAR Characteristics[1]

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

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

Table 1.2-9 PULSTAR Fuel Characteristics

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

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

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

Table 1.2-10 Spiral Fuel Assembly Characteristics

Parameter	Value
Number of elements per assembly	10
Fuel element type	Curved plate
Nominal dimensions of element (cm)	0.147 × 7.33 × 63.5 (individual plate)
Chemical form of fuel meat	U-Al_x-alloy
Cladding material	Aluminum
Nominal over-all dimensions (cm)	63.818 (height) × 10.16 diameter[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

[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	4,000 pounds [2]
Maximum Content Length	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	347	375
Maximum ^{235}U Depletion (%)	87.4	80.4	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 and caddy weight.

Table 1.2.3-16 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.

1.3 Quality Assurance

The Nuclear Regulatory Commission (NRC) has assigned Approval Number 18 to the Nuclear Assurance Corporation Quality Assurance program that satisfies the provisions of Subpart H of 10 CFR 71.

The Quality Assurance program provides control over all activities that are important to safety that are applicable to the design, fabrication, assembly, testing, maintenance, repair, modification, and use of the packaging for transportation of radioactive materials. The program applies controls to the various activities in a graded approach, such that the effort expended on an activity is consistent with its importance to safety. The program is consistent in approach and method with Regulatory Guide 7.10 and satisfies the specific requirements of 10 CFR 71.101 (a), (b), and (c).

In accordance with the requirements of 10 CFR 71.37(a), the approved Quality Assurance program has been applied to the design, analysis, package fabrication, assembly, testing, maintenance, and repair or modification of the NAC-LWT package. An equivalent NRC approved program maintained by a Registered User would be applied to use of the package.

1.4 License Drawings

This section contains the license drawings pertinent to the NAC-LWT cask (refer to the List of Drawings in the Table of Contents for Chapter 1).

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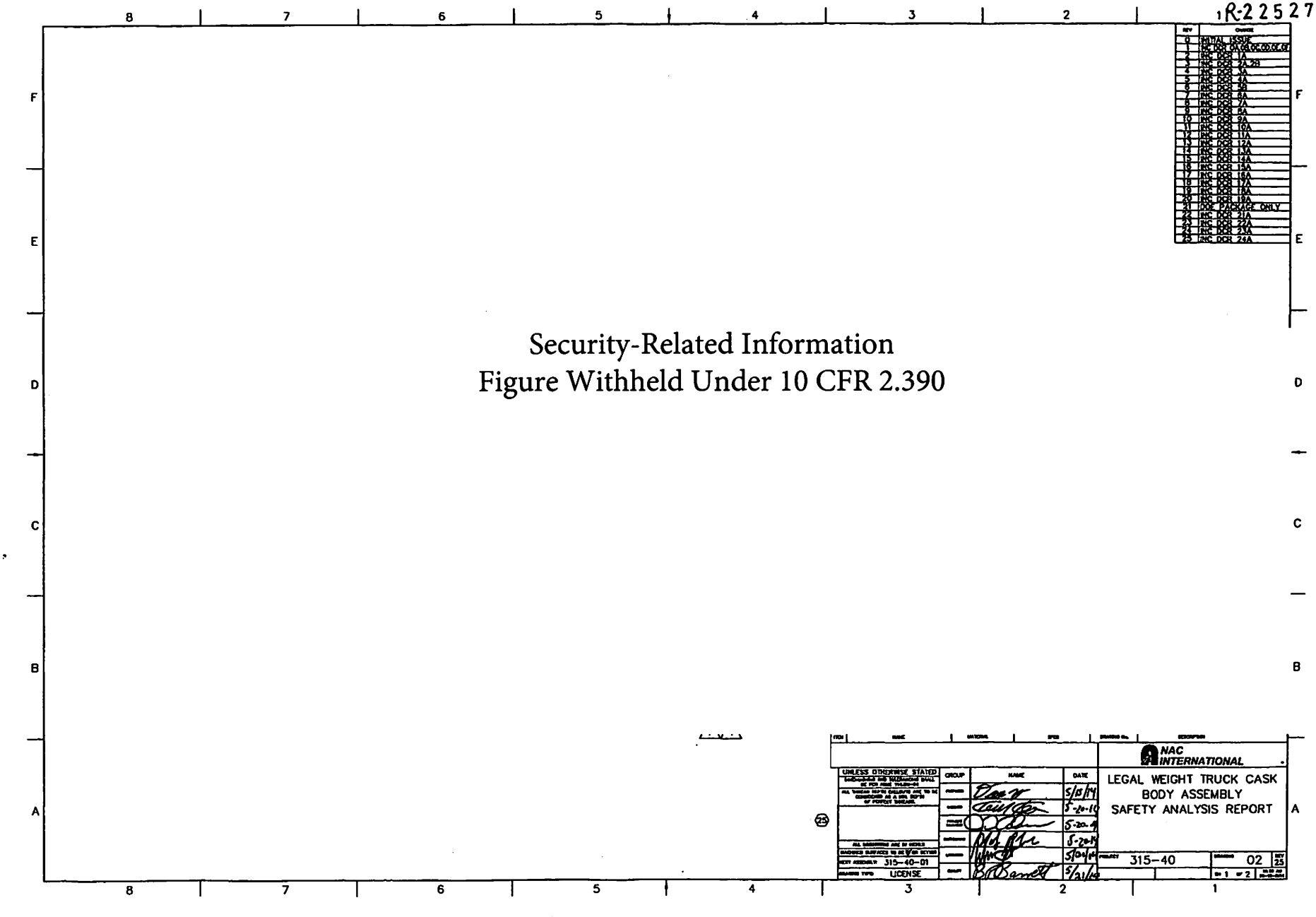

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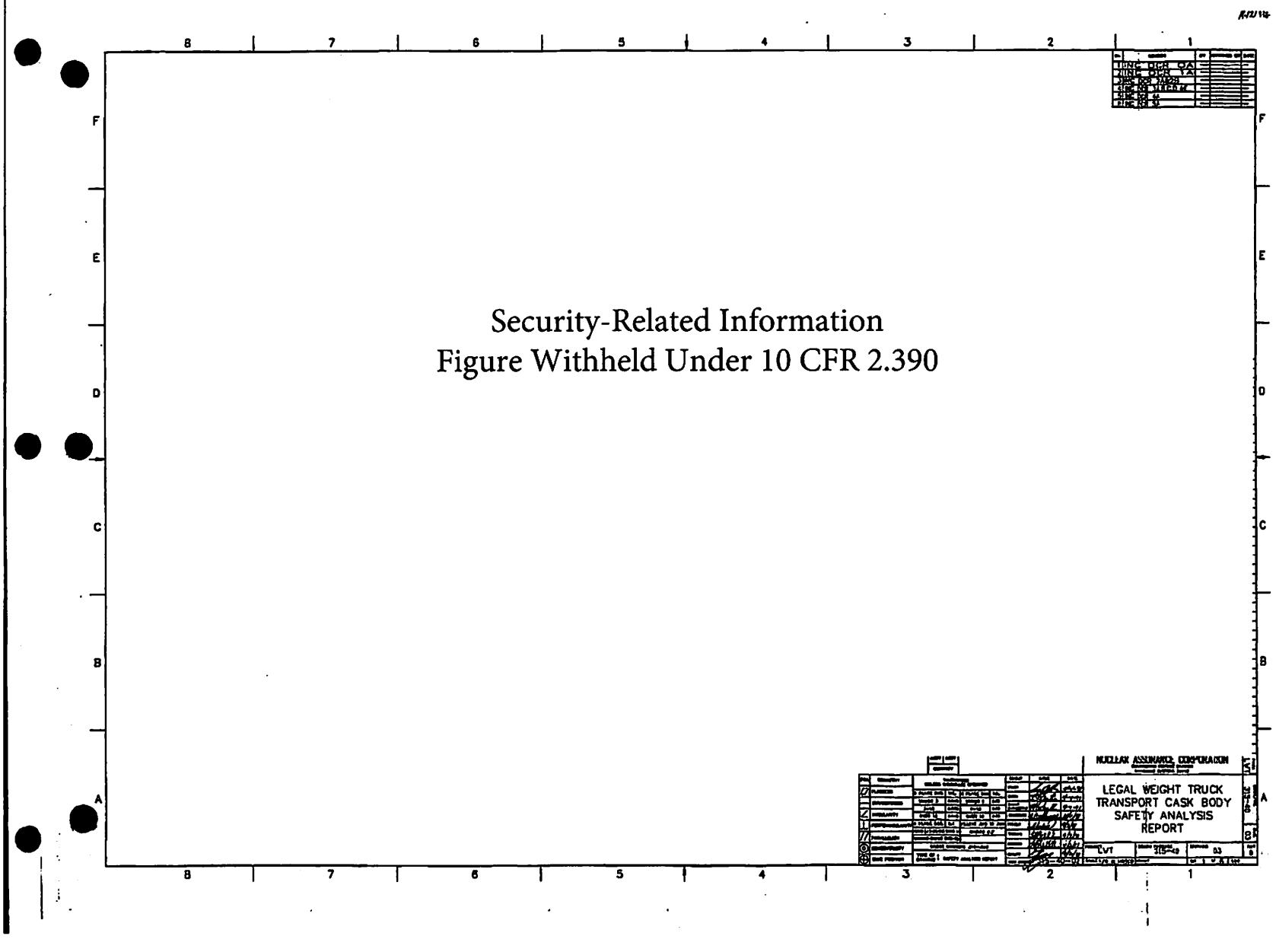
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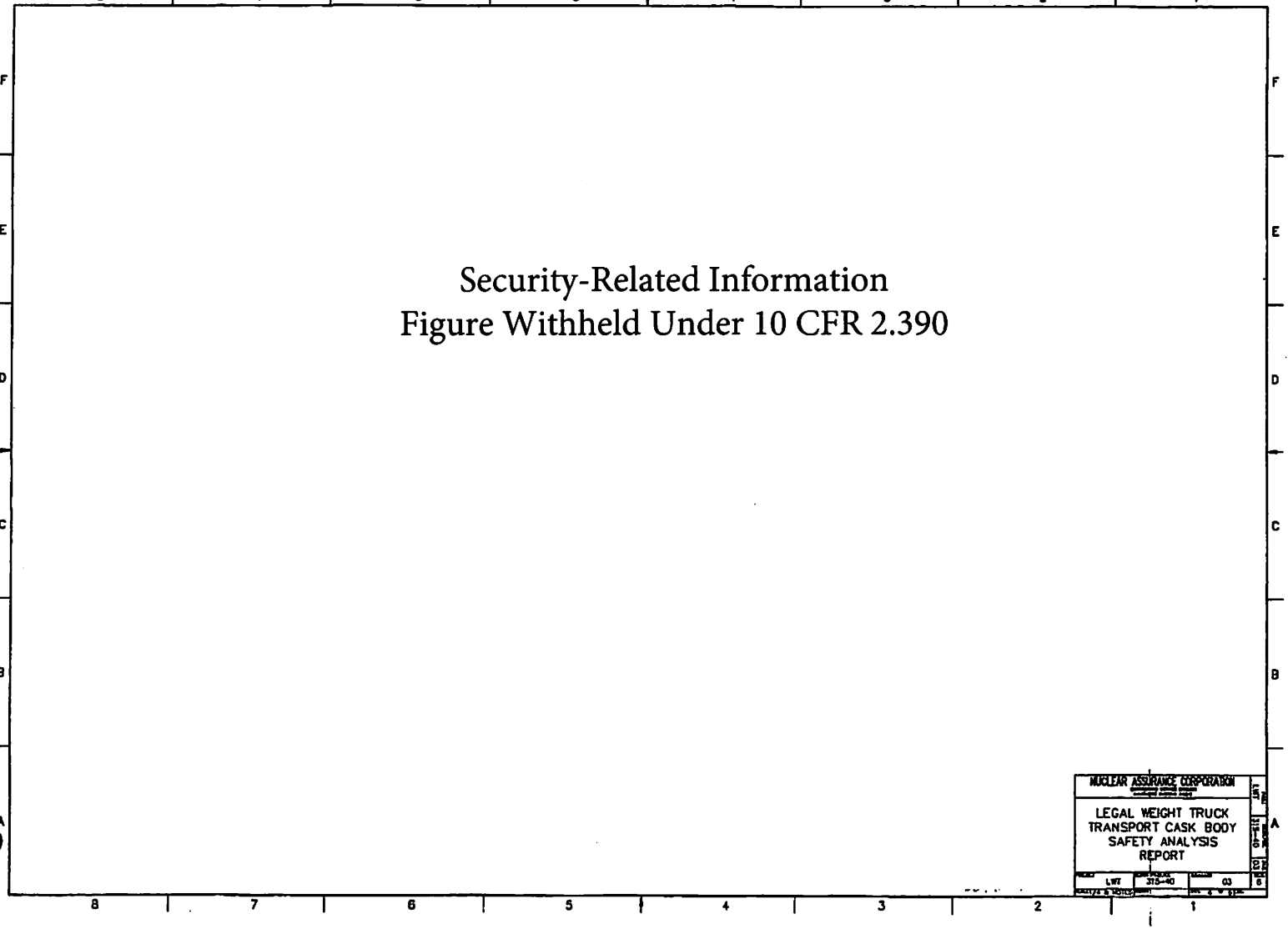
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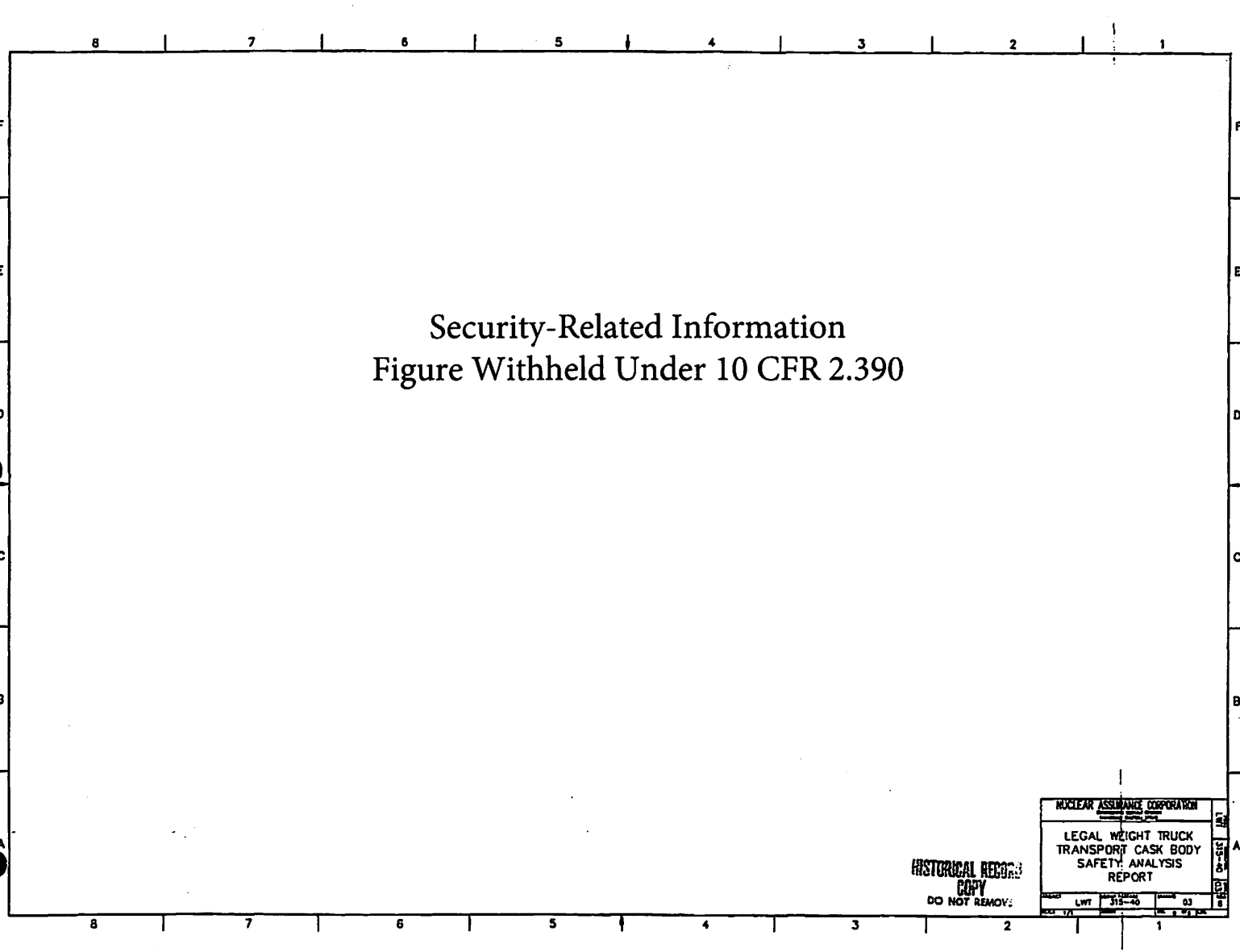
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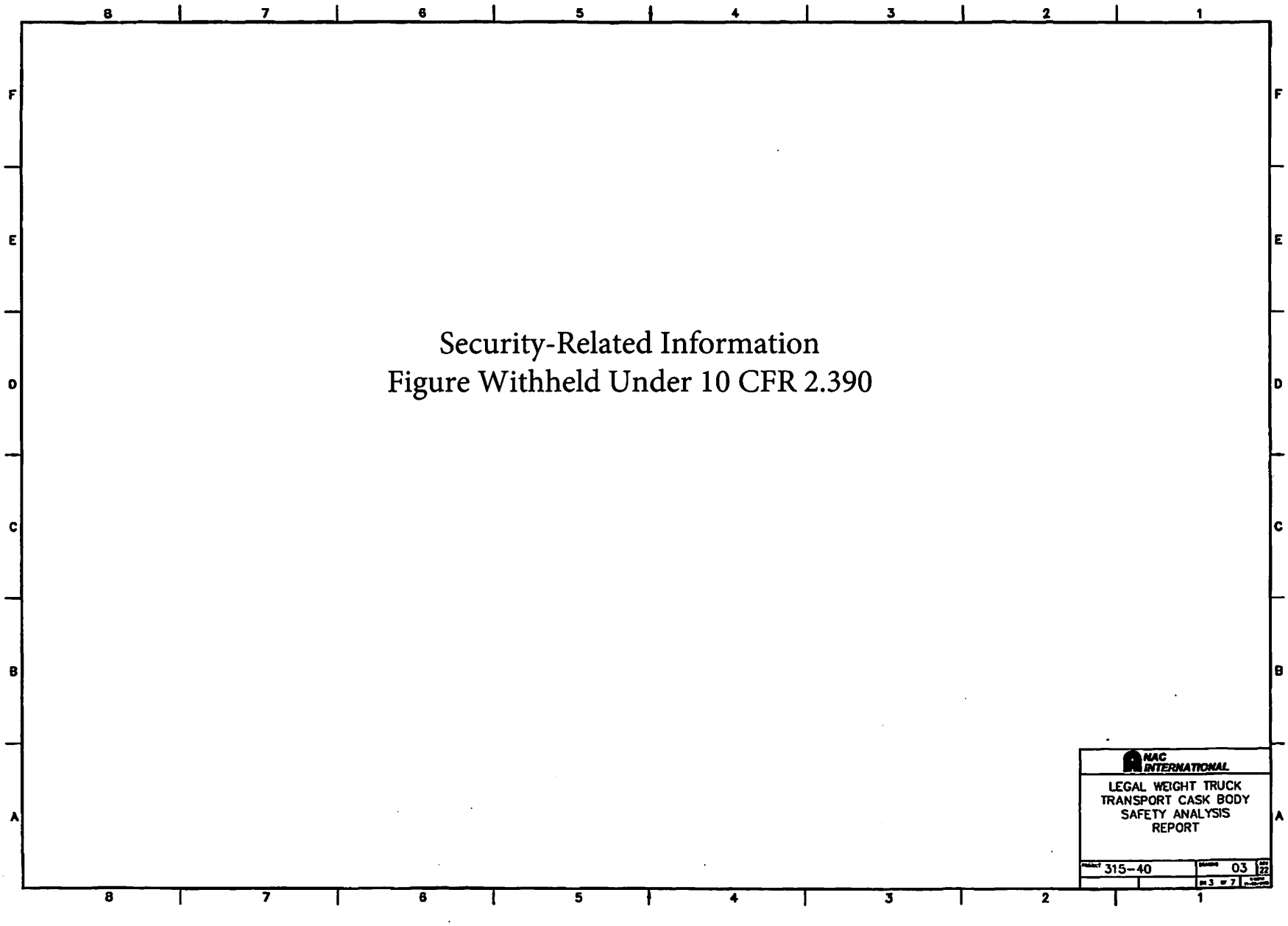
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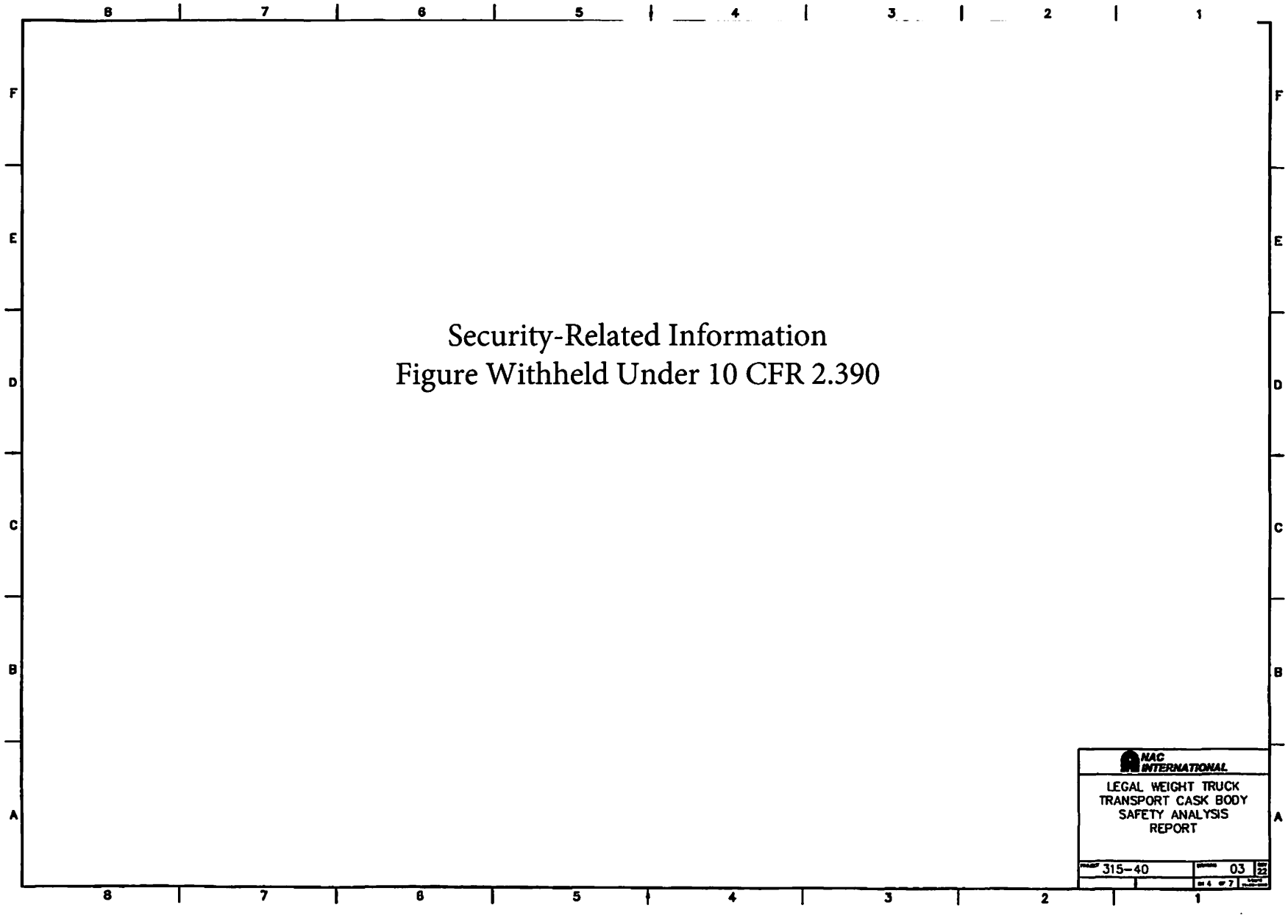
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1	UNC DCR 6A, 8B, 8C
2	UNC DCR 1A
3	UNC DCR 2A & 2B
4	UNC DCR 3A
5	UNC DCR 4A
6	UNC DCR 5A & 5B
7	UNC DCR 6A
8	UNC DCR 7A
9	UNC DCR 8A
10	UNC DCR 9A
11	UNC DCR 10A
12	UNC DCR 11A, 11B

Security-Related Information
Figure Withheld Under 10 CFR 2.390

GROUP	NAME	DATE
ORIGINATOR		11/29/11
CHECKED		12-22-11
APPROVED		1-25-12
ENGINEERING		12-27-11
LICENSING		12/29/11
QUALITY		1/25/12

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK LID ASSY
SAFETY ANALYSIS
REPORT

PROJECT 315-40 | DRAWING 04 | REV 12

SCALE N.T.S. (12) | SHT (12) | SH 1 OF 1

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK
UPPER IMPACT LIMITER
SAFETY ANALYSIS
REPORT

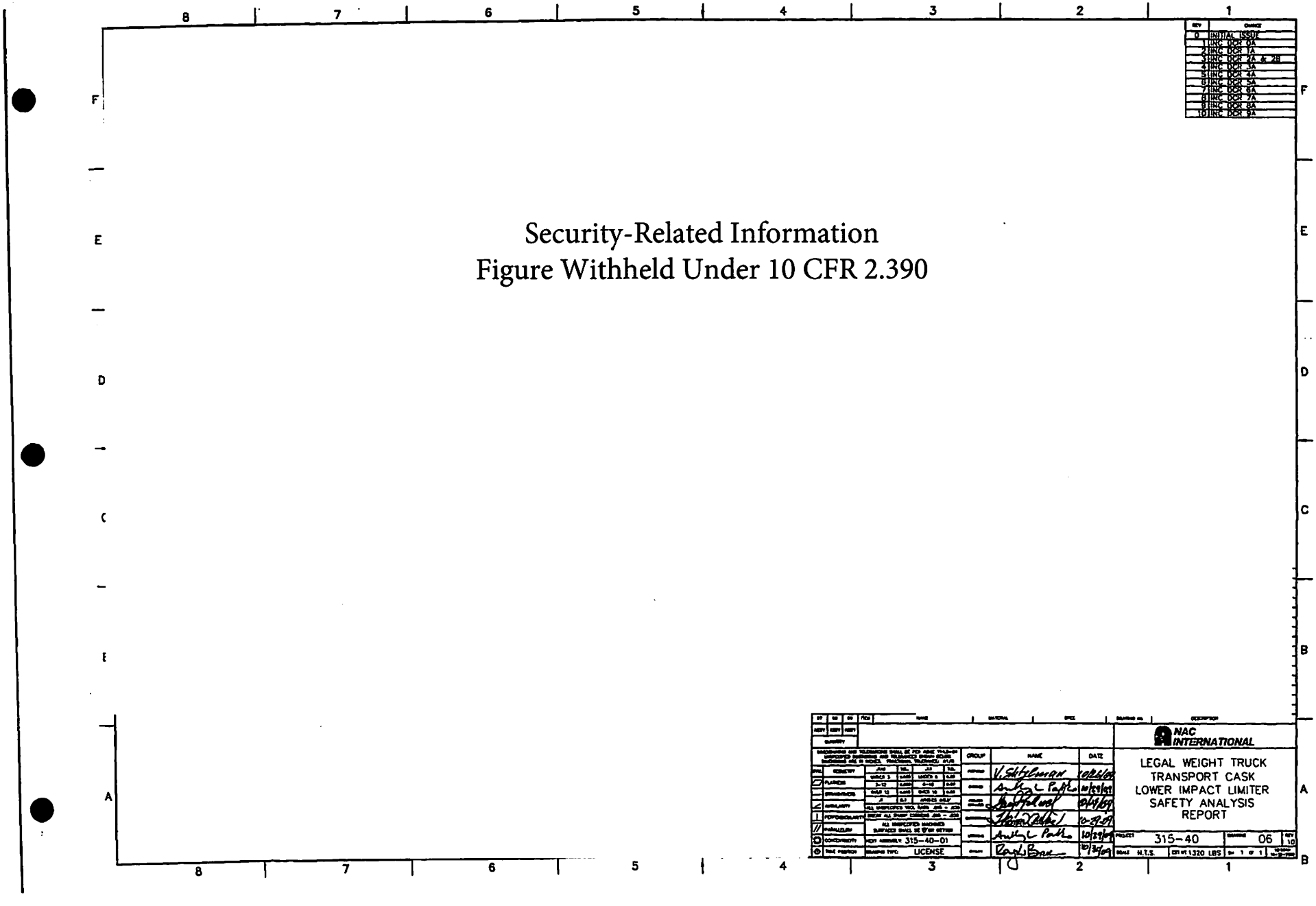
315-40

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK
UPPER IMPACT LIMITER
SAFETY ANALYSIS
REPORT

PROJECT	DRAWING	REV
315-40	05	10
SCALE N. T. S.	AS NOTED	SH 2 OF 2


Security-Related Information
Figure Withheld Under 10 CFR 2.390
NAC INTERNATIONAL
LEGAL WEIGHT TRUCK
TRANSPORT CASK
LOWER IMPACT LIMITER
SAFETY ANALYSIS
REPORT
315-40
06

R-20,7531

Security-Related Information
Figure Withheld Under 10 CFR 2.390

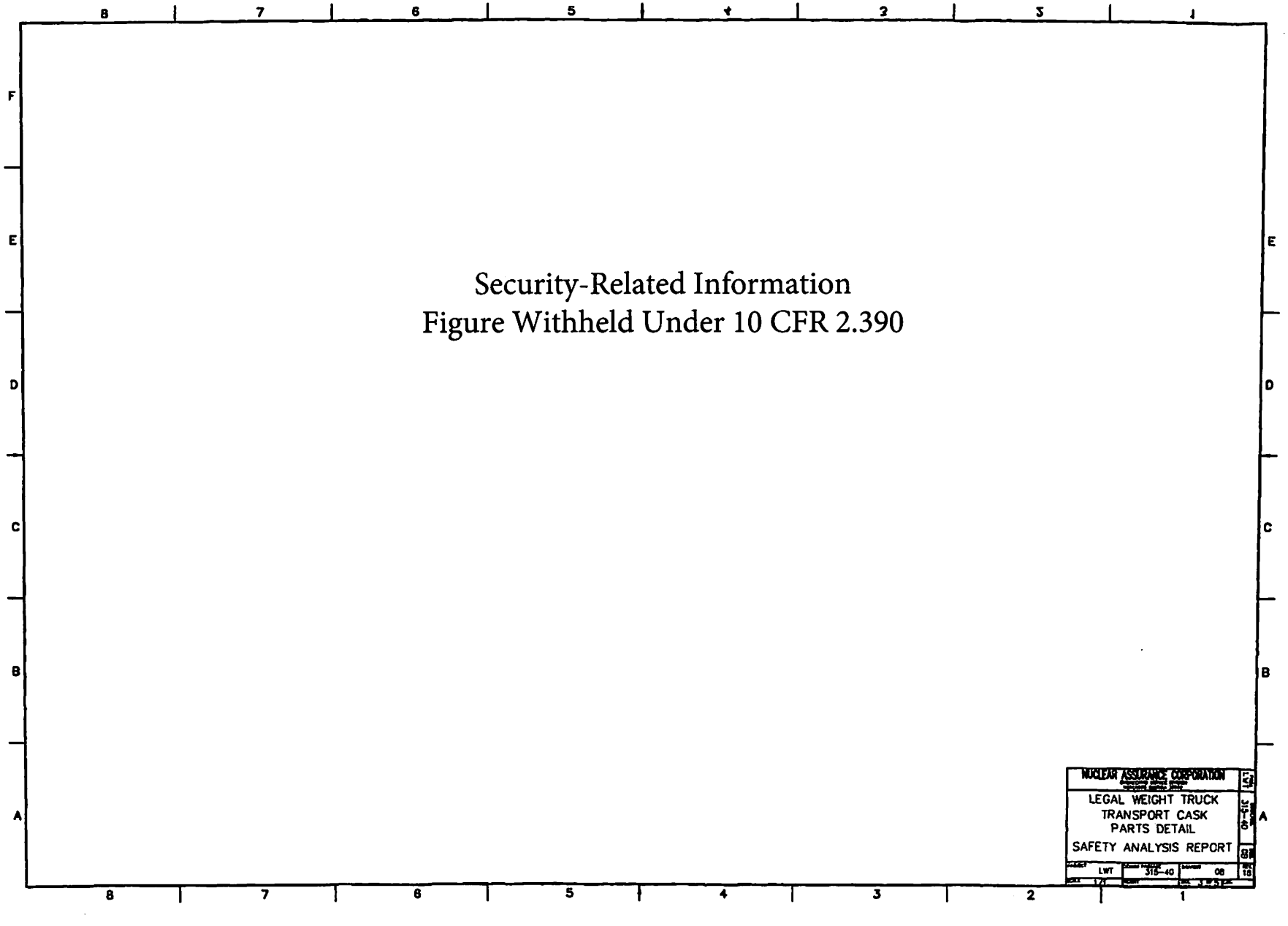
NUCLEAR ASSURANCE CORPORATION

LEGAL WEIGHT TRUCK
TRANSPORT CASK
PARTS DETAIL
SAFETY ANALYSIS REPORT

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NUCLEAR ASSURANCE CORPORATION

LEGAL WEIGHT TRUCK
TRANSPORT CASK
PARTS DETAIL
SAFETY ANALYSIS REPORT


Security-Related Information
Figure Withheld Under 10 CFR 2.390
NUCLEAR ASSURANCE CORPORATION
LEGAL WEIGHT TRUCK
TRANSPORT CASK
PARTS DETAIL
SAFETY ANALYSIS REPORT
LWT
315-40
08

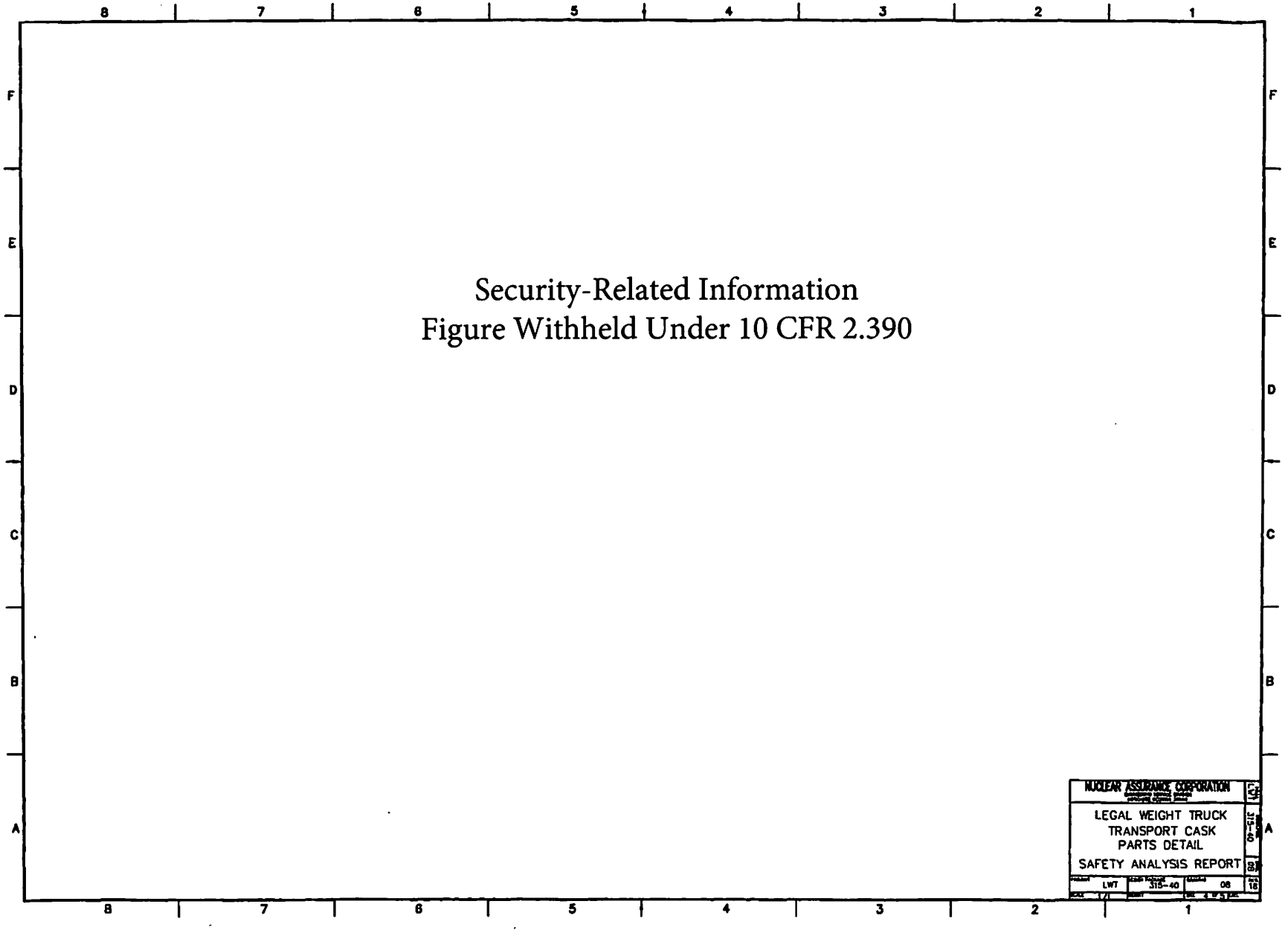

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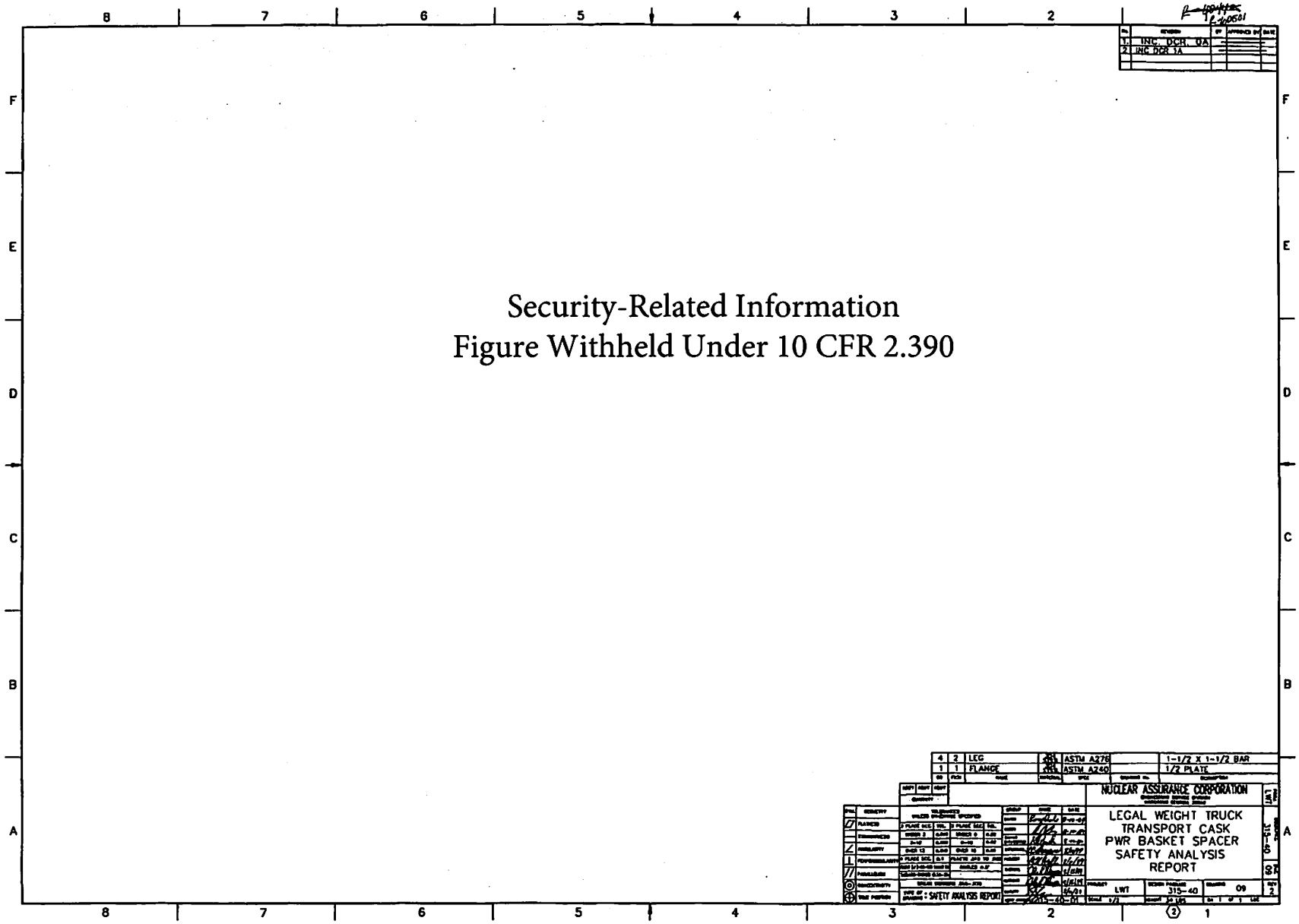
Figure Withheld Under 10 CFR 2.390
NUCLEAR ASSURANCE CORPORATION
LEGAL WEIGHT TRUCK
TRANSPORT CASK
PARTS DETAIL
SAFETY ANALYSIS REPORT
LWT
315-40
08

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NUCLEAR ASSURANCE CORPORATION

LEGAL WEIGHT TRUCK
TRANSPORT CASK
PARTS DETAIL
SAFETY ANALYSIS REPORT

LWT | 315-40 | 08


Security-Related Information
Figure Withheld Under 10 CFR 2.390
NUCLEAR ASSURANCE CORPORATION
LEGAL WEIGHT TRUCK
TRANSPORT CASK
PWR BASKET SPACER
SAFETY ANALYSIS
REPORT

NAC DCRM 01

Security-Related Information
Figure Withheld Under 10 CFR 2.390

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LWT CASK
PWR BASKET
SAFETY ANALYSIS
REPORT

315-40 | 10 | 8

SCALE 1/4 | UNLESS NOTED | SH 2 OF 2

Q-13 1995

NO.	REVISION	BY	APPROVED BY	DATE
0	INITIAL ISSUE			
1	INC DCR 0A & 0B			
2	INC DCR 1A			

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NUCLEAR ASSURANCE CORPORATION

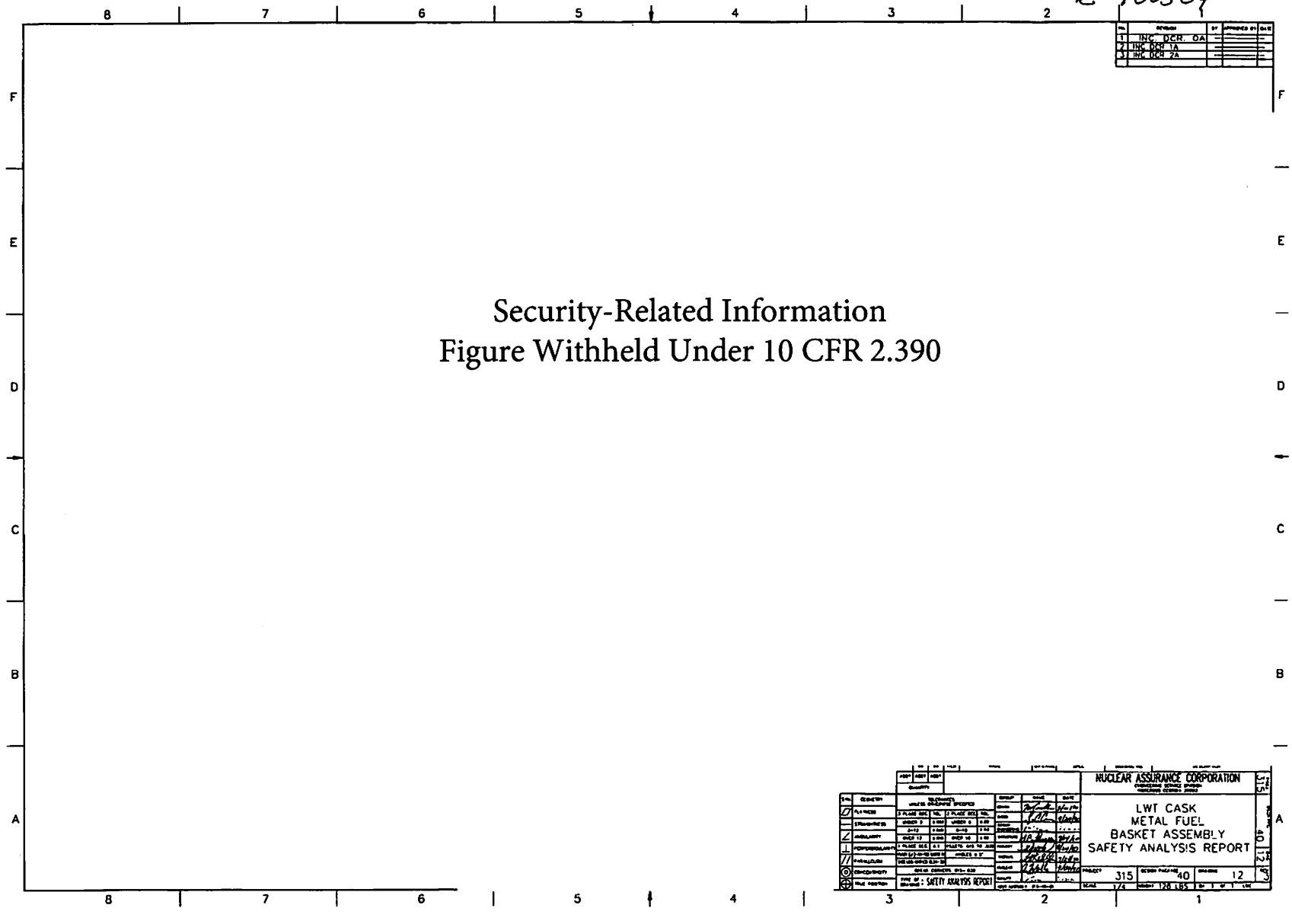
BWR FUEL BASKET ASSEM
LWT CASK
SAFETY ANALYSIS REPORT

TYPE OF DRAWING: LISCENSING

PROJECT LWT

NAC DCRM 07

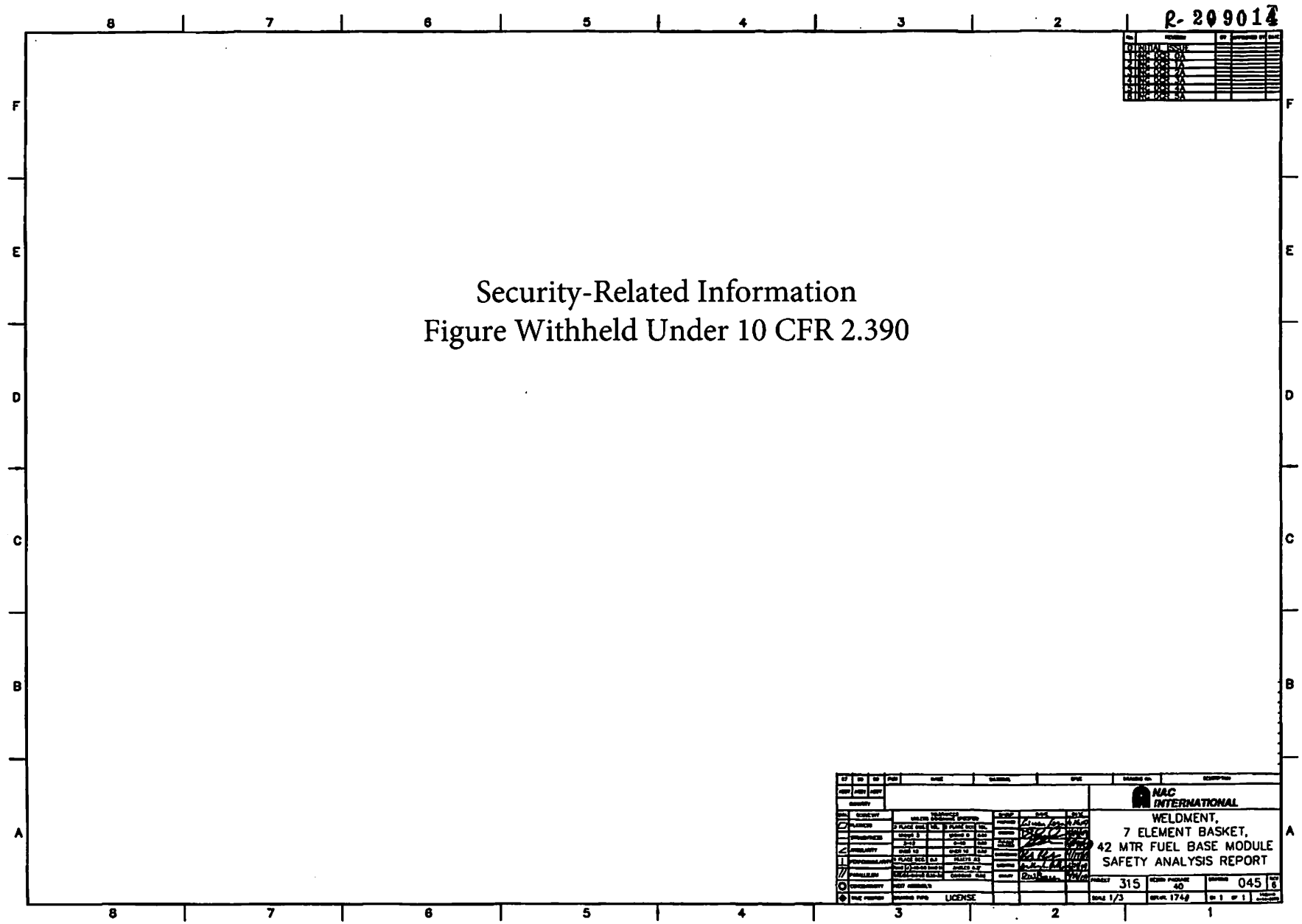
Q-100504



Security-Related Information
Figure Withheld Under 10 CFR 2.390

NUCLEAR ASSURANCE CORPORATION

LWT CASK
METAL FUEL
BASKET ASSEMBLY
SAFETY ANALYSIS REPORT


Security-Related Information
Figure Withheld Under 10 CFR 2.390
NAC INTERNATIONAL
WELDMENT,
7 ELEMENT BASKET,
42 MTR FUEL BASE MODULE
SAFETY ANALYSIS REPORT
315
045

R-209015

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 ELEMENT BASKET, 42
MTR FUEL INTERMEDIATE MODULE,
SAFETY ANALYSIS REPORT

315 | 40 | 046

SCALE 1/3 | SHEET 1 OF 1

Security-Related Information
Figure Withheld Under 10 CFR 2.390

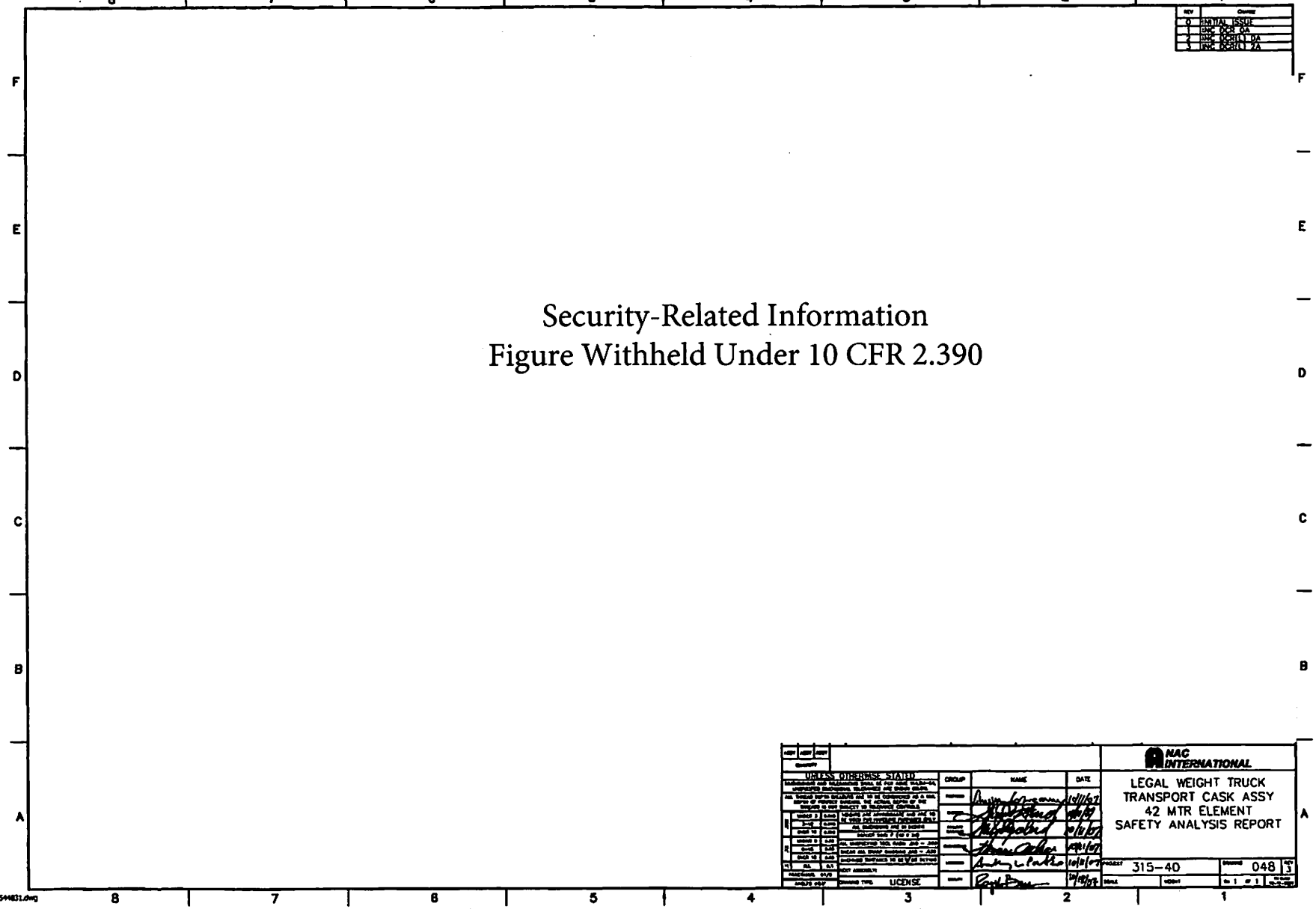
NAC INTERNATIONAL

WELDMENT,
7 ELEMENT BASKET, 42
MTR FUEL TOP MODULE,
SAFETY ANALYSIS REPORT

PROJECT 315 | DRAWING 047 | REV 6

SCALE 1/3 | SHEET 1 OF 1

e-206257



NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
42 MTR ELEMENT
SAFETY ANALYSIS REPORT

315-40

048

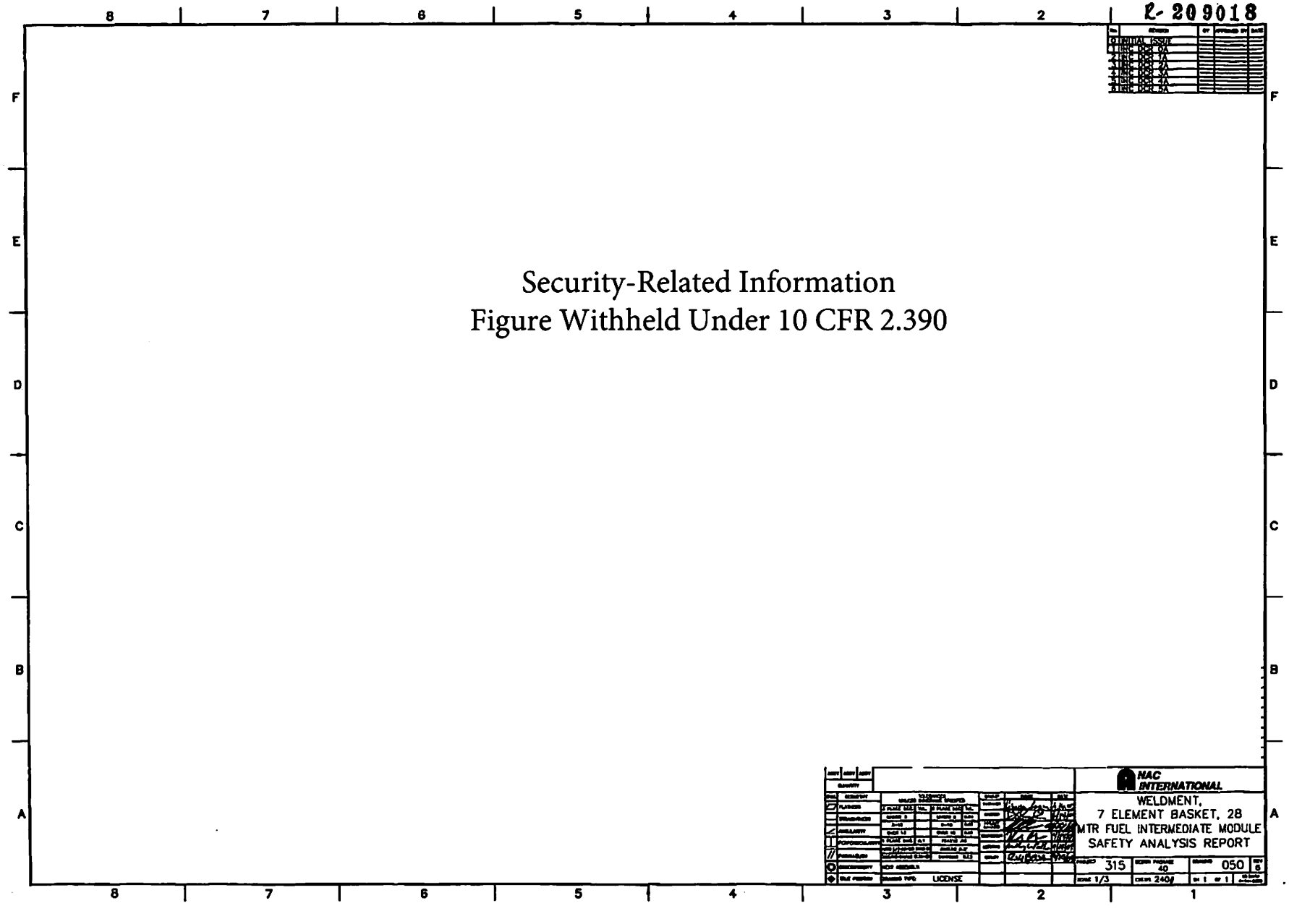
R-20 9017

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 ELEMENT BASKET,
28 MTR FUEL BASE MODULE
SAFETY ANALYSIS REPORT

PROJECT 315 | DRAWING 049


8
7
6
5
4
3
2
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D
C
B
A
L-209018
Security-Related Information
Figure Withheld Under 10 CFR 2.390
NAC INTERNATIONAL
WELDMENT,
7 ELEMENT BASKET, 28
MTR FUEL INTERMEDIATE MODULE
SAFETY ANALYSIS REPORT
315
40
050

e-209019

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 ELEMENT BASKET,
28 MTR FUEL TOP MODULE,
SAFETY ANALYSIS REPORT

315 | 40 | 051 | 6

SCALE 1/3 | SHT 1 OF 1

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
28 MTR ELEMENT
SAFETY ANALYSIS REPORT

315-40 052

M:\ACADFILE\315\License\31545231.dwg

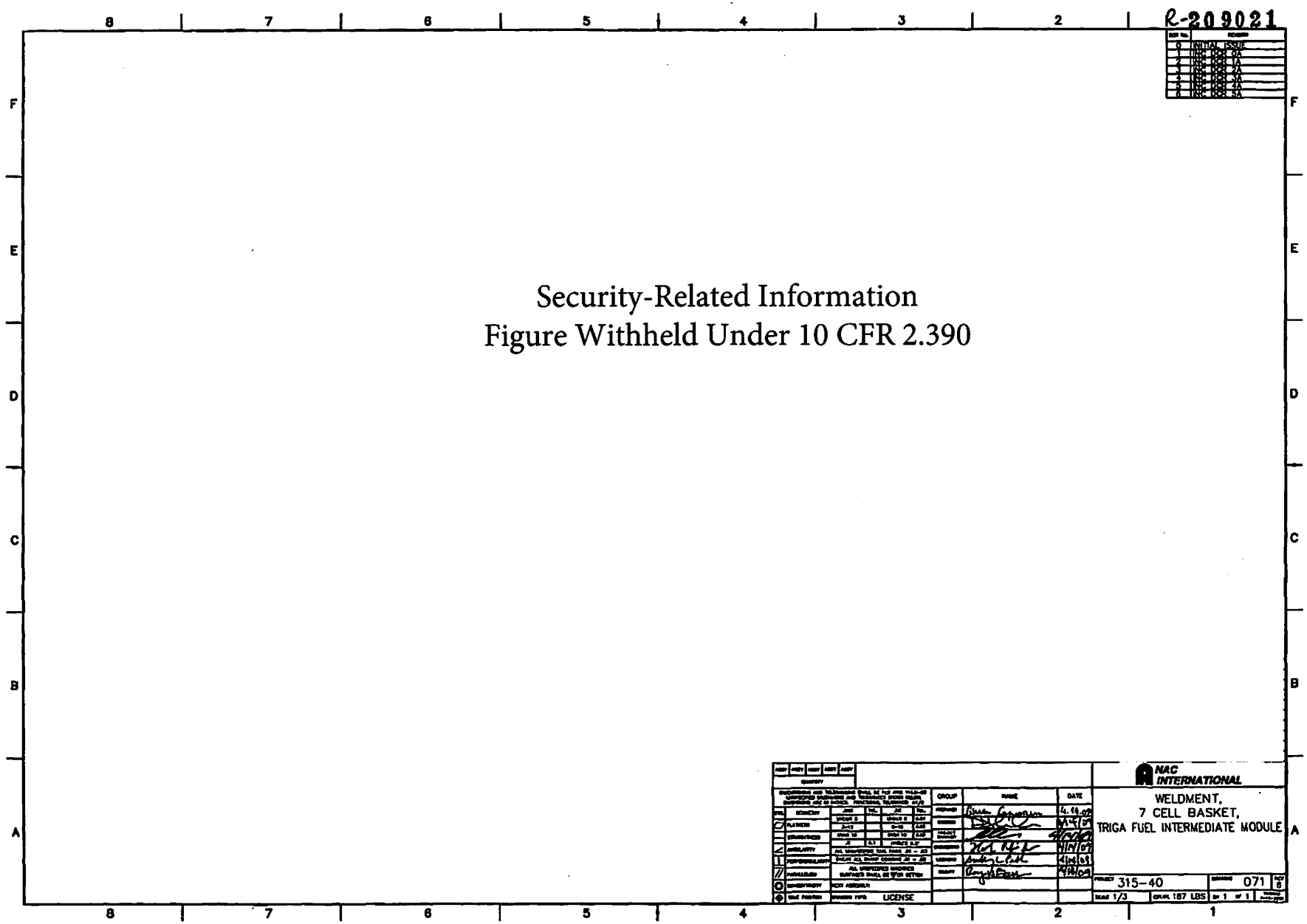
R-20,9020

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
TRIGA FUEL BASE MODULE

315-40 070


R-209021
Security-Related Information
Figure Withheld Under 10 CFR 2.390
NAC INTERNATIONAL
WELDMENT,
7 CELL BASKET,
TRIGA FUEL INTERMEDIATE MODULE
315-40
071
LICENSE

R-209022

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
TRIGA FUEL TOP MODULE

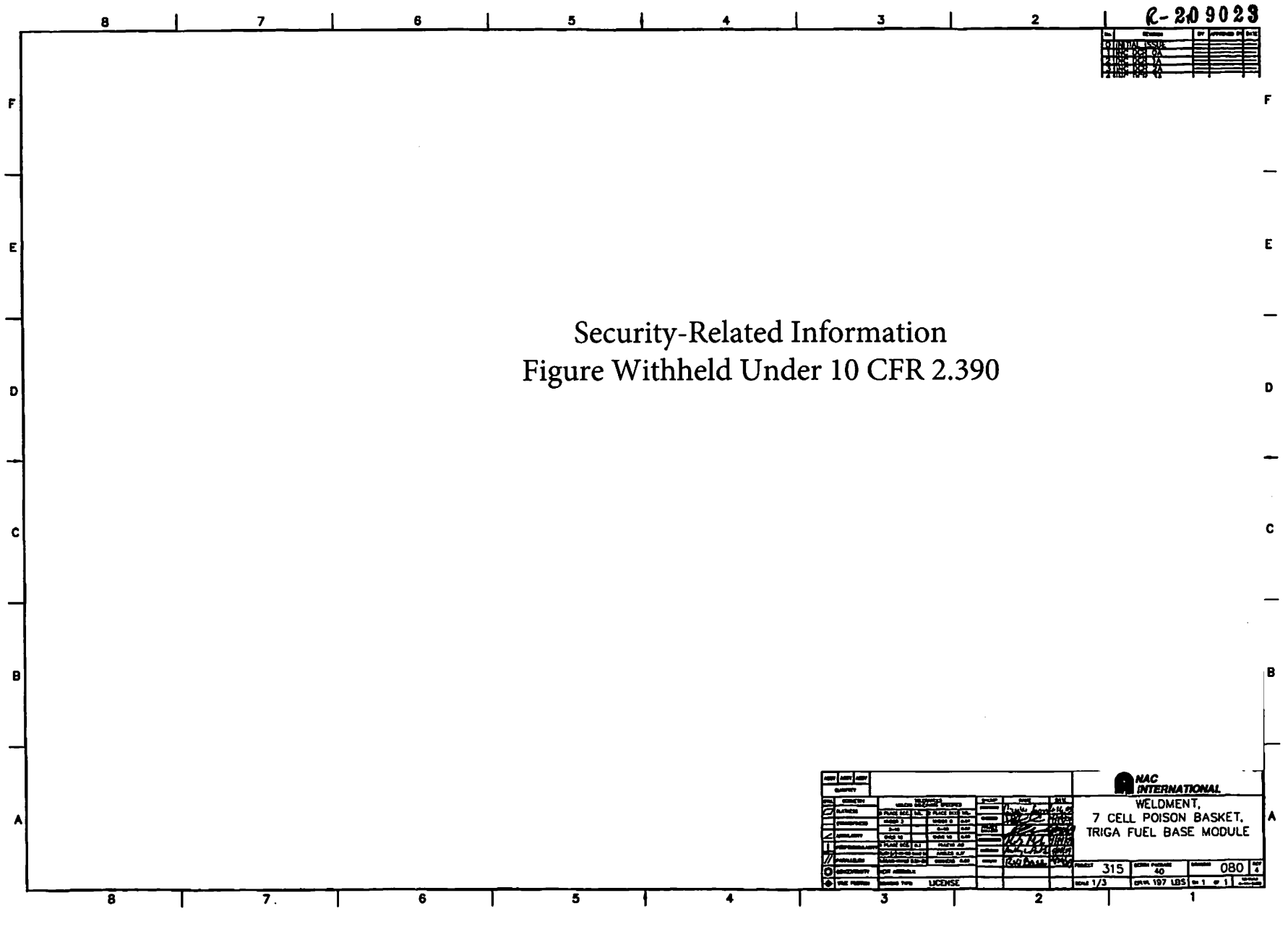
315-40 | 072

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK TRANSPORT CASK ASSY, 120 TRIGA FUEL ELEMENTS OR 480 CLUSTER RODS

315-40 | 079 | 6


R-20 9023
Security-Related Information
Figure Withheld Under 10 CFR 2.390
NAC INTERNATIONAL
WELDMENT,
7 CELL POISON BASKET,
TRIGA FUEL BASE MODULE
315
40
080
LICENSE

R-209024

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

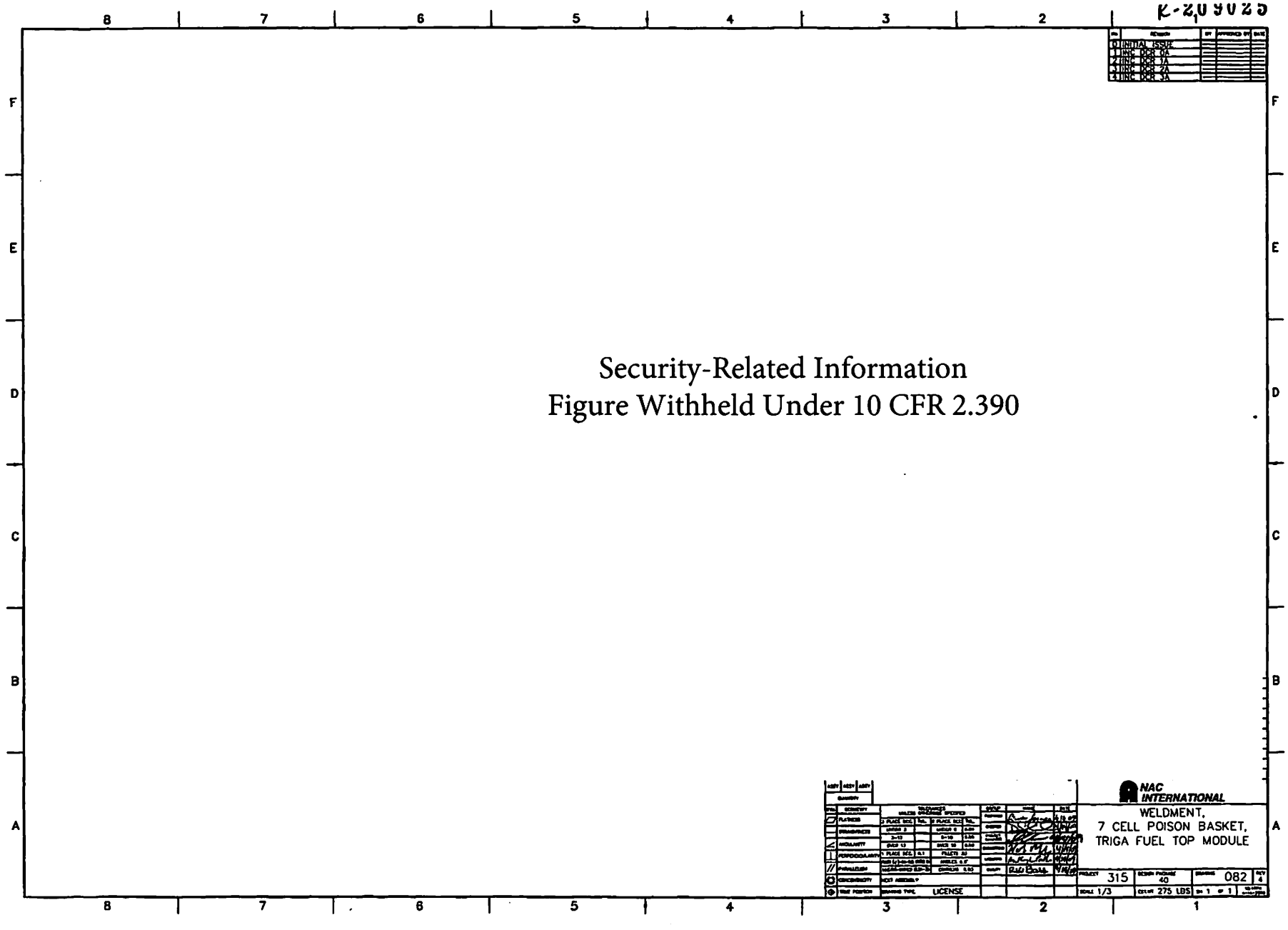
WELDMENT,
7 CELL POISON BASKET,
TRIGA FUEL INTERMEDIATE MODULE

315 | 40 | 081 | 4

SCALE 1/3 | WEIGHT 187 LBS | SHT 1 OF 1

LICENSE

Security-Related Information
Figure Withheld Under 10 CFR 2.390



R-128690

REVISION	BY	APPROVED BY	DATE
0 INITIAL ISSUE			

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

SPACER,
LWT CASK ASSEMBLY
TRIGA FUEL

PROJECT	DESIGN PACKAGE	DRAWING	REV
315	040	083	0

SCALE 1/2 | SHT 1 OF 1

NEXT ASSEMBLY 315-040-84

DRAWING TYPE LICENSE

NAC DCRM 01

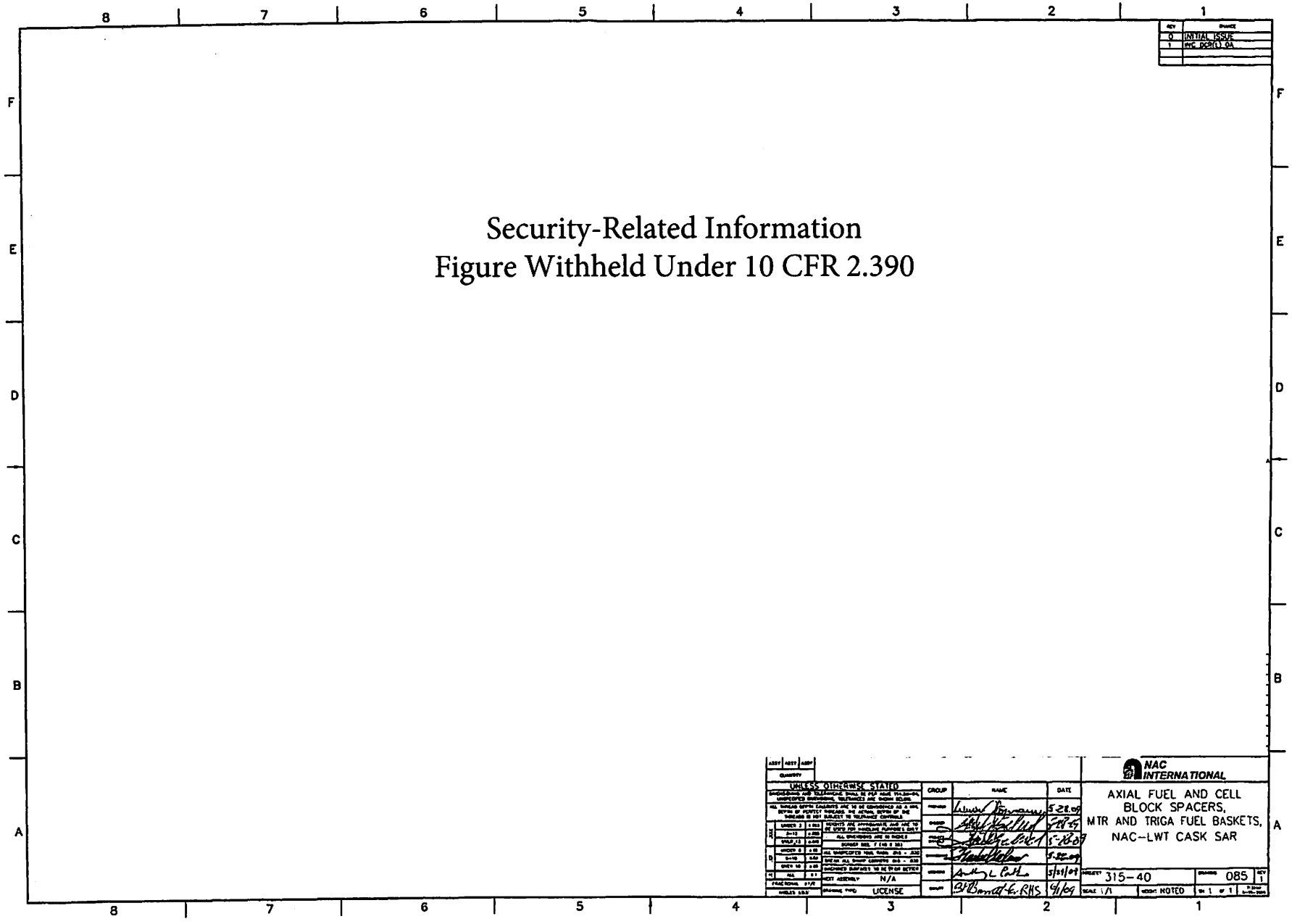
Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
140 TRIGA ELEMENTS

315-40 | 084

Security-Related Information
Figure Withheld Under 10 CFR 2.390



R-203199

REV	CHANGE
0	INITIAL ISSUE
1	PER DCR 04

Security-Related Information
Figure Withheld Under 10 CFR 2.390

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	ORIGINATOR	R.W. Walker	2-22-05
	CHECKED	[illegible]	2-22-05
	ENGINEERING APPROVAL	[illegible]	2-22-05
	QUALITY ASSURANCE	[illegible]	2/24/05
ALL DIMENSIONS ARE IN INCHES			
FINISHED SURFACES TO BE 125 MICRO INCHES OR BETTER	APPROVED	Anthony L Pattle	2/24/05
NEXT ASSEMBLY:			
DRAWING TYPE: LICENSE	RELEASED	[illegible]	2.25.05

NAC INTERNATIONAL

ASSEMBLY,
SEALED FAILED FUEL CAN,
TRIGA FUEL

PROJECT 315-40 | DRAWING 086 | REV 1 | SHEET 1 OF 1

NAC DCRM 01

R-217263

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A
2	INC DCR 1A
3	INC DCR 2A
4	INC DCR 3A
5	INC DCR 4A
6	INC DCR 5A
7	INC DCR 6A

UNLESS OTHERWISE STATED

GROUP	NAME	DATE
ENGINEER		12/21/11
CHECKER		12-21-11
QUALITY ASSURANCE		12/23/11
MANAGER		12-29-11
APPROVER		12 29 11
DRAFTER		Dec 9/12

315-40-086

LICENSE

NAC INTERNATIONAL

CANISTER LID ASSEMBLY, SEALED FAILED FUEL CAN, TRIGA FUEL

PROJECT 315-40 | DRAWING 087 | REV 7

SCALE FULL | WEIGHT 5# | SHEET 1 OF 1

1 R-2 17265

DCR No.	REVISION
0	INITIAL ISSUE
1	INC. DCR 0A
2	INC. DCR 1A
3	INC. DCR 2A

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

CANISTER BODY ASSEMBLY, SEALED FAILED FUEL CAN, TRIGA FUEL

PROJECT 315-40 | DRAWING 088 | REV 3

SCALE N.T.S (3) | SHT 1 OF 1

NEXT ASSEMBLY 315-40-086

DRAWING TYPE LICENSE

R-209026

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 ELEMENT BASKET,
35 MTR FUEL BASE MODULE.

315-40 090

LICENSE

NAC DCRM

K-209027

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 ELEMENT BASKET, 35
MTR FUEL INTERMEDIATE MODULE

PROJECT 315-40
DRAWING 091
REV 4
SCALE 1/3
SHT 1 OF 1

E-209028

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 ELEMENT BASKET,
35 MTR FUEL TOP MODULE

315-40 092

L-206264

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR 0A
2	INC. DCR 1A
3	INC. DCR(1) 2A
4	INC. DCR(1) 3A

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
35 MTR ELEMENT

PROJECT	DRAWING	REV
315-40	094	4

SCALE 1/8 | SHEET 1 OF 1

UNLESS OTHERWISE STATED

GROUP	NAME	DATE
ENGINEER		10/11/07
CHECKED		10/11/07
QUALITY ASSURANCE		10/11/07
MANAGER		10/10/07
APPROVED		10/10/07
STRESS		10/11/07
DRAFTING		10/12/07

LICENSE

NAC DCRM 01

M:\ACADFILE\315\License\31549441.dwg

R-206443

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR 0A
2	INC. DCR 1A
3	INC. DCR 2A

Security-Related Information
Figure Withheld Under 10 CFR 2.390

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	DRAWN		11/2/07
	CHECKED		1-2-08
	ENGINEER		11/6/07
	MANAGER		1-7-08
	QUALITY		1-7-08
	APPROVED		1.3.08

LICENSE

NAC INTERNATIONAL

FUEL CLUSTER ROD INSERT, ③ TRIGA FUEL

PROJECT 315-40 | DRAWING 096 | REV 3

SCALE FULL | SHEET 1 OF 1

NAC DCRM 01

P:\NACADFILE\315\License\315096321.dwg

K-208704

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

PWR/BWR ROD
TRANSPORT CANISTER
ASSEMBLY

315-40

098

LICENSE

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

PWR/BWR ROD
TRANSPORT CANISTER
ASSEMBLY

315-40 | 098 | REV 6
SH 2 OF 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

PWR/BWR ROD
TRANSPORT CANISTER
ASSEMBLY

PROJECT 315-40 | DRAWING 098 | REV 6
1/2 | NOTED | SH 3 of 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

CAN WELDMENT
PWR/BWR TRANSPORT
CANISTER

PROJECT 315-40 | DRAWING 099 | REV 3

SCALE 1/8 | ERVR NOTED | SH 2 OF 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

CAN WELDMENT
PWR/BWR TRANSPORT
CANISTER

315-40 | 099 | 3

R-207547

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LIDS,
PWR/BWR ROD TRANSPORT
CANISTER

315-40

NAC DCRM 01

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LIDS,
PWR/BWR ROD TRANSPORT
CANISTER

4

315-40 | 100 | REV 4

SHEET 2 OF 5

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LIDS,
PWR/BWR ROD TRANSPORT
CANISTER
④

315-40 | 100 | 4
3 of 5

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LIDS,
PWR/BWR ROD TRANSPORT
CANISTER

315-40 | 100 | 4

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LIDS,
PWR/BWR ROD TRANSPORT
CANISTER

PROJECT 315-40 | DRAWING 100 | REV 4

K-13470U

REV. No.	REVISION
0	INITIAL ISSUE

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

4 X 4 INSERT
PWR/BWR TRANSPORT
CANISTER

PROJECT	315-40	DRAWING	101
SCALE	1/1	DO NOT SCALE	NOTED

NAC DCRM 01

K 208706

DWG No.	REVISION
0	INITIAL ISSUE
1	INC DOC 0A
2	INC DOC 1A

Security-Related Information
Figure Withheld Under 10 CFR 2.390

	NAME	DATE
DRAWN		2/25/09
CHECKED		2/25/09
ENGR APPR		2/25/09
MFG APPR		2/25/09
QA APPR		2/25/09
APPROVED		2/26/09

NAC INTERNATIONAL

5 X 5 INSERT
PWR/BWR TRANSPORT
CANISTER

PROJECT 315-40 | DRAWING 102 | REV 2

SCALE 1/1 | CHK'R NOTED | SH 1 OF 1

NEXT ASSEMBLY 315-40-098

DRAWING TYPE LICENSE

NAC DOCUMENT 61

K-134702

DCN No.	REVISION
0	INITIAL ISSUE

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

PIN SPACER
PWR/BWR TRANSPORT
CANISTER

PROJECT 315-40 | DRAWING 103 | REV 0

SCALE 2/1 | SHEET 1 OF 1

NAC DCRM 01

R-213234

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK TRANSPORT CASK ASSY, PWR/BWR ROD TRANSPORT CANISTER

PROJECT 315-40 DRAWING 104 REV 5

SCALE NONE SHEET 1 OF 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
PWR/BWR ROD
TRANSPORT CANISTER

315-40 | 104 | 6

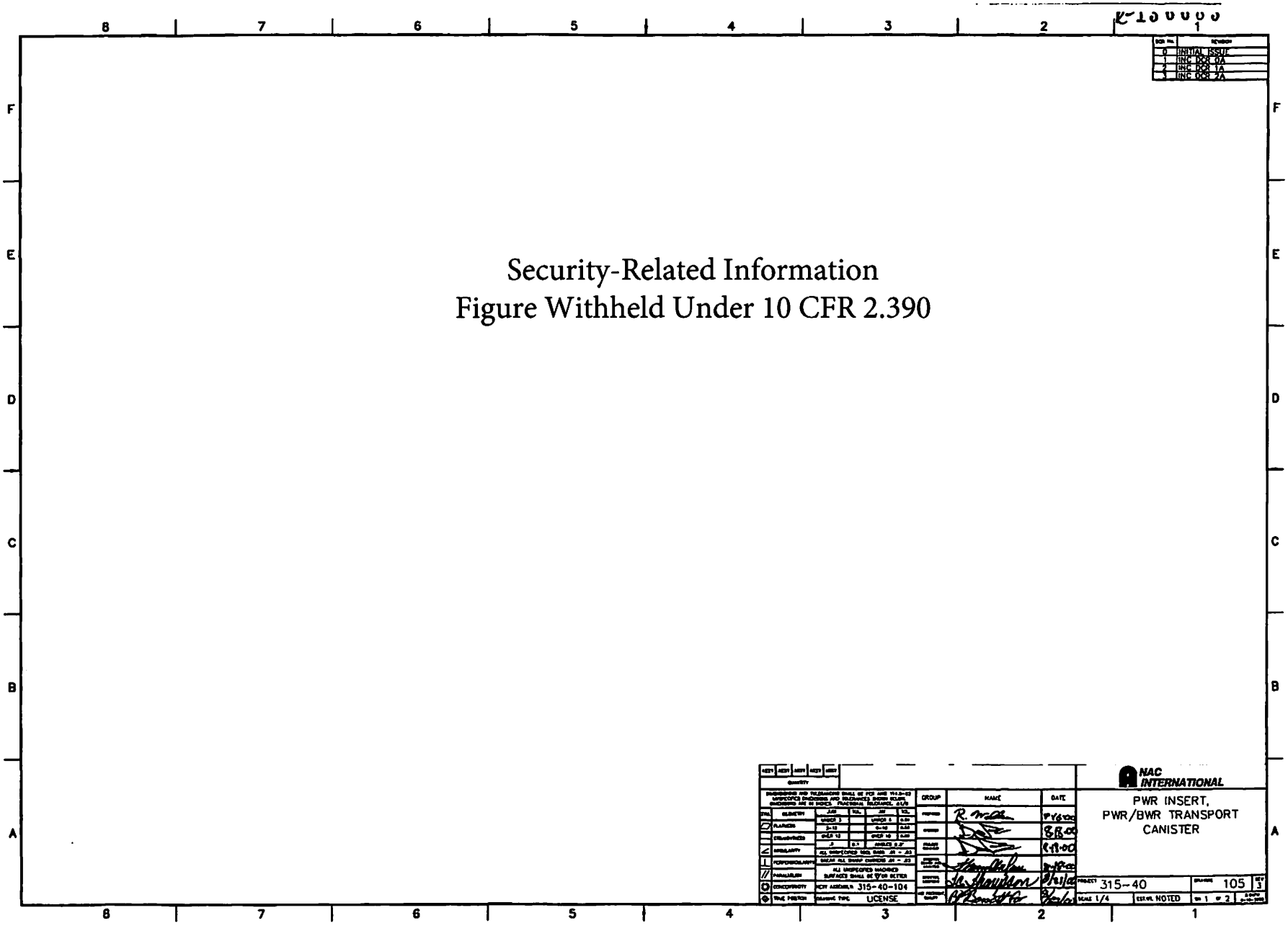
Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
PWR/BWR ROD
TRANSPORT CANISTER

315-40 | 104 | REV 6
SHT 3 OF 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390



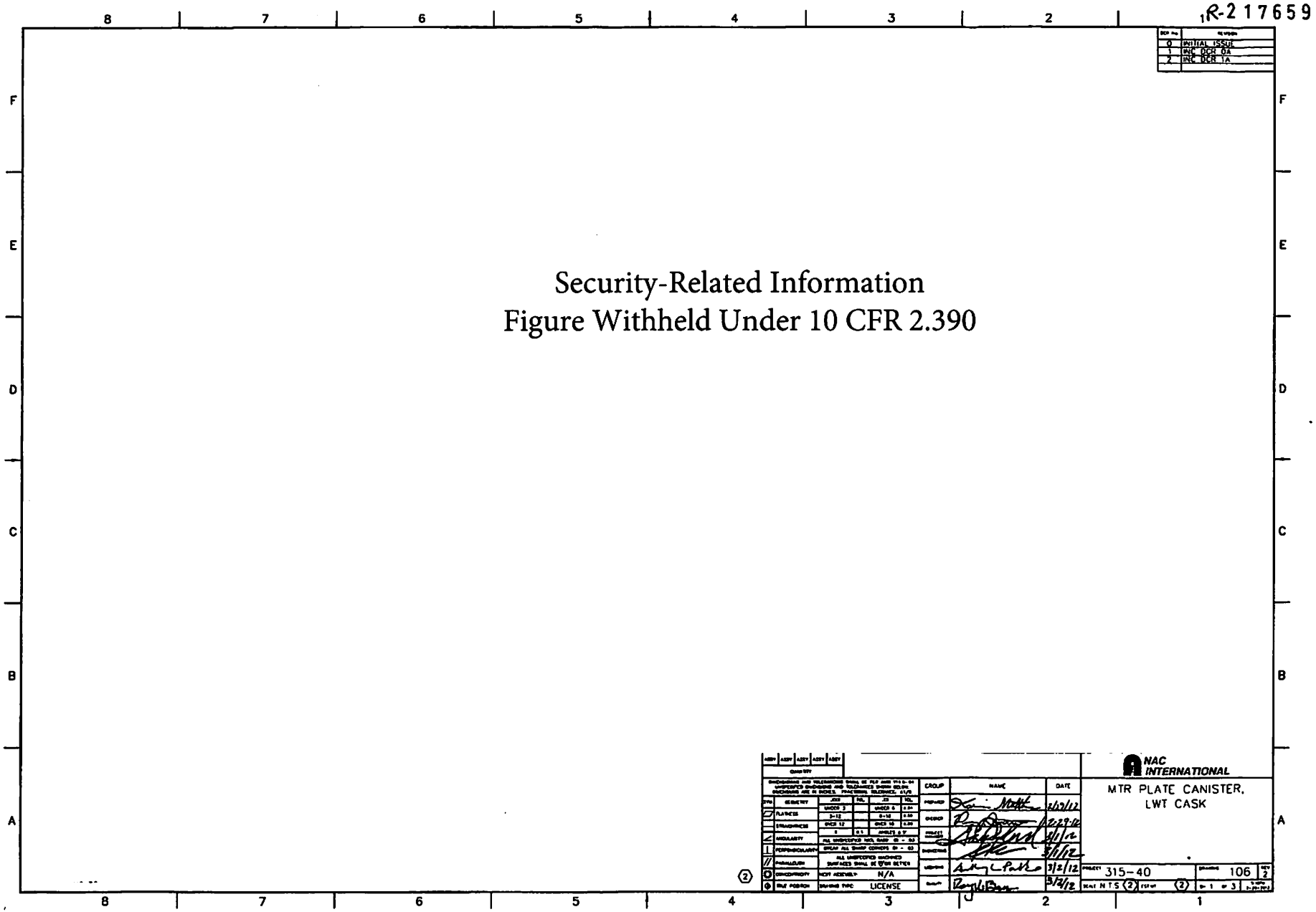
Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

PWR INSERT,
PWR/BWR TRANSPORT
CANISTER

315-40 | 105 | 3
1/4 | UNLESS NOTED | SH 2 OF 2

Security-Related Information
Figure Withheld Under 10 CFR 2.390



Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

MTR PLATE CANISTER, LWT CASK

315-40 | 106 | 2

NTS | (2) | 2 of 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

MTR PLATE CANISTER,
LWT CASK

315-40 | 106 | 2

N.T.S | 2 | 3 of 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
TOP MODULE,
DIDO FUEL

PROJECT 315-40 | DRAWING 108 | REV 1

SCALE 1/2.5 | UNLESS NOTED | SHEET 1 OF 3

LICENSE DRAWING 315-40-111

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR 01A

GROUP	NAME	DATE
DRAWN	[illegible]	9/6/01
CHECKED	R. Mueller	9/6/01
ENGR APPR.	[illegible]	9/6/01
MFG APPR.	[illegible]	9/6/01
QA APPR.	S.C. Thompson	9/6/01
APPROVED	B.P. Bandt for PH	9/6/01

NAC DCRM 01

R141924

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
TOP MODULE,
DIDO FUEL

315-40 | 108 | 1

1/2 | UNLESS NOTED | SH 2 OF 3

R141924

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
TOP MODULE,
DIDO FUEL

315-40 | 108 | 1

1/2 | UNLESS NOTED | 3 OF 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC DCRM 01

R141525

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
INTERMEDIATE MODULE,
DIDO FUEL

315-40 | 109 | REV 1

SCALE 1/2 | CUSTOM NOTED | SH 2 OF 3

R141925

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
INTERMEDIATE MODULE,
DIDO FUEL

315-40 | 109 | 1

1/2 | UNLESS NOTED | 3 OF 3

R141926

REV	CHANGE
0	INITIAL ISSUE
1	PIC 3DCH DA

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
BASE MODULE,
DIDO FUEL

PROJECT 315-40 | DRAWING 110 | REV 1

SCALE 1/2.5 | UNITS NOTED | SH 1 OF 3

	NAME	DATE
ORIGINATOR		9/14/01
CHECKER		9.6.01
ENGR APPR		9/6/01
MGR APPR		9/6/01
QA APPR		9/10/01

DRAWING TYPE: LICENSE

NEXT ASSEMBLY: 315-40-111

NAC DCRM 01

R141926

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
BASE MODULE,
DIDO FUEL

315-40 | 110 | REV 1

SCALE 1/2 | UNLESS NOTED | SH 2 OF 3

RI41926

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
BASE MODULE,
DIDO FUEL

315-40 | 110 | 1

SCALE 1/2 | UNLESS NOTED | 3 OF 3

K-297549

REV	
0	INITIAL ISSUE
1	PER DCRM 01A
2	PER DCRM 01A

Security-Related Information
Figure Withheld Under 10 CFR 2.390

	NAME	DATE
DRAWN		7/27/05
CHECKED		8/1/08
ENGR/APPR		8/8/08
MFG/APPR		8/6/08
QA		8-8-08
APPROVED		8-11-08

UNLESS OTHERWISE STATED
ALL DIMENSIONS ARE IN INCHES
NEXT ASSEMBLY: N/A
DRAWING TYPE: LICENSE

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
DIDO FUEL

PROJECT 315-40 | DRAWING 111 | REV 2 | SH 1 OF 1

NAC DCRM 01

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC DCRM 01

SPACERS, TOP MODULE DIDO FUEL

NAC INTERNATIONAL

315-40

113

REV	CHANGE
0	INITIAL ISSUE
1	NAC DCR 04
2	NAC DCR 14

Security-Related Information
Figure Withheld Under 10 CFR 2.390

GROUP	NAME	DATE
DRAWN	B. Wells	9-29-03
CHECKED	B. Lee	9-29-03
ENGR APPR.	Tim Hardy for RKK	9-29-03
MFG APPR.		9-30-03
QA APPR.	J.C. Thompson	5-1-03
COMMENTS		5/1/03

NAC INTERNATIONAL

TOP MODULE,
GENERAL ATOMICS IFM,
LWT CASK

PROJECT 315-40 | DRAWING 120 | REV 2

SCALE 1/3 | SIZE B | SHT 1 OF 3

ALL UNSPECIFIED MACHINED SURFACES SHALL BE 125 OR BETTER

ROT ASSEMBLY 315-40-124

DRAWING TYPE LICENSE

NAC DCRM 01

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

TOP MODULE,
GENERAL ATOMICS IFM,
LWT CASK

PROJECT 315-40 | DRAWING 120 | REV 2

SCALE 1/3 | UNLESS NOTED | SHT 2 OF 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

TOP MODULE,
GENERAL ATOMICS IFM,
LWT CASK

315-40 | 120 | 2

SCALE 1/1 | SIZE NOTED | SHT 3 OF 3

R-15,2727

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC DCRM 01

NAC INTERNATIONAL

SPACER,
GENERAL ATOMICS IFM,
LWT CASK

315-40

123

1/3

NOTED

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

SPACER,
GENERAL ATOMICS IFM,
LWT CASK

PROJECT 315-40		DRAWING 123	REV 1
SCALE 1/3	UNLESS NOTED	SHT 2 OF 2	

R-204655

REV	CHANGE
0	INITIAL ISSUE
1	INC. BORAL QA

Security-Related Information
Figure Withheld Under 10 CFR 2.390

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	DRAWN		5-19-06
	CHECKED		5-19-06
	ENGR APPR		5-19-06
	QA APPR		5-23-06
	APPROVED		5-23-06

NOT ASSIGNED: N/A
DRAWING TYPE: LICENSE

NAC INTERNATIONAL

TRANSPORT CASK ASSEMBLY, GENERAL ATOMICS IFM, LWT CASK

PROJECT	DRAWING	REV
315-40	124	1
1/8	N/A	SHEET 1 OF 1

NAC DCRM 01

R-204656

REV	CHANGE
0	INITIAL ISSUE
1	INC DOC 0A
2	INC DOC 1A
3	INC DOC 2A

Security-Related Information
Figure Withheld Under 10 CFR 2.390

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
			5-18-06
			5/19/06
			5/19/06
			5/19/06
			5/22/06
N/A			5-23-06
LICENSE			5-23-06

NAC INTERNATIONAL

TRANSPORT CASK ASSEMBLY, FRAMATOME/EPRI, LWT CASK

315-40 | 125 | 3 | 1 of 3

NAC DCRM 01

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

TRANSPORT CASK ASSEMBLY,
FRAMATOME/EPRI,
LWT CASK

315-40 | 125 | 3 | 2 of 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

TRANSPORT CASK ASSEMBLY,
FRAMATOME/EPRI,
LWT CASK

315-40 | 125 | 3

K-201516

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENTS,
FRAMATOME/EPRI,
LWT CASK

315-40

126

NAC DCRM 02

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENTS,
FRAMATOME/EPRI,
LWT CASK

315-40 | 126 | 2

1/2 | UNLESS NOTED | SH 2 OF 2

R-20465?

REV	CHANGE
0	INITIAL ISSUE
1	INC DCR 0A
2	INC DCR 1A

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

SPACER ASSEMBLY,
TPBAR SHIPMENT,
LWT CASK

315-40

127

NAC DCRM 01

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

SPACER ASSEMBLY,
TPBAR SHIPMENT,
LWT CASK

315-40 | 127

R-217267

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
TPBAR SHIPMENT
SAFETY ANALYSIS REPORT

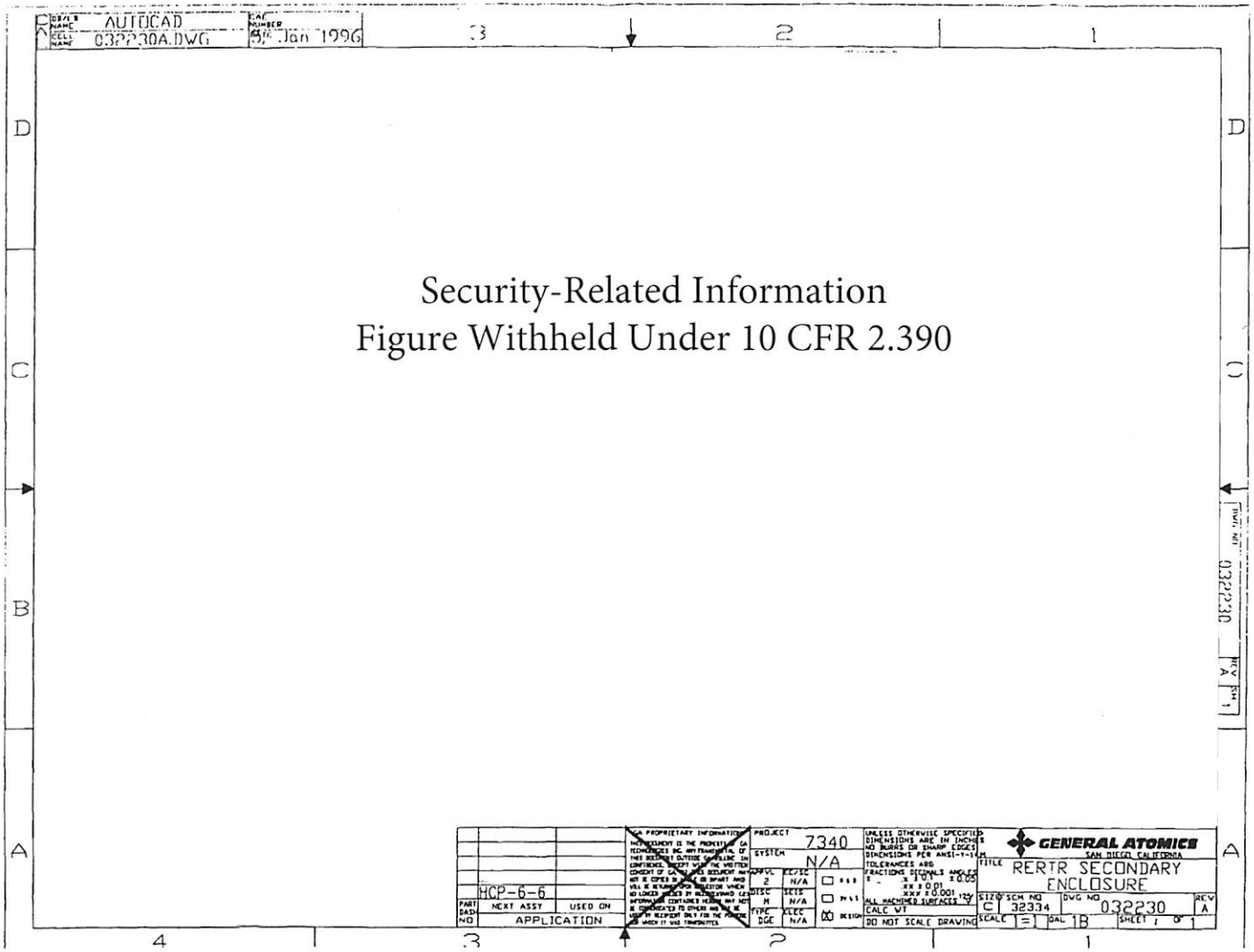
Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

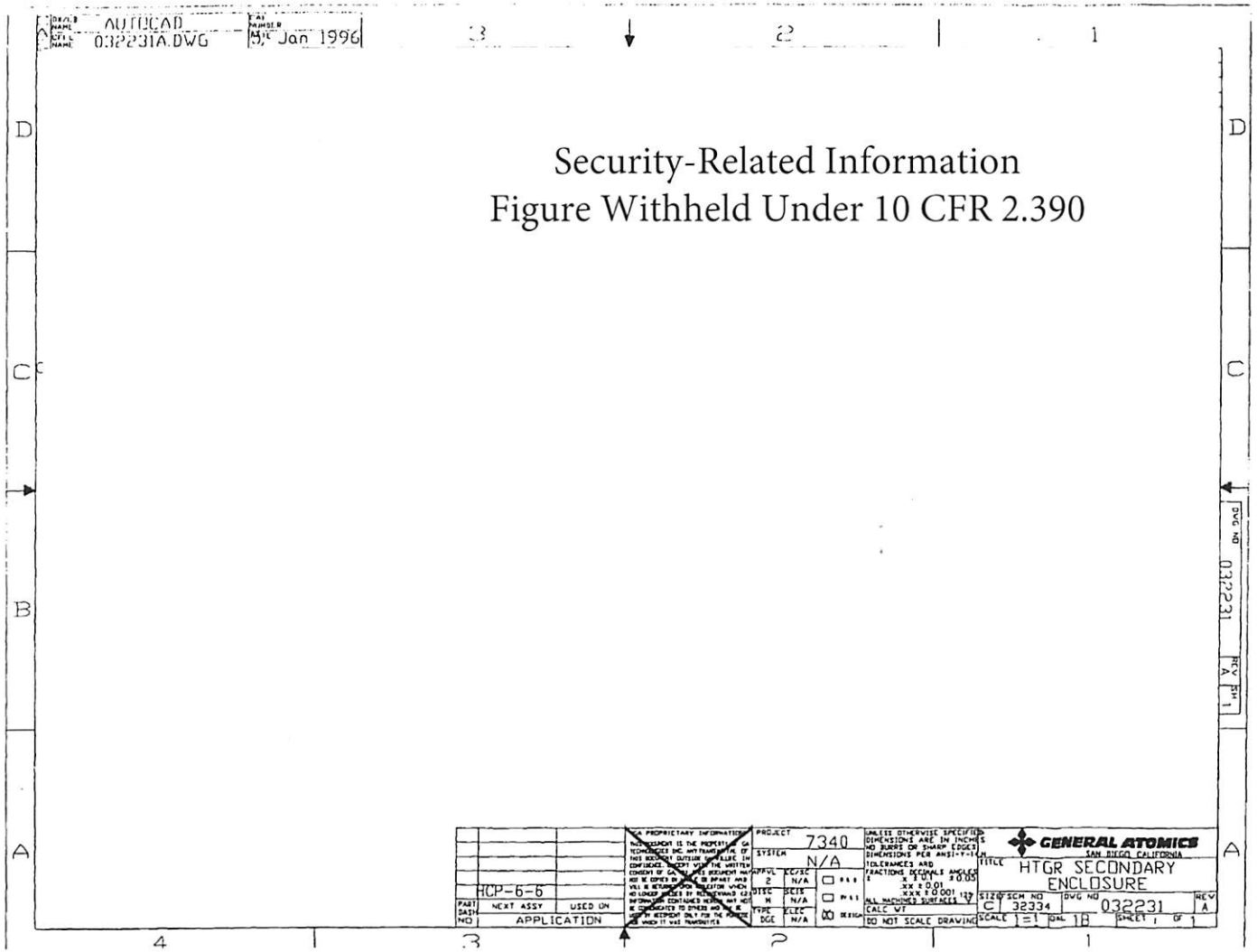
LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
TPBAR SHIPMENT
SAFETY ANALYSIS REPORT

315-40 | 128 | 4
N.T.S. | 2 of 2

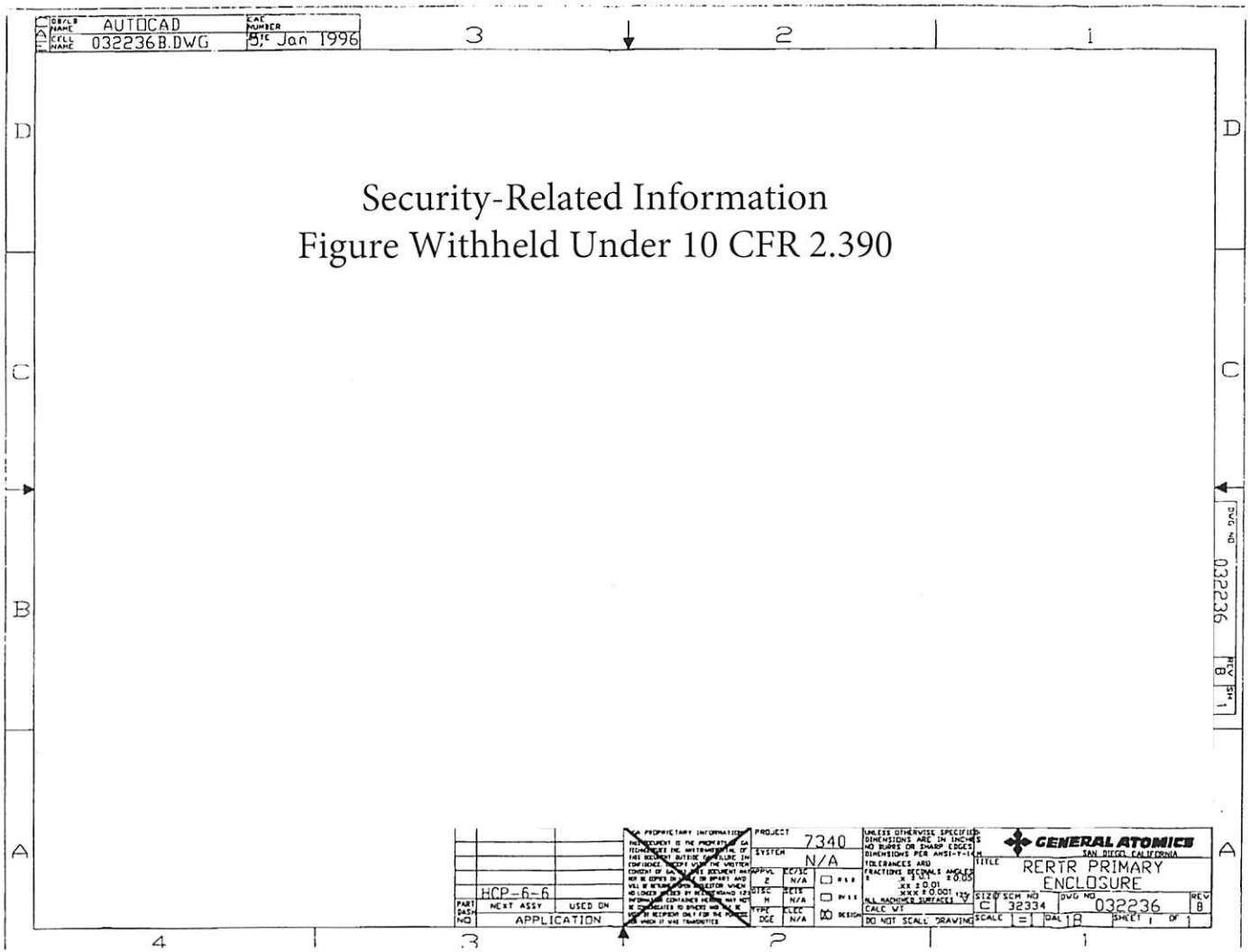
R-202644



NAC DCRM 01


AUTOCAD
032231A.DWG
5 Jan 1996
Security-Related Information
Figure Withheld Under 10 CFR 2.390
PROJECT 7340
SYSTEM N/A
HCP-6-6
APPLICATION
GENERAL ATOMICS
SAN DIEGO, CALIFORNIA
HTGR SECONDARY ENCLOSURE
SIZE C
SCM NO 32334
DWG NO 032231
REV A
SCALE 1=1
SHEET 1 OF 1

R-202646



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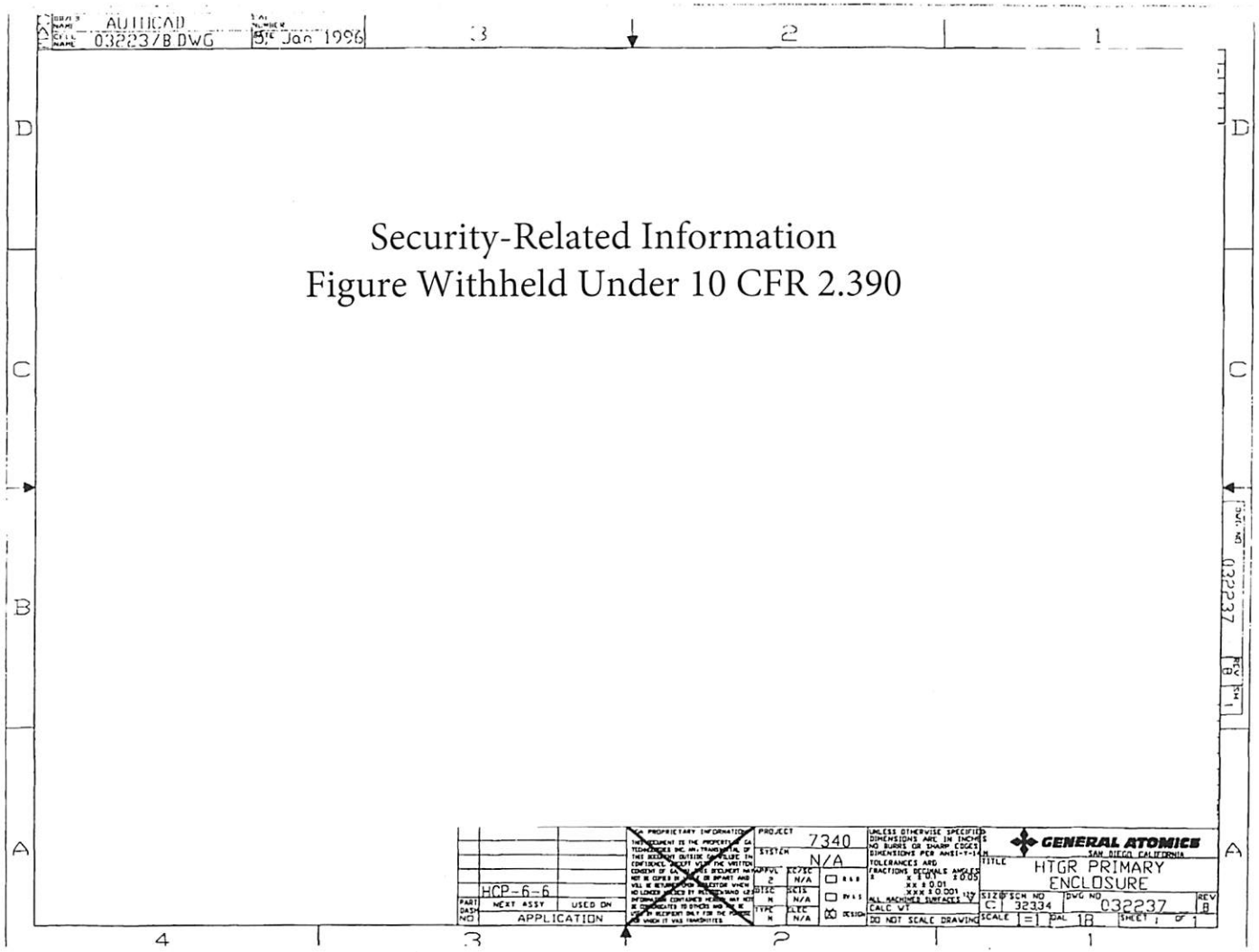
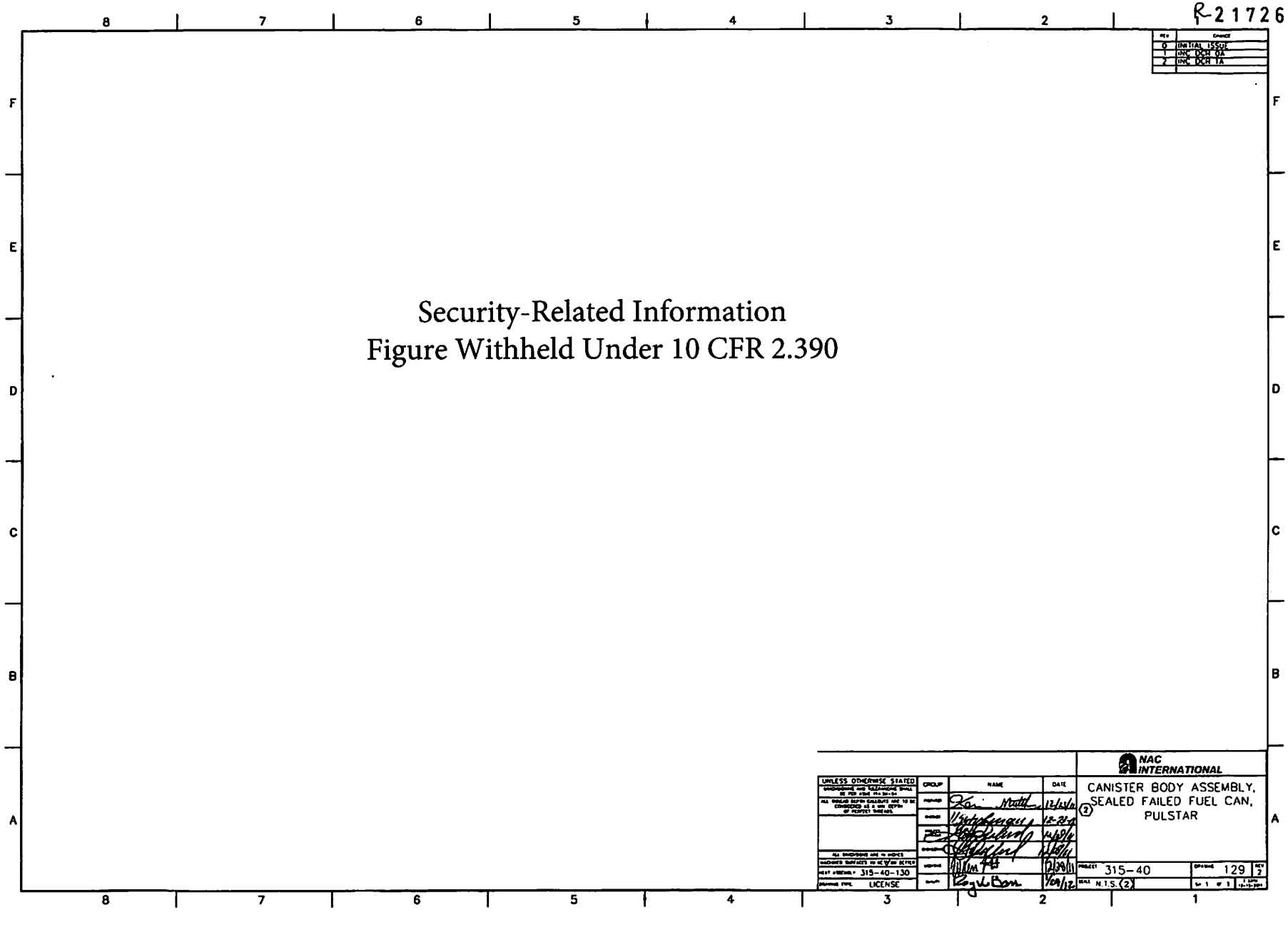


R-217269



REV	CHANGE
0	INITIAL ISSUE
1	INC DCN 0A
2	INC DCN 1A

NAC INTERNATIONAL

CANISTER BODY ASSEMBLY, SEALED FAILED FUEL CAN, PULSTAR (2)

PROJECT 315-40 | DRAWING 129 | REV 2

SCALE N.T.S. (2) | SHT 1 OF 1

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	PREPARED		12/14/11
	CHECKED		12-21-11
	ENG		12/28/11
	QA		12/28/11
	APPROVED		12/28/11
	RELEASED		1/09/12

MATERIAL: 315-40-130

DRAWING TYPE: LICENSE

Rr217271

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	CHANGE
0	INITIAL ISSUE
1	INC PCN 0A
2	INC PCN 1A

NAC INTERNATIONAL

ASSEMBLY,
SEALED FAILED FUEL CAN,
② PULSTAR

PROJECT 315-40 | DRAWING 130 | REV 2

SCALE N.T.S.(2) | SHT 1 OF 1

UNLESS OTHERWISE STATED

ALL DIMENSIONS ARE IN INCHES

MACHINED SURFACES TO BE ▽ OR BETTER

NEXT ASSEMBLY 315-40-133

DRAWING TYPE LICENSE

GROUP	NAME	DATE
PREPARED		
CHECKED		
ENGINEERING		
QUALITY ASSURANCE		
MANUFACTURING		
APPROVED		

R-1217273

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR(S) 0A
2	INC. DCR(S) 1A

Security-Related Information
Figure Withheld Under 10 CFR 2.390

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
ALL DIMENSIONS ARE IN INCHES	DRAWN		11/21/11
FINISHED SURFACES TO BE 125 OR BETTER	ENGINEER		12-23-11
NEXT ASSEMBLY N/A	CHECKED		12/27/11
DRAWING TYPE LICENSE	APPROVED		12/27/11
	MATERIAL		12/29/11
	QA		1/2/12

NAC INTERNATIONAL

TRANSPORT CASK ASSEMBLY, PULSTAR SHIPMENT, LWT CASK

PROJECT 315-40 | DRAWING 133 | REV 2

SCALE NTS (2) | SHEET 1 OF 2

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

TRANSPORT CASK ASSEMBLY,
PULSTAR SHIPMENT,
LWT CASK

315-40 | 133 | 2

R-1217275

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	CHANGE
0	INITIAL ISSUE
1	INC DCN(S) 0A
2	INC DCN(S) 1A

NAC INTERNATIONAL

BODY WELDMENT, SCREENED FUEL CAN, PULSTAR FUEL

UNLESS OTHERWISE STATED

NEXT ASSEMBLY 315-40-135

LICENSE

GROUP	NAME	DATE
		11/21/11
		12-28-11
		12-30-11
		12-28-11
		12/28/11
		1/24/12

PROJECT 315-40

DRAWING 134

REV 2

SCALE N.T.S (2)

SHEET 1 OF 1

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR 04

Security-Related Information
Figure Withheld Under 10 CFR 2.390

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
		R. Wolfe	2-3-05
			2-3-05
			2/4/05
			2/4/05
			2/9/05
			2/9/05

NAC INTERNATIONAL

ASSEMBLY,
SCREENED FUEL CAN,
PULSTAR FUEL

PROJECT 315-40 | DRAWING 135 | REV 1

NAC DCRM 02

K-207550

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR 04

Security-Related Information
Figure Withheld Under 10 CFR 2.390

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
DRAWN			7/27/01
CHECKED			7/16/02
ENGR APPR.			7/16/02
MFG APPR.			7/16/02
QA APPR.			1-1-08
COMMENTS			5-12-08

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
ANSTO FUEL

PROJECT 315-40 | DRAWING 139 | REV 1

SCALE 1/8 | WEIGHT | SHT 1 OF 1

NAC DCRM 01

R-207551

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC DCRM 01

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
TOP MODULE,
ANSTO FUEL

PROJECT 315-40 | DRAWING 140 | REV 1

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
TOP MODULE,
ANSTO FUEL

PROJECT 315-40 | DRAWING 140 | REV 1
SHEET 1/2 | SCALE N/A | 2 OF 2

R- 207552

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC DCRM 01

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
INTERMEDIATE MODULE,
ANSTO FUEL

315-40

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
INTERMEDIATE MODULE,
ANSTO FUEL

315-40 | 141 | 1

1/2 | UNLESS NOTED | SH 2 OF 2

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
BASE MODULE,
ANSTO FUEL

PROJECT 315-40 | DRAWING 142 | REV 1
SCALE 1/2.5 | WEIGHT NOTED | SHT 1 OF 2

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

WELDMENT,
7 CELL BASKET,
BASE MODULE,
ANSTO FUEL

315-40 | 142 | 1

SCALE 1/2 | WEIGHT NOTED | SHT 2 OF 2

REV	CHANGE
0	INITIAL ISSUE

Security-Related Information
Figure Withheld Under 10 CFR 2.390

	NAME	DATE
DRAWN		10-20-06
CHECKED		10-23-06
ENGR APPR		10-23-06
MFG APPR		10-23-06
QA APPR		10-23-06

UNLESS OTHERWISE STATED
ALL DIMENSIONS ARE IN INCHES
LICENSE

NAC INTERNATIONAL

IRRADIATED HARDWARE,
LID SPACER,
LWT CASK

PROJECT 315-40 | DRAWING 145 | REV 0 | SH 1 OF 1

R-20,7554

REV	CHANGE
0	INITIAL ISSUE

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
ANSTO-DIDO
COMBINATION BASKET

UNLESS OTHERWISE STATED			
COPY ASSEMBLY TO	N/A		
DRAWING TYPE	LICENSE		
		DRAWN	8/5/08
		CHECKED	8/5/08
		ENGR APPR	8/5/08
		MFG APPR	8/5/08
		QA	8/5/08
		APPROVED	8/5/08

PROJECT 315-40 | DRAWING 148 | REV 0 | 1/8 | SH 1 OF 1

NAC DCRM 01

R-218406

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	CHANGE
0	INITIAL ISSUE
1	ENC DCR 09A
2	ENC DCR 11A
3	ENC DCR 12A

	GROUP	NAME	DATE
	PREPARER		5/1/12
	CHECKER		5/1/12
	PROJECT MANAGER		5/1/12
	ENGINEERING		5/1/12
	LICENSING		5/1/12
	QUALITY		5/22/12

UNLESS OTHERWISE STATED

NEXT ASSEMBLY: N/A

DRAWING TYPE: LICENSE

NAC INTERNATIONAL

CANISTER ASSEMBLY
SLOWPOKE FUEL

PROJECT 315-40 | DRAWING 156 | REV 3

SCALE: N.T.S. | WEIGHT: N/A | SH 1 OF 1 | 5/21/2012

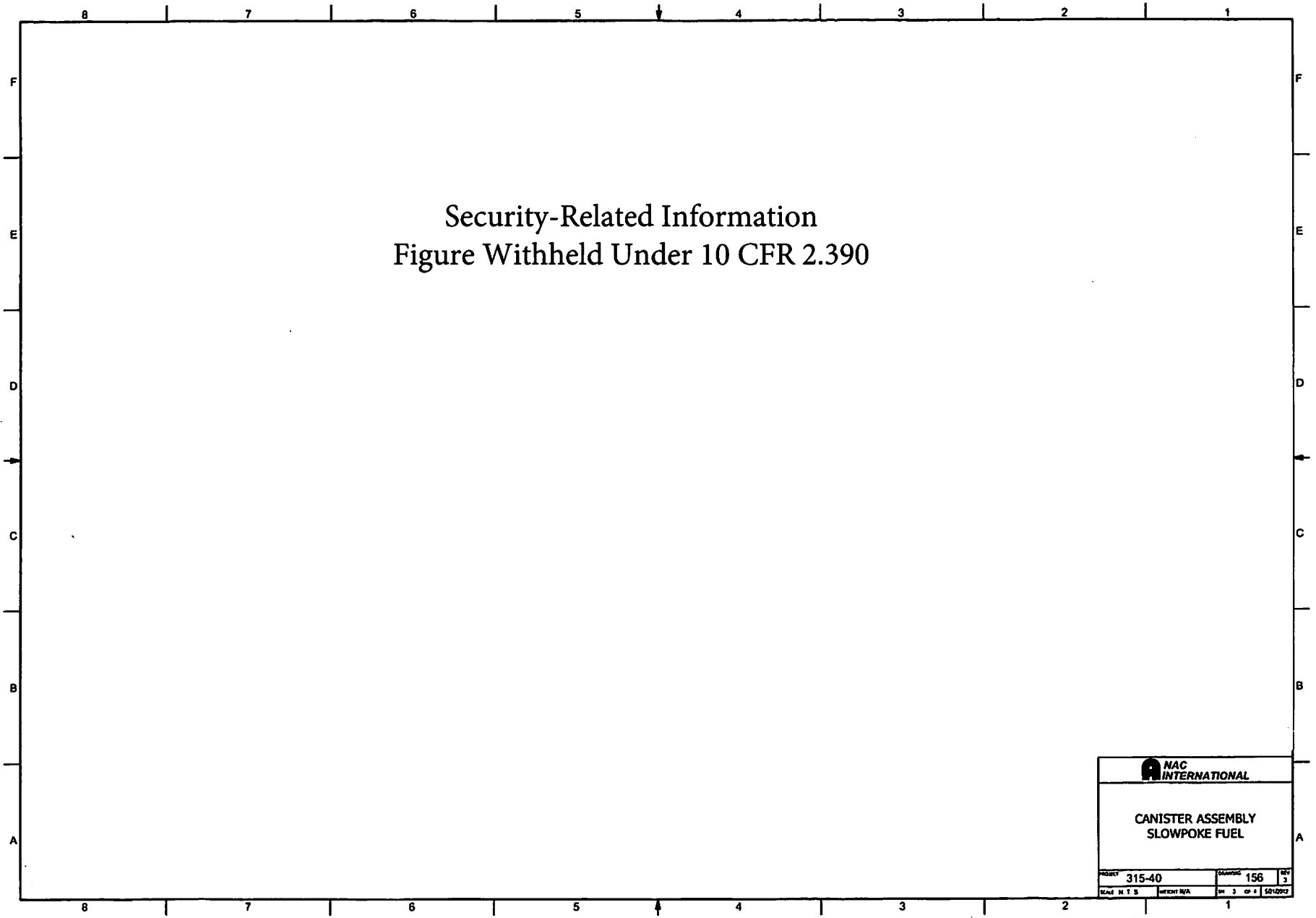
Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

CANISTER ASSEMBLY
SLOWPOKE FUEL

315-40 | 156 | 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390



Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

CANISTER ASSEMBLY
SLOWPOKE FUEL

315-40 | 156 | REV 3

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LEGAL WEIGHT TRUCK
TRANSPORT CASK ASSY
SLOWPOKE FUEL

315-40 | 158 | 0

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LWT TRANSPORT CASK ASSY., AECL NRU/NRX COMPONENTS

315-40 | 170 | 1

R-219901

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	CHANGE
0	INITIAL ISSUE

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	PREPARED	Matt	9/26/12
	CHECKED		9-26-12
	PROJECT MANAGER		9/26/12
	STRUCTURE		9/26/12
	LICENSING		9/26/12
315-40-170	QUALITY		9/26/12
LICENSE			

NAC INTERNATIONAL

LID ASSEMBLY, NRU/NRX

PROJECT 315-40 | DRAWING 172 | REV 0

SCALE N T S | WEIGHT N/A | SH 1 OF 2 | 9132012

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

LID ASSEMBLY, NRU/NRX

315-40 | 172 | 0

R-223631

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	CHANGE
0	INITIAL ISSUE
1	PIC DCR 04 & 05
2	PIC DCR 1A

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	PREPARER		10/17/13
	CHECKER		10-17-13
	PROJECT MANAGER		10/17/13
	NUCLEONICS		10/18/13
	LICENSING		10/17/13
315-40 170	QUALITY		10/18/13
LICENSE			

NAC INTERNATIONAL

BASKET WELDMENT, NRU/NRX

PROJECT 315-40 | DRAWING 173 | REV 2

SCALE N.T.S. | WEIGHT N/A | SH 1 OF 2 | 10/17/2013

Security-Related Information
Figure Withheld Under 10 CFR 2.390

NAC INTERNATIONAL

BASKET WELDMENT, NRU/NRX

315-40 | 173 | 7

SCALE N.T.S | WEIGHT N/A | SH 2 OF 2

R-219903

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	CHANGE
0	INITIAL ISSUE

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	PREPARER		9/26/12
	CHECKER		9/26/12
	PROJECT MANAGER		9/26/12
	ENGINEERING		9/26/12
	LICENSING		9/26/12
	QUALITY		9/27/12

NAC INTERNATIONAL

BASKET SPACER, NRU/NRX

PROJECT 315-40 | DRAWING 174 | REV 0

SCALE N.T.S | WEIGHT N/A | SH 1 OF 1 | 9/27/2012

R-220304

REV	CHANGE
0	INITIAL ISSUE
1	INC. DCR 04

Security-Related Information
Figure Withheld Under 10 CFR 2.390

UNLESS OTHERWISE STATED	GROUP	NAME	DATE
	PREPARED		10/10/12
	CHECKED		10-9-12
	PROJECT MANAGER		10/9/12
			10/9/12
	LICENSING		10/9/12
315-40-170	QUALITY		10-22-12
LICENSE			

NAC INTERNATIONAL

CADDY ASSEMBLY, NRU/NRX

PROJECT	DRAWING	REV
315-40	175	1

SCALE N.T.S | WEIGHT N/A | SH 1 OF 1 | 10/9/2012

R-220695

REV	CHANGE
0	INITIAL ISSUE

"NAC PROPRIETARY INFORMATION
WITHHELD PER 10 CFR 2.390"

ASSY	ASSY	ASSY
QUANTITY		

UNLESS OTHERWISE STATED
DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5M-94.
ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN DEPTH OF PERFECT THREADS
ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES SHALL BE UNCOATED
NEXT ASSEMBLY: N/A
DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARER	V Stitz Cuevas	12-17-12
CHECKER		12-17-12
PROJECT MANAGER		12-17-12
ENGINEERING		12/17/12
LICENSING		12/17/12
QUALITY		12/18/12

NAC INTERNATIONAL

LWT TRANSPORT CASK ASSEMBLY, HEUNL CONTENTS

PROJECT	DRAWING	REV (DN1)
315-40	180	
SCALE N.T.S. / WEIGHT N/A	SH 1 OF 1	12/7/2012

R-220697

REV	CHANGE
0	INITIAL ISSUE

"NAC PROPRIETARY INFORMATION
WITHHELD PER 10 CFR 2.390"

ASSY	ASSY	ASSY
QUANTITY		

UNLESS OTHERWISE STATED
DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5M-94.
ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN DEPTH OF PERFECT TREADS
ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES SHALL BE 125 OR BETTER
NEXT ASSEMBLY: 315-40-180
DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARER	[signature]	12-17-12
CHECKER	[signature]	12-17-12
PROJECT MANAGER	[signature]	12-17-12
ENGINEERING	[signature]	12/17/12
LICENSING	[signature]	12/17/12
QUALITY	[signature]	12-18-12

NAC INTERNATIONAL

CONTAINER ASSEMBLY, HEUNL

PROJECT 315-40 | DRAWING 181 | REV 0N17

SCALE N. T. S | WEIGHT N/A | SH 1 OF 1 | 12/7/2012

R-220699

REV	CHANGE
0	INITIAL ISSUE

"NAC PROPRIETARY INFORMATION
WITHHELD PER 10 CFR 2.390"

ASSY	ASSY	ASSY
QUANTITY		

UNLESS OTHERWISE STATED
DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5M-94.
ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS MIN. DEPTH OF PERFECT THREADS
ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES SHALL BE [illegible]
NEXT ASSEMBLY: 315-40-180
DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARER	V. Gilstrap	12-17-12
CHECKER	[illegible]	12-17-12
PROJECT MANAGER	[illegible]	12-17-12
ENGINEERING	[illegible]	12/17/12
LICENSING	[illegible]	12/17/12
QUALITY	Roy W. Barr	12/18/12

NAC INTERNATIONAL

CONTAINER SPACER, HEUNL

PROJECT	DRAWING	REV
315-40	182	ONP

SCALE	WEIGHT	SH	OF	
N. T. S	N/A	1	1	12/6/2012

R-220701

REV	CHANGE
0.	INITIAL ISSUE

"NAC PROPRIETARY INFORMATION
WITHHELD PER 10 CFR 2.390"

ASSY	ASSY	ASSY
QUANTITY		

UNLESS OTHERWISE STATED
DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5M-94.
ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN. DEPTH OF PERFECT THREADS
ALL DIMENSIONS ARE IN INCHES
MACHINED SURFACES SHALL BE 125 OR BETTER
NEXT ASSEMBLY: 315-40-180
DRAWING TYPE: LICENSE

GROUP	NAME	DATE
PREPARER	[signature]	12-17-12
CHECKER	[signature]	12-17-12
PROJECT MANAGER	[signature]	12-17-12
ENGINEERING	[signature]	12/18/12
LICENSING	[signature]	12/17/12
QUALITY	[signature]	12.18.12

NAC INTERNATIONAL

CONTAINER GUIDE,
HEUNL

PROJECT 315-40 | DRAWING 183 | REV 0NP
SCALE N.T.S. | WEIGHT N/A | SH 1 OF 1 | 12/7/2012

1.5 Unclassified DOE Reference Documents and Drawings

The unclassified DOE reference documents and drawings are contained in the following appendices.

- Appendix 1-A – TTQP-1-015, "Description of the Tritium-Producing Burnable Absorber Rod for the Commercial Light Water Reactor," Revision 14
- Appendix 1-B – TTQP-1-091, "Unclassified TPBAR Releases, Including Tritium," Revision 11
- Appendix 1-C – TTQP-1-111, "Unclassified Bounding Source Term, Radionuclide Concentrations, Decay Heat, and Dose Rates for the Production TPBAR," Revision 5
- Appendix 1-D – DOE Drawing H-3-307845, "Production TPBAR Reactor Interface Dimensions Watts Bar," Revision 10, Sheet 1 of 2
- Appendix 1-E – DOE Drawing H-3-308875, "Production TPBAR Reactor Interface Dimensions Sequoyah," Revision 5, Sheet 1 of 2
- Appendix 1-F – DOE Drawing H-3-310568, "Mark 8 Multi-Pencil TPBAR – Watts Bar Reactor Interface," Revision 0, Sheet 1 of 2
- Appendix 1-G – PNNL Letter, TTP-06-056, Subject: Exposure of Shipping Casks to Tritium, February 21, 2006

APPENDIX 1-A

TTQP-1-015, "Description of the Tritium-Producing Burnable Absorber Rod for the Commercial Light Water Reactor," Revision 14

TRITIUM TECHNOLOGY PROGRAM

DESCRIPTION OF THE TRITIUM-PRODUCING BURNABLE ABSORBER ROD FOR THE COMMERCIAL LIGHT WATER REACTOR

TTQP-1-015

Revision 14

Effective Date: 3/10/06

TRITIUM TECHNOLOGY PROGRAM

DESCRIPTION OF THE TRITIUM-PRODUCING BURNABLE ABSORBER ROD FOR THE COMMERCIAL LIGHT WATER REACTOR

Revision 14

Major formatting revision; no revision marks

Prepared By:	D.D. Lanning, Author	2/27/06 Date
Concurrence:	R.O. Gates, Independent Reviewer	2/28/06 Date
Concurrence:	Authorized Derivative Classifier	3/2/06 Date
Approved By:	T. M. Brewer, Quality Engineer	3-3-06 Date
Approved By:	B.D. Reid, Design Task Manager	3/6/06 Date
Approved By:	C.K. Thornhill, TTP Project Manager	3/8/06 Date

1.0 ABSTRACT

Tritium-producing burnable absorber rods (TPBARs) used in the U.S. Department of Energy's Tritium Readiness Program are designed to produce tritium when placed in a Westinghouse or Framatome 17x17 fuel assembly and irradiated in a pressurized water reactor (PWR). This document provides an unclassified description of the design baseline for the TPBARs. This design baseline is currently valid only for Watts Bar reactor production cores.

2.0 DESIGN BASIS DOCUMENTS

The TPBAR design basis for the Watts Bar reactor production cores consists of this unclassified design basis description plus a collection of design basis documents. The design basis documents include the design drawings, the design specifications, and the component acceptance test requirements. These documents are listed in Appendices A, B, and C, respectively.

3.0 GENERAL FUNCTIONS AND REQUIREMENTS

TPBARs are similar in size and nuclear characteristics to standard, commercial PWR, stainless-steel-clad burnable absorber rods. The exterior of the TPBAR is a stainless-steel tube, approximately 152 inches from tip to tip at room temperature. The nominal outer diameter of the stainless-steel cladding is 0.381 inches. The internal components have been designed and selected to produce and retain tritium.

Figure 1 illustrates the concentric, cylindrical, internal components of a TPBAR. Within the stainless-steel cladding is a metal getter tube that encircles a stack of annular, ceramic pellets of lithium aluminate. The pellets are enriched with the ^{6}Li isotope. When irradiated in a PWR, the ^{6}Li pellets absorb neutrons, simulating the nuclear characteristics of a burnable absorber rod, and produce tritium, a hydrogen isotope. The tritium chemically reacts with the metal getter, which captures the tritium as a metal hydride.

To meet design limitations on rod internal pressure and burn-up of the lithium pellets, the amount of tritium production per TPBAR is limited to a maximum of 1.2 grams over the full design life of the rod (approximately 550 equivalent full-power days). The potential release rate of tritium into the reactor coolant is subject to a design limit that is consistent with the plant tritium release limits from the plant licensing basis. This is achieved by the combined effects of the metal getter tube surrounding the lithium aluminate pellets and an aluminide barrier coating on the inner surface of the cladding.

4.0 TPBAR COMPONENTS

The TPBAR cladding is double-vacuum-melted, Type 316 stainless steel. To prevent hydrogen from diffusing inward from the coolant to the TPBAR getter and to prevent

tritium from diffusing outward from the TPBAR to the reactor coolant, an aluminide coating is on the inner surface of the cladding. This coating barrier must remain effective during fabrication, handling, and in-reactor operations.

The annular ceramic pellets are composed of sintered, high-density, lithium aluminate ($LiAlO_2$).

The metal getter tube located between the cladding and the lithium aluminate pellets is composed of nickel-plated Zircaloy-4. The getter absorbs the molecular tritium (T_2) generated during irradiation. Nickel plating is used on both sides of the getter to prevent oxidation of the Zircaloy-4 surfaces, which would reduce the tritium absorption rate. Consequently, this plating must remain effective during fabrication, handling, and in-reactor operations.

One or more unplated Zircaloy-4 tube(s) line the inside of the annular pellets. This component is called the "liner." (In the Mark 8 design these include the liner and the cracking flange). Because the tritium produced in the pellets is mainly released as oxidized molecules (T_2O), a reactive metal liner is needed to reduce these species to molecular tritium by reacting with the oxygen. The liner also provides mechanical support to prevent axial movement of pellet material in case any pellets crack during TPBAR handling or operation.

5.0 PREVIOUS PRODUCTION TPBAR DESIGNS

In this section, two previous TPBAR designs are described: the production TPBAR design, in which the pellet column and getter tubes are segmented into sections called "pencils"; and the production full-length getter TPBAR design, in which the getter tube runs the full length of the TPBAR. These designs are augmented by added features in the Mark 8 TPBAR design, described in Section 6.0.

5.1 Production TPBAR Design (Irradiated in Watts Bar Cycles 6 and 7)

The getter tube is cut and rolled over (coined) to capture the liner and pellets within an assembly called a "pencil." There are a total of 11 pencil assemblies stacked within the cladding tube of each TPBAR (see Figure 2.) The majority of the pencils are of standard length (approximately 12 inches). Two of the pencils are of variable length.

To minimize the impact of power peaking in adjacent fuel rods resulting from the axial gaps between the stacked pencils, there is more than one type of TPBAR. The types are differentiated by where the variable-length pencils are loaded within the pencil stack. The loading sequence of the pencils is tracked, and each TPBAR is identified by type so that the location of each TPBAR type within a TPBAR assembly can be specified.

5.2 Production Full-Length Getter TPBAR Design Option

The axial arrangement of components is altered for the production full-length getter TPBAR design option. In this design, a single getter tube runs the full length of the TPBAR, and surrounds both the pellet column and the upper and lower spacer tubes (see Figure 3). The spacer tubes at the top and bottom of the pellet column are nickel-plated Zircaloy getters. The Zircaloy liner tubes and lithium aluminate pellet stacks in the full-length getter design are longer than in the standard design: typically approximately 16 inches compared to approximately 12 inches in the standard design.

The use of the production full-length getter design eliminates the need for variable-length pencils and different TBPAR types to minimize the impact of power peaking in adjacent fuel rods resulting from axial gaps between pencils. The pellet column in the production full-length getter TPBAR design is essentially continuous, and there is no power peaking penalty from axial gaps in the absorber column.

5.3 Common TPBAR Design Features

For hermetic closure of the TPBARs, end plugs similar to those used in commercial PWR burnable absorber rods are welded to each end of the cladding tube. As shown in Figures 2 and 3, a gas plenum space is located above the top of the absorber column and below the top end plug. A spring clip in this plenum space holds the internals in place during pre-irradiation handling and shipping. Depending on the design, either a top plenum getter tube or a spacer tube is placed in the plenum space to getter additional tritium.

The length of the column of enriched lithium aluminate must be variable to provide optimal flexibility in reactor core design. Consequently, the column of enriched lithium aluminate pellets is approximately centered axially about the core mid-plane elevation, but ranges in total length from about 126 to 132 inches. A thick-walled, nickel-plated, Zircaloy-4 spacer tube is placed between the bottom of the absorber column and the bottom end plug both to support the absorber column and to getter tritium.

6.0 THE MARK 8 DESIGN

The Mark 8 multi-pencil design corresponds with the production TPBAR designs described in Section 5.0 above, with the following changes and additions:

- Each pencil contains an added short flanged Zircaloy tube, called a "cracking flange", which interfaces with the inner liner at the top of the pencil, as shown in Figure 4. In the multi-pencil design, the pencil getter tube is coined to capture the pellet column

and the inner liner, as in the production TPBAR design; and the flange on the cracking flange similarly lies below and is captured by the coined-over getter on the top of the pencil.

- The pellet stack within each standard length pencil will consist of 13 pellets each approximately 1 inches long, instead of 6 pellets each approximately 2 inches long as in previous designs. However, the overall pellet stack length remains unchanged. The pellets within variable length pencils will similarly be slightly less than 1 inch in length.
- The upper and lower plenums in the multi-pencil design each contain "spacer assemblies" consisting of an outer NPZ getter tube (the "plenum getter") and an NPZ spacer tube within this outer getter tube (the "spacer getter").
- The upper spacer assembly contains two sections of NPZ spacer getter tube. The upper portion of the assembly contains an NPZ spacer getter tube only. The lower portion of the assembly contains in addition a Zircaloy "spacer liner tube" inside the lower section of the spacer getter tube (Figure 4). The spacer liner tube is flanged at its top end, and this flange separates the upper and lower sections of the spacer getter tube.
- The bottom spacer assembly in the multi-pencil design includes an outer NPZ getter tube and within that an NPZ lower spacer getter tube. A flanged spacer liner tube is inserted into the top of the lower spacer assembly. The outer NPZ getter tube is coined to capture both the lower spacer getter tube and the spacer liner (Figure 4).
- The top end plug design has been altered to include a hex- shaped shank on the upper body, and the neck-down region of the end plug has been removed. In addition, the diameter of the bored out region has been reduced and the length of the end plug insert has been reduced.
- The bored out region in the bottom end plug is removed, the length of the end plug insert has been reduced, and an NPZ getter disk resides on the insert of the bottom end plug (Figure 4).

7.0 TPBAR ASSEMBLIES

A TPBAR assembly is shown in Figure 5. It should be noted, however, that a typical design used in a 17x17 fuel assembly would be 20 TPBARs, rather than the eight illustrated in Figure 5 Compatibility with alternate fuel assembly designs can be accommodated by changes to the TPBAR lengths and end plugs.

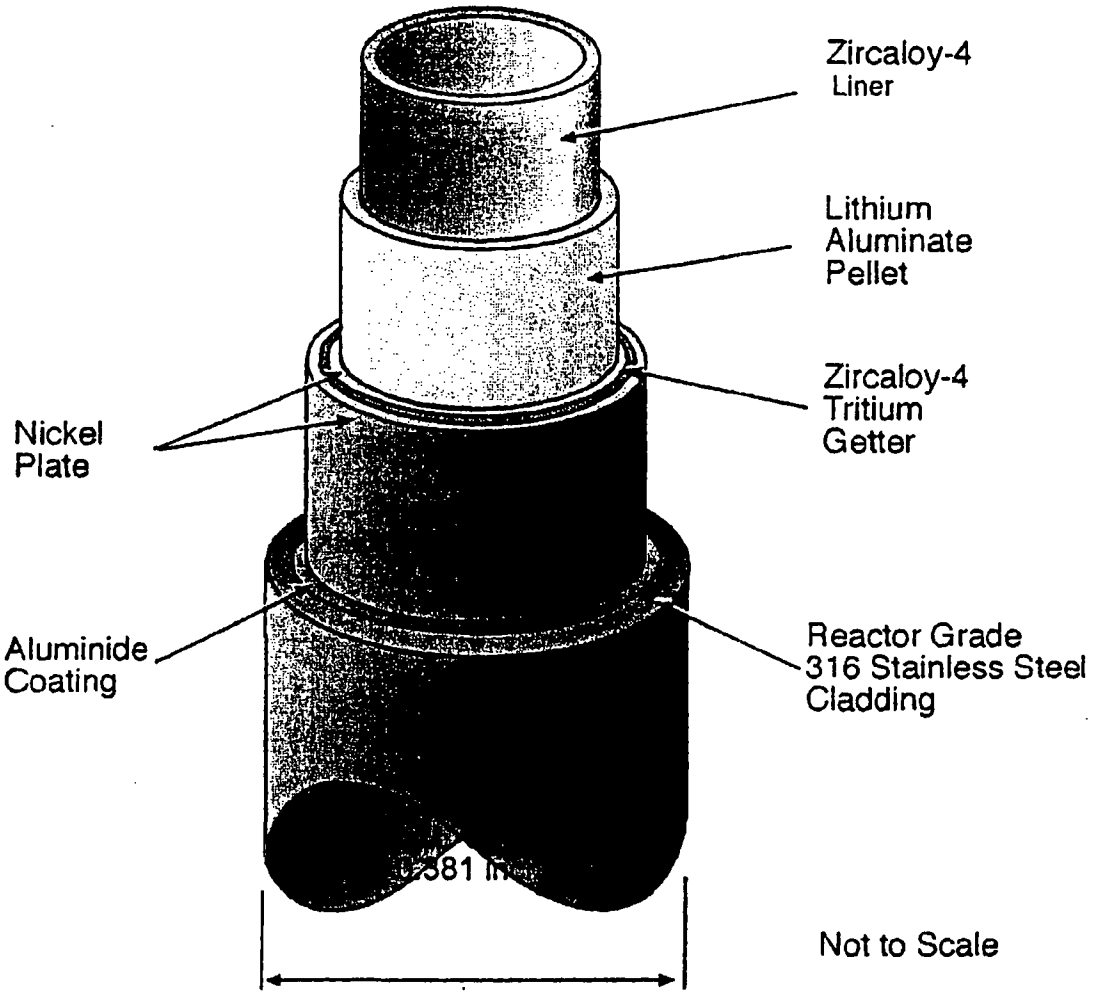


Figure 1. Isometric Section of a Tritium-Producing Burnable Absorber Rod

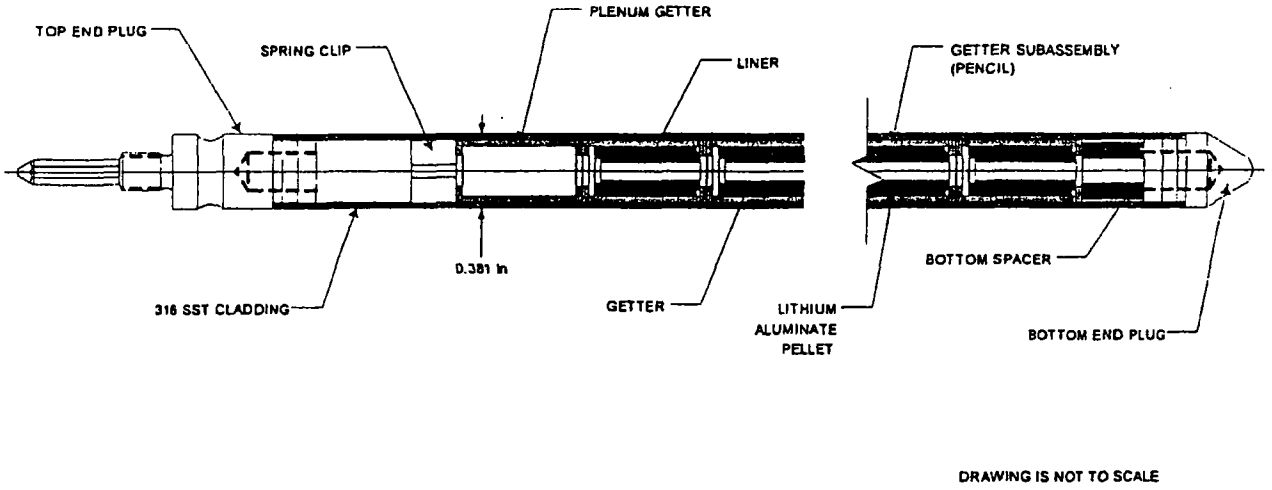


Figure 2. Axial Layout of TPBAR Internal Components –Production Standard Design

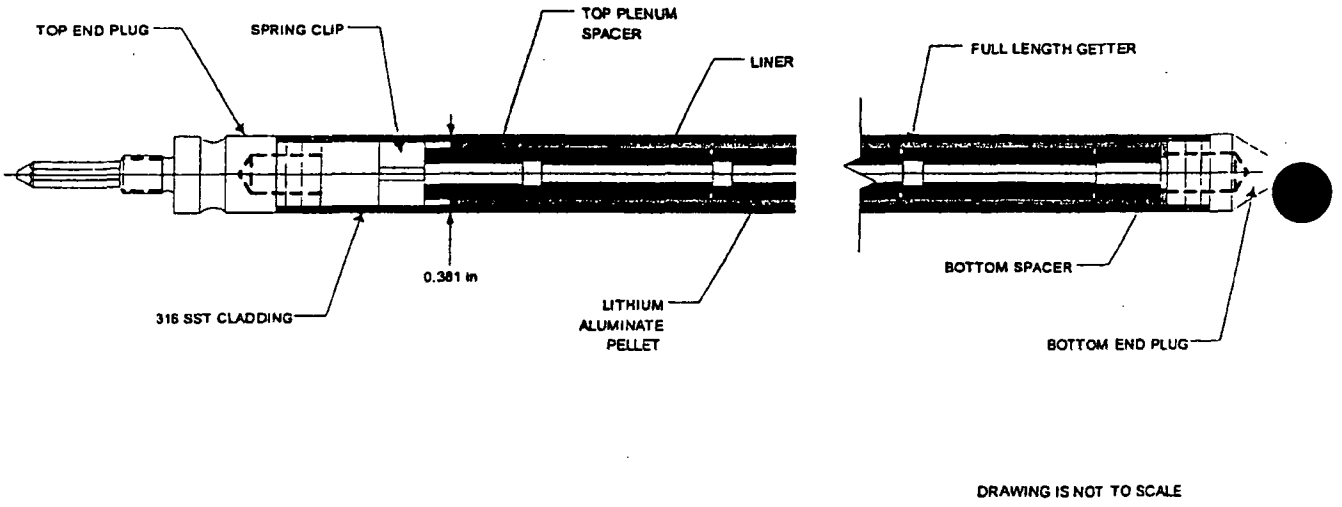


Figure 3. Axial Layout of TPBAR Internal Components –Production Full-Length Getter Design

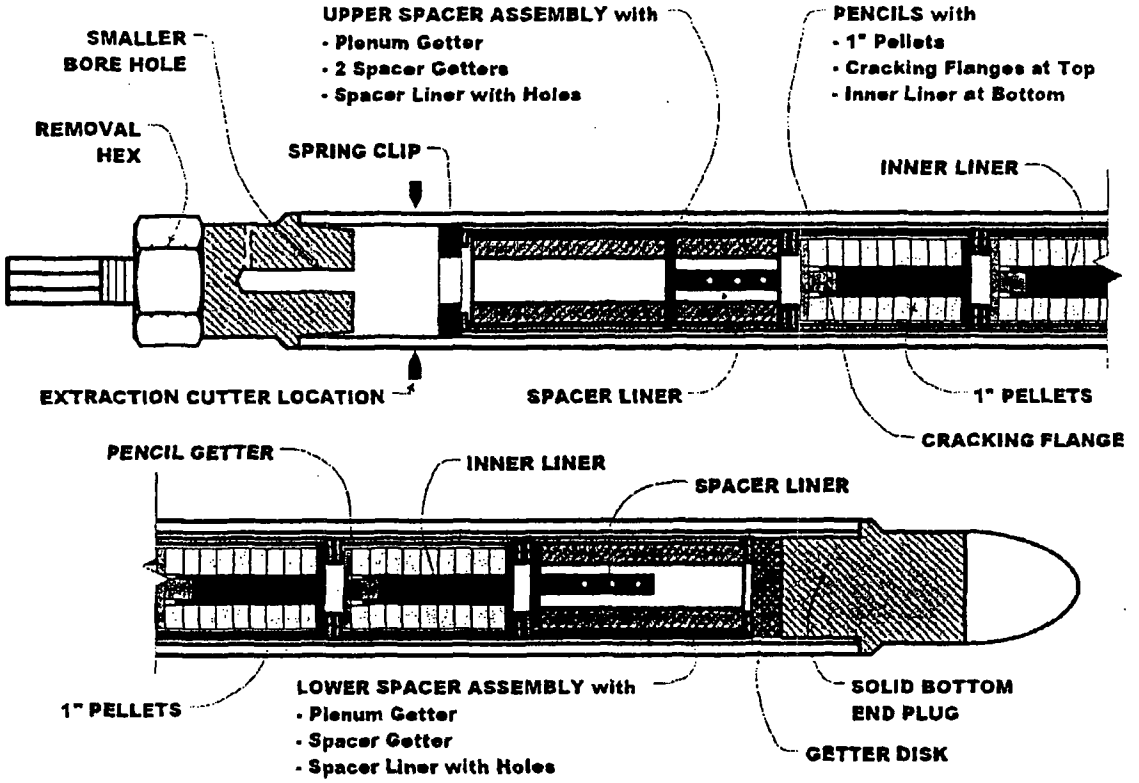


Figure 4 Axial Layout of Internal Components – Mark 8 Multi Pencil Design

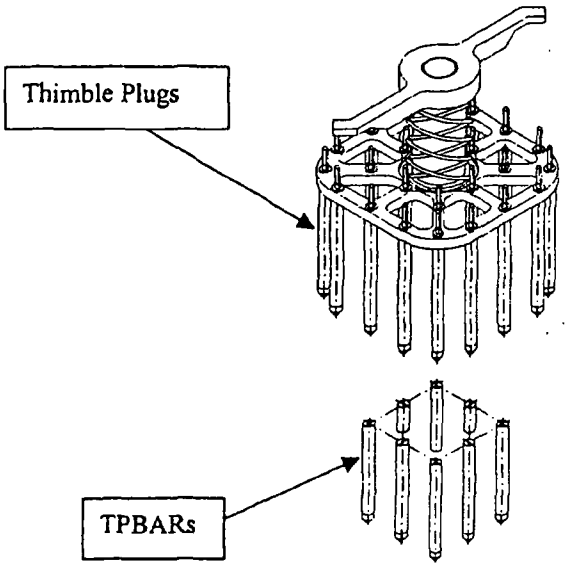


Figure 5 Typical TPBAR Assembly

APPENDIX A: LIST OF DESIGN DRAWINGS

Table A.1. List of Design Drawings for Standard Production TPBAR Design

Drawings are compiled in the latest revision of PNNL-TTQP-1-720, *Design Drawings for the Production TPBAR.*

Drawing	Title (Note: "U" designates an unclassified title.)	Classification
H-3-307843 Sheets 1 to 8	Production TPBAR Assembly Watts Bar (U)	Classified Sheet 2 is Unclassified
H-3-308874 Sheets 1 to 8	Production TPBAR Sequoyah (U)	Classified Sheet 2 is Unclassified
H-3-307844	Production Design Drawing List	Unclassified
H-3-307845 Sheets 1 and 2	Production TPBAR Interface Dimensions Watts Bar	Sheet 1 Unclassified Sheet 2 Classified
H-3-308875 Sheets 1 and 2	Production TPBAR Interface Dimensions Sequoyah	Sheet 1 Unclassified Sheet 2 Classified
H-3-307846	Production Cladding Tube	Unclassified
H-3-307847	Production Coated Cladding Tube (U)	Classified
H-3-307848 Sheets 1 and 2	Production Trimmed Coated Cladding Tube with End Prep (U)	Classified
H-3-307849	Production Standard Pencil Assembly (U)	Classified
H-3-307850	Production Variable Length Pencil Assembly (U)	Classified
H-3-307851 Sheets 1 and 2	Production Bottom Spacer (U)	Classified
H-3-307852	Production Top Plenum Spacer (U)	Classified
H-3-307853	Production Standard Pellet Stack	Unclassified
H-3-307854	Production Variable Length Pellet Stack	Unclassified
H-3-307855	Production Getter Tube Stock	Unclassified
H-3-307856 Sheets 1 and 2	Production Plated Getter Tube (U)	Classified
H-3-307857	Production Standard Inner Liner Tube	Unclassified
H-3-307858	Production Variable Length Inner Liner Tube	Unclassified
H-3-307859	Production Bottom Spacer Tube Stock	Unclassified
H-3-307860 Sheets 1 to 3	Production Top End Plug	Unclassified
H-3-307861 Sheets 1 and 2	Production Bottom End Plug	Unclassified
H-3-307862	Production Spring Clip	Unclassified
H-3-307325	Production Coated Cladding Bottom End Plug Assembly (U)	Classified
H-3-307326	Production Coated Cladding Bottom End Plug Assembly With End Prep (U)	Classified
H-3-309517	Activation Heat Treatment Profiles (U)	Classified
Full-Length Parts Needed FOR Multi-Pencil TPBAR Design (See PNNL-TTQP-1-769)		
H-3-307317	Spring Clip	Unclassified
H-3-310191 Sheets 1 to 3	Top End Plug	Unclassified
H-3-310192 Sheets 1 and 2	Bottom End Plug	Unclassified

Table A.2. List of Design Drawings for Production Full-Length Getter TPBAR Design

Drawings are compiled in the latest revision of PNNL-TTQP-1-769, *Production Full-Length Getter TPBAR Design Drawings (U)*

Drawing	Title (Note: "U" designates an unclassified title.)	Classification
H-3-307310 Sheets 1 to 6	Production Full-Length Getter TPBAR - Watts Bar (U)	Classified Sheet 2 is Unclassified
H-3-307311 Sheets 1 to 6	Production Full-Length Getter TPBAR - Sequoyah (U)	Classified Sheet 2 is Unclassified
H-3-307312 Sheets 1 to 4	Full-Length Getter TPBAR Interface Dimensions	Sheets 1 and 3 Unclassified Sheet 2 and 4 Classified
H-3-307313	Reserved for future use	
H-3-307314	Full-Length Getter Spacer Stock	Unclassified
H-3-307315	Full-Length Getter Plated Spacer (U)	Classified
H-3-307316	Full-Length Getter Finished Bottom Spacer (U)	Classified
H-3-307317	Spring Clip	Unclassified
H-3-307318	Reserved for future use	---
H-3-307319	Full-Length Getter Finished Top Plenum Spacer (U)	Classified
H-3-307320	Full-Length Getter Pellet Stack	Unclassified
H-3-307321	Full-Length Getter Inner Liner Tube	Unclassified
H-3-307322	Full-Length Getter Tube Stock	Unclassified
H-3-307323 Sheets 1 and 2	Full-Length Getter Plated Getter Tube (U)	Classified
H-3-307324	Production Full-Length Getter TPBAR Design Drawing List	Unclassified
H-3-307327	Activation Heat Treatment Profiles for Spacers (U)	Classified
H-3-310191 Sheets 1 to 3	Top End Plug	Unclassified
H-310192 Sheets 1 and 2	Bottom End Plug	Unclassified
Production Parts Needed for Full-Length Getter TPBAR Design (See PNNL-TTQP-1-720)		
H-3-307325	Production Coated Cladding Bottom End Plug Assembly (U)	Classified
H-3-307326	Production Coated Cladding Bottom End Plug Assembly With End Prep (U)	Classified
H-3-307846	Production Cladding Tube	Unclassified
H-3-307847	Production Coated Cladding Tube (U)	Classified
H-3-307848 Sheets 1 and 2	Production Trimmed Coated Cladding Tube with End Prep (U)	Classified
H-3-307853	Production Standard Pellet Stack	Unclassified
H-3-307854	Production Variable Length Pellet Stack	Unclassified
H-3-307857	Production Standard Inner Liner Tube	Unclassified
H-3-307858	Production Variable Length Inner Liner Tube	Unclassified
H-3-307860 Sheets 1 to 3	Production Top End Plug	Unclassified
H-3-307861 Sheets 1 and 2	Production Bottom End Plug	Unclassified

Table A.3. List of Design Drawings for Mark 8 Multi-Pencil TPBAR Design

Drawings are compiled in the latest revision of PNNL-TTQP-1-976, *Mark 8 TPBAR Design Drawings.*

Drawing	Title (Note: "U" designates an unclassified title.)	Classification
H-3-310566	Mark 8 TPBAR Drawing List	Unclassified
H-3-310567 Sheets 1 to 6	Mark 8 TPBAR Multi-Pencil Watts Bar (U)	Classified Sheet 2 is Unclassified
H-3-310568 Sheets 1 and 2	Mark 8 TPBAR Multi Pencil –Reactor Interface Mark 8 TPBAR Multi-Pencil –Extraction Interface	Sheet 1 Unclassified Sheet 2 Classified
H-3-310571 Sheets 1 to 3	Top End Plug	Unclassified
H-3-310572 Sheets 1 and 2	Trimmed Cladding Tube with End Prep (U)	Classified
H-3-310573	Coated Cladding Bottom End Plug Assembly (U)	Classified
H-3-310574	Coated Cladding Bottom End Plug Assembly with End Prep (U)	Classified
H-3-310575	Upper Spacer Assembly (U)	Classified
H-3-310576	Spacer Getters (U)	Classified
H-3-310580	Pencil Assemblies – Cracking Flange (U)	Classified
H-3-310583	Lower Spacer Assembly (U)	Classified
H-3-310584	Getter Disk (U)	Classified
H-3-310585	Getter Disk Stock	Unclassified
H-3-310586 Sheets 1 and 2	Bottom End Plug	Unclassified
H-3-310587	Cracking Flange	Unclassified
H-3-310591	Spacer Liner	Unclassified
H-3-310593	Mark 8 Variable Pellet Stack	Unclassified
H-3-310594	Mark 8 Standard Pellet Stack	Unclassified
H-3-310595 Sheets 1 to 5	Mark 8 EM TPBAR	Classified Sheet 2 Unclassified
H-3-310596	Mark 8 EM Pencil Assemblies (U)	Classified
H-3-310597	Mark 8 EM Beta Liner	Unclassified
H-3-310598	Mark 8 EM End Effect Pellet Stack	Unclassified

Table A.3. List of Design Drawings for Mark 8 Multi-Pencil TPBAR Design (continued)

Drawings listed below are reference drawings from PNNL-TTQP-1-720 and PNNL-1-769 (at the latest revision) for parts or items used in the Mark 8 design.

Drawing	Title (Note: "U" designates an unclassified title.)	Classification
H-3-307846	Production Cladding Tube	Unclassified
H-3-307847	Production Coated Cladding Tube (U)	Classified
H-3-307862	Production Spring Clip	Unclassified
H-3-307855	Production Getter Tube Stock	Unclassified
H-3-307856 Sheets 1 and 2	Production Plated Getter Tube (U)	Classified
H-3-307314	Full Length Getter Spacer Stock	Unclassified
H-3-307315	Full Length Getter Plated Spacer (U)	Classified
H-3-307853	Production Standard Pellet Stack	Unclassified
H-3-307854	Production Variable Length Pellet Stack	Unclassified
H-3-307857	Production Standard Inner Liner Tube	Unclassified
H-3-307858	Production Variable Length Inner Liner Tube	Unclassified
H-3-309517	Activation Heat Treatment Profiles (U)	Classified
H-3-307327	Activation Heat Treatment Profiles for Spacers (U)	Classified

APPENDIX B: LIST OF DESIGN SPECIFICATIONS (All at Latest Revision)

NOTE: "PNNL" prefix in the document number denotes a classified document, and "U" following the document title designates an unclassified title.

Document Number	Title
TTQP-1-072	*Production Specification for 316 Stainless Steel Seamless Cladding Tubes*
TTQP-1-073	*Manufacturing Specification for Production LWR Tritium Target Rod Getter Tube Stock*
TTQP-1-075	*Production Specification for LWR Tritium Target Rod Stainless Steel Bar Stock for Cladding*
TTQP-1-076	*Production Specification for Enriched Annular $LiAlO_2$ Pellets*
TTQP-1-077	*Production Specification for LWR Tritium Target Rod Bare Zircaloy Tube*
TTQP-1-079	*Production Specification for LWR Tritium Target Rod Top and Bottom End Plugs*
TTQP-1-080	*Production Specification for LWR Tritium Target Rod Top and Bottom End Plug Welding*
TTQP-1-083	*Production Specification for LWR Tritium Target Rod Stainless Steel Bar Stock for End Plugs*
TTQP-1-089	*Production Specification for LWR Tritium Target Rod Spring Clip*
TTQP-1-134	*Production Specification for Assembling TPBARs onto a Holddown Base Plate*
PNNL-TTQP-1-690	*Production Specification for LWR Tritium Target Rod Final Assembly (U)*
PNNL-TTP-1-1078	*Mark 8 Final Assembly Specification (U)*
PNNL-TTQP-1-692	*Specification for LWR Tritium Target Rod Inside Diameter Aluminide Barrier (U)*
PNNL-TTQP-1-826	*Final Product Specification for Production LWR Activated, Plated Getter Tubes (U)*
PNNL-TTQP-1-920	*Specification for Production LWR Full-Length Getter Tubes (U)*
PNNL-TTQP-1-941	*Production Specification for LWR Tritium Target Rod Final Assembly Using Full-Length Getters (U)*
PNNL-TTP-1-1073	*Specification for LWR TPBAR Getter Disks (U)*

APPENDIX C: COMPONENT ACCEPTANCE TEST REQUIREMENTS (ALL AT LATEST REVISION)

Note: "PNNL" prefix in the document number denotes a classified document, and "U" following the document title designates an unclassified title.

Document Number	Title
TTQP-1-081	*TPBAR Component Characteristics and Related Importance Factors*
TTQP-1-085	*Design Requirements for TTQP Weld Joint Burst Testing Matrix/Test Plan*
TTQP-1-129	*Qualification Requirements for Coated Cladding Bending*
PNNL-TTQP-1-829	*Standard Getter Rate Test Requirements (U)*
PNNL-TTQP-1-830	*Requirements for a Standard Cladding D_2 Permeation Test (U)*
PNNL-TTQP-1-867	*Test Plan for Target Rod Spring Clip (U)*

APPENDIX 1-B

TTQP-1-091, "Unclassified TPBAR Releases, Including Tritium," Revision 11

TRITIUM TECHNOLOGY PROGRAM

UNCLASSIFIED TPBAR RELEASES, INCLUDING TRITIUM

TTQP-1-091

Revision 11

Effective Date: 08/16/06

TRITIUM TECHNOLOGY PROGRAM

UNCLASSIFIED TPBAR RELEASES, INCLUDING TRITIUM

Revision 11

Prepared By:	D.D. Lanning	8/15/06
	D.D. Lanning, Author	**Date**
Reviewed By:	E.R. Gilbert	8/15/06
	E.R. Gilbert, Independent Reviewer	**Date**
Concurrence:	Ann Labahan	8/16/06
	TTP Authorized Derivative Classifier	**Date**
	VS Dukelow for TMB	4/15/06
	T.M. Brewer, Quality Engineer	**Date**
	Ann Labahan for BD Reid	8/16/06
	B.D. Reid, Design Task Manager	**Date**
Approval:	CK Thornhill	8/16/06
	C.K. Thornhill, TTP Project Manager	**Date**

1.0 INTRODUCTION

This document provides a complete listing of all unclassified tritium release values that should be assumed for unclassified analysis. Much of the information is brought forth from the related documents listed in Section 5.0 to provide a single-source listing of unclassified release values. Some information, however, is new or updated based on current design analysis and available experimental data.

This document provides unclassified information for a larger number of release scenarios than previously analyzed. This information is summarized in Tables 1, 2, and 3. In addition, a section is included to address lithium and aluminum release in the event of a 24-TPBAR breach in the spent fuel pool.

2.0 SUMMARY OF UNCLASSIFIED RELEASES, INCLUDING TRITIUM

All tritium-producing burnable absorber rod (TPBAR) analysis assumes a maximum of 1.2 grams of tritium per TPBAR will be generated during an 18-month operating cycle.

2.1 Intact TPBAR In-reactor Tritium Permeation

The in-reactor tritium permeation rate deduced from RCS tritium activity for the group of 240 TPBARs in Watts Bar Nuclear Cycle 6, averaged over a year extending to end-of-cycle, was 2.4 ± 1.8 Ci/TPBAR/year (95% confidence interval) (Lanning and Pagh, 2005). The 95% upper bound of 2.4 +1.8 = 4.2 Ci/TPBAR/year is recommended as the basis for assessing the tritium release from intact TPBARs.

2.2 In-reactor Tritium Release from a Failed TPBAR

The first scenario involves a TPBAR that may have a fabrication defect or may be damaged prior to insertion into the reactor for irradiation. In this case, 100 percent of the tritium generated in the TPBAR is assumed to be released to the reactor coolant as it is generated.

2.3 TPBAR Releases from Spent Fuel Pool Accidents

2.3.1 Spent Fuel Pool Tritium Concentration Limit

It has been determined that following the simultaneous breach of 24 TPBARs, the Tennessee Valley Authority take-action limit for tritium concentration in the spent fuel pool water will not be exceeded. The concentration limit is 60 microcuries per milliliter. The best estimate of total tritium release in this event is less than 25% of the TPBAR inventory. The release will not be instantaneous, but will occur

at a steady rate over a time period substantially greater than 8 hours. The rate will thus be less than 3% (of initial inventory) per hour.

2.3.2 Instantaneous Tritium Release per TPBAR

In particular, the instantaneous release of tritium from breached TPBARs in the spent fuel pool (as gas within the released gas from the TPBARs) will not exceed 0.001 Ci/TPBAR.

2.3.3 Lithium and Aluminum Release

In the event of a 24-TPBAR breach in the spent fuel, the following concentration limits for lithium and aluminum will not be exceeded:

- 400 ppb lithium
- 50 ppb aluminum.

2.4 Tritium Releases from TPBARs within Storage Canisters (<200°F)

The upper-bounding tritium partial pressure within storage canisters containing lead test assembly (LTA) TPBARs and sections is not expected to exceed 20 torr under nominal storage conditions (~86°F). The quoted bounding pressure for maximum temperatures (<200°F) is estimated by increasing this figure by the ratio of Kelvin temperatures, to 25 torr.

Tritium release from extracted TPBARs in storage will not exceed 1% of the declared post-extraction residual tritium (Clemmer et al. 1984; and Johnson et al. 1976).

In both cases, the form of the released tritium will be tritiated water vapor or condensate (HTO).

2.5 TPBAR Transportation Cask Event Releases

2.5.1 Intact TPBARs

2.5.1.1 For TPBAR temperatures ranging from ambient to less than 200°F, and for casks containing 1,200 or less TPBARs, the tritium release from the entire cask loading would be less than the regulatory requirement of 0.05 mCi per hour (10 CFR 71.51). The tritium would be released from the TPBARs in the form of molecular tritium gas (i.e., T_2 or HT).

2.5.1.2 For TPBAR temperatures ranging from 200°F to 650°F, the average tritium release would be less than 0.48 mCi per

TPBAR per hour based on the upper-bound in-reactor release rate of 4.2 Ci/TPBAR/year. The tritium would be released from the TPBARs in the form of tritium gas.

2.5.1.3 For TPBAR temperatures ranging from 650°F up to 1050°F (565°C), the tritium release should be considered to be an instantaneous release of less than 0.5 Ci per TPBAR per hour. Again, the tritium would be released from the TPBARs in the form of tritium gas.

The potential for TPBAR rupture was assessed at 1050°F because this is one of the temperature break-points in the Modal Study matrix cited earlier (Laity 1998). It was determined that the TPBARs are unlikely to rupture at temperatures less than 1050°F, but may rupture at higher temperatures.

2.5.1.4 Helium release from intact TPBARs is negligible.

2.5.2 Event-failed TPBARs

2.5.2.1 For TPBAR temperatures ranging from ambient to 200°F, the tritium release from a TPBAR whose cladding fails mechanically (e.g., due to impact forces) after cask loading should be considered to be less than 0.1 Ci per TPBAR per hour, not to exceed 1% of the tritium inventory in the lithium aluminate pellets. The release should be considered to be in the form of tritiated water and a very small fraction of methane.

2.5.2.2 For TPBAR temperatures ranging from 200°F to 650°F, the tritium release from a TPBAR whose cladding fails mechanically (e.g., due to impact forces) after cask loading should be considered to be less than 55 curies total due to desorption release. The release should be considered to be in the form of tritiated water and a very small fraction of methane.

2.5.2.3 For TPBAR temperatures ranging from 650°F to 1050°F, the tritium release should be considered to be up to 100% of the TPBAR tritium inventory, in the form of tritiated water and methane.

2.5.2.4 For TPBAR temperatures in excess of the T4 Modal Study break-point (1050°F), it should be assumed that 100 percent of

the tritium inventory of the TPBAR would be instantaneously released in the form of tritiated water and methane.

2.5.2.5 The helium inventory per TPBAR following shutdown and a 90-day cooling period is calculated to be 0.42 moles (total of He-4 from fill gas plus tritium production, plus residual He-3 and decay-generated He-3) [Pagh 2003]. The additional He-3 moles per TPBAR generated by tritium decay at any time "t" (years) following the cooldown can be calculated as:

$$\text{He-3(moles)} = 0.39\{1 - \exp[-\ln(2.0)t/12.33]\}.$$

It is recommended that 100% of all He-3 and He-4 be assumed to be released from event-failed TPBARs. This assumption may be significantly conservative for decay-generated He-3, since it is largely retained within the solid internal components of the TPBAR. However, a specific postirradiation temperature history for the TPBAR components would be required to calculate specific release fractions.

2.5.3 Pre-failed TPBARs

2.5.3.1 For pre-failed TPBARs at temperatures ranging from ambient to less than 200°F, the tritium release would be less than 0.1 Ci per TPBAR per hour. The release should be considered to be in the form of tritiated water and a very small quantity of methane. This rate applies to both rods breached in the dry condition and to rods which were breached in water (spent fuel pool drop) prior to cask loading, but which were dried after cask loading.

2.5.3.2 Without further definition of the cask environmental conditions and prefailed TPBAR conditions, it is assumed that the pre-failed TPBAR is waterlogged, and that consequently 100 percent of its tritium inventory would be released to the cask during transport when temperatures exceed 200°F. The tritium release will be in the form of tritiated water (i.e., T_2O and HTO) and, potentially, some tritiated methane. A further definition of the cask environment during transportation may permit a less-conservative tritium release estimate to be defined for some classes of pre-failed rods. To provide a more complete analysis of pre-failed rods, PNNL would need the following information: temperature range(s) for analysis; time period that TPBARs are in the temperature range(s)

(a time/temperature profile would be sufficient); and the maximum allowable quantity of tritium in the cask atmosphere.

3.0 FLAMMABLE GAS SOURCES

Because accident temperatures are not estimated to exceed 400°F, flammable gas generation for temperatures greater than that temperature are not considered here. The very limited tritium release from intact rods at temperatures <650°F have already been stated to be in the form of T_2 and HT.

Releases from event-failed rods at <200°F have been declared to be in the form of tritiated water and negligible methane fraction. Conversion of this water to T_2 or HT at such low temperatures is negligible.

Releases from event-failed rods at <650°F (i.e., 55Ci/TPBAR) have been declared to be in the form of T_2O and HTO. However, as a bounding estimate for flammable gas source, it will be assumed that 2% of this release will be converted to T_2 or HT from reaction with hot metal surfaces.

The pre-failed TPBARs are assumed to be waterlogged, for the purposes of estimating tritium release (Section 2.5.3.2 above). The potential for flammable hydrogen (H_2) gas formation from these rods is dependent upon actual conditions regarding water inventory, water release from the TPBARs, and water vapor reduction by hot metal surfaces. These conditions are not well defined. Hence, a bounding estimate of 0.15 moles per pre-failed TPBAR per year is made here, for temperatures between 200 and 400°F. This is calculated assuming 100% release of the potential 7.7 moles of water per TPBAR and a bounding conversion of 2% of this water to hydrogen gas (per year) from reaction with hot steel surfaces. Note that this is a very conservative (high) estimate, since anticipated cask internal temperatures are significantly less than 400°F. Below 200°F, hydrogen formation is considered negligible.

{These estimates do not include addition of hydrogen formed from radiolysis; however prior calculations indicate this would be less than 1% of available water per year, or less than 0.075 moles per pre-failed TPBAR per year.}

These bounding estimates for flammable gas formation are summarized in Table 4.

4.0 SHIPMENT OF TPBAR SEGMENTS AND FINES

Shipment of sectioned TPBARs plus cutting fines is planned. Such shipments will be bounded in content by up to 55 equivalent TPBAR lengths, with tritium content of the TPBARs less than the design limit of 1.2 grams tritium per TPBAR. The segments are expected to retain their internal components largely intact; however, impact loads during shipment could result in an undetermined extent of pellet cracking and further

fragmentation of pellet pieces. Conservatively, it is assumed that 100% of the tritium in the pellets is released during shipment. (It is noted that less than 40% of the tritium produced per TPBAR is contained in the pellets at the end of irradiation (Lanning et al. 2003.) This bounding assumption regarding tritium release from pellets is judged to include any in-shipment release of the residual tritium in the cutting fines.

The same declarations made in section 3.0 above apply to the shipment of TPBAR segments, regarding the expected form of the released tritium and the conversion to flammable species. That is, the expected forms of the released tritium are T_2O and HTO and the conversion to flammable species (T_2 and HT) is expected to be <2% per year, given cask temperatures less than 400°F.

Table 5 has been added to indicate the bounding quantities of released tritium and flammable gas generation for shipment of TPBAR segments as described above. As in Table 4, the flammable gas estimates do not include conversion due to radiolysis effects; but these are expected to be less than 1% of the available tritiated water vapor per year, or less than 0.044 moles per year.

5.0 RELATED DOCUMENTS

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Lanning, DD, and RT Pagh, 2005. *Estimation of WBN Cycle 6 TPBAR Tritium Release from Analysis and Qualification of RCS Tritium Activity*, TTP-1-2064, Revision 0, Pacific Northwest National Laboratory, Richland, Washington.

Pagh, RT. 2003. *Release of Gas-Phase Components and Fines During Transportation Breach of Production TPBAR*, TTQP-1-2061, Revision 1, Pacific Northwest National Laboratory, Richland, Washington.

Table 1. Summary of Unclassified Tritium Release Assumptions for Non-Transportation Scenarios

In-Reactor Permeation	In-Reactor Release from Defective TPBARs	Spent Fuel Pool Accident Releases (<200°F)	Tritium Releases from TPBARs in Storage Canisters (<200°F)
Less than 0.48 mCi per TPBAR per hour	Released as it is generated	The Tennessee Valley Authority take-action limit of 60 microcuries per ml of spent fuel pool water will not be exceeded following the simultaneous breach of up to 24 TPBARs. The best estimate total tritium release in this event is less than 25% of the total TPBAR tritium inventory. The release rate will be < 3% (of initial inventory) per hour. The instantaneous release of tritium from breached TPBARs (as gas within the released gas from the TPBARs) will not exceed 0.001 Ci/TPBAR. The concentration of lithium and aluminum in the spent fuel pool following a 24-TPBAR breach will not exceed 400 ppb and 50 ppb, respectively.	Tritium partial pressure within storage canisters containing LTA TPBARs and sections will not exceed 25 torr. Tritium release from extracted TPBARs will not exceed 1% of the declared tritium residual.

Table 2. Summary of Unclassified Tritium Release Assumptions for Cask Transportation Scenarios

Intact TPBARs			Event-Failed TPBARs				TPBARs Pre-Failed In-Reactor	
<200°F	200°F to 650°F	650°F to 1050°F	Ambient to <200°F	200°F to 650°F	650°F to 1050°F	>1050°F	Ambient to <200°F	>200°F
< 0.05 mCi per hour for 1200 or less TPBARs	<0.48 mCi per TPBAR per hour (based on average TPBAR in the core)	<0.5 Ci per TPBAR per hour	<0.1 Ci per TPBAR per hour, not to exceed 1% of the pellet tritium inventory	<55 Ci total per TPBAR	<100% of inventory	100% of inventory	<0.1 Ci per TPBAR per hour	up to 100% of inventory

Table 3. Unclassified Helium Release Assumption for Cask Transportation Scenarios

TPBAR Condition	Helium Release to Cask
Intact	No release
Event-Failed	0.42 moles per TPBAR (following shutdown and 90-day cooling period), plus the decay-generated moles of He-3 at time t (years) following the cooldown, calculated as: $He\text{-}3(moles) = 0.39\{1 - \exp[-\ln(2.0)t/12.33]\}$

Table 4. Summary of Unclassified Bounding Flammable Gas Formation for Cask Transportation Scenarios (moles refer to moles H_2 equivalent)

Intact TPBARs		Event-Failed TPBARs		TPBARs Pre-Failed In-Reactor	
<200°F	200°F to 400°F	Ambient to <200°F	200°F to 400°F	Ambient to <200°F	200°F to 400°F
<7.1E-13 moles per TPBAR per hour	<<2.0E-9 moles per TPBAR per hour	Negligible moles per TPBAR	<1.9E-5 moles per TPBAR per year	Negligible moles total per TPBAR	<0.15 moles total per TPBAR per year

Table 5. Summary of Unclassified Bounding Tritium Release and Flammable Gas Formation for Cask Shipment of TPBAR Segments and Cutting Fines (up to 55 Equivalent TPBARs)

Tritium Releases		Flammable Gas Generation (moles refer to moles H_2 equivalent)	
<200°F	200°F to 400°F	Ambient to <200°F	200°F to 400°F
100% of Pellet inventory = < 26.4 grams	100% of Pellet inventory = < 26.4 grams	Negligible moles per TPBAR	< 0.088 moles per year

APPENDIX 1-C

TTQP-1-111, "Unclassified Bounding Source Term, Radionuclide Concentrations, Decay Heat, and Dose Rates for the Production TPBAR," Revision 5

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TRITIUM TECHNOLOGY PROGRAM

UNCLASSIFIED BOUNDING SOURCE TERM, RADIONUCLIDE CONCENTRATIONS, DECAY HEAT, AND DOSE RATES FOR THE PRODUCTION TPBAR

TTQP-1-111

Revision 5

Effective Date: 12/14/05

TRITIUM TECHNOLOGY PROGRAM

UNCLASSIFIED BOUNDING SOURCE TERM, RADIONUCLIDE CONCENTRATIONS, DECAY HEAT, AND DOSE RATES FOR THE PRODUCTION TPBAR

Revision 5

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TTP Design Analysis Report	D01398-EDP03 Rev. 12 EDP: TTQP-1-112, Rev. 12
Title: Unclassified Bounding Source Term, Radionuclide Concentrations, Decay Heat, and Dose Rates for the Production TPBAR (U)	Number: TTQP-1-111 Revision: 5

Purpose and Description of Design Analysis: The constituents of a TPBAR become radioactive during irradiation in a reactor. This analysis will determine the unclassified bounding source term, radionuclide concentrations, decay heat, and dose rates of an irradiated production TPBAR and the hold-down assembly.

Changes to Previous Proven Designs or the Analysis of Previous Proven Designs: Inclusion of Appendix D containing trace radionuclide concentrations in TPBAR.

Unverified Assumptions and/or Unverified Inputs (including source identification if available): None

Method of Analysis: Radionuclide concentrations, decay heat, and source terms are estimated using ORIGEN2. Dose rates are estimated using MCNP.

Computer Codes used including Version and Computer Processor(s) or Model(s) Used: ORIGEN2 Version 2.1b, MCNP 4C, and Excel 97 on a Dell OptiPlex Gx1, Pentium II processor. ORIGEN2 Version 2.2 on a Dell Precision 650, Pentium IV processor.

Summary of Results: The primary calculated values are given in the body of this report. Complete results for TPBAR radionuclide concentrations, decay heat, and source terms are presented in Tables 3 through 5, respectively, for various decay times. Similar results for the hold-down assembly are presented in Tables 6-8, results for the thimble plug are given in Tables 9-11. Complete results for the dose rates for a TPBAR and hold-down assembly are presented in Tables 12 and 13, respectively. Axial power profile is shown in Figure 2. Material constituents are given in Appendix A. ORIGEN2 input is given in Appendix B. MCNP input is given in Appendix C. Trace radionuclide concentrations for the TPBAR are provided in Appendix D.

	Signature	Date
Responsible Engineer(s)	RT Pagh Richard T Pagh	12/13/05
Design Verifier(s)	George H. Meinhardt	12/13/05
TTP ADC	C B Reid	12/13/05
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Design Task Manager	C B Reid	12/13/05
Design Database Administrator (N/A for Revision 0)	Neil Marcy	12/13/05

1.0 INTRODUCTION

During the tritium-producing burnable absorber rod (TPBAR) irradiation, the components of the TPBAR will become radioactive as a result of neutron capture. The irradiated TPBAR will emit a spectrum of photons from the radioactive decay of these activation products. This radioactive decay also generates decay heat in the TPBAR.

Unclassified bounding estimates of radionuclide concentrations, photon source term, and decay heat have been made for an irradiated production TPBAR and are presented in this calculation. These results bound irradiation of the production TPBAR in any anticipated host reactor. This information is needed to address waste classification, waste disposal, and transportation. Additionally, the source term is needed for dose-rate calculations. Dose rate calculations are performed for several representative configurations and are included in this calculation.

These calculations are performed for both the TPBAR (absorber, getter, liner, cladding, plenum, spring clip, and end plugs) and the hold-down assembly. This calculation bounds all TPBAR designs including the full-length getter design.

2.0 METHODOLOGY

2.1 ORIGEN2 Methodology

The radionuclide concentrations, source term, and decay heat of an irradiated TPBAR and hold-down assembly were estimated using the ORIGEN2 code (RSIC 1996). The ORIGEN family of codes has been used extensively in the past to estimate radionuclide inventories when measurements were not available. Input to ORIGEN2 consists primarily of the total masses of the constituent elements (including trace elements), the power density of the fuel, and the irradiation time.

Reactor data is given in Table 1. A uranium-235 enrichment of 3% was assumed. A lower enrichment is more conservative than a higher enrichment because the neutron flux will be higher to maintain the desired power level. The specific power used for the ORIGEN2 input was calculated by dividing the assembly burnup by the irradiation time. The specific power represents a radial peaking factor of 1.5 for the reactor.

Masses for the elements present in a TPBAR and hold-down assembly are derived in Appendix A. Impurities, which are important for both source term and waste classification analysis, are included for the various components. The cobalt in the stainless steel is the primary contributor to the dose rate for both the TPBAR and hold-down assembly. Both SS-304 and SS-316 contain 500 ppm cobalt. It needs to be noted that the bounding mass derived in Appendix A is valid only for

radiological source calculations. For mechanical analysis or radiological shielding analysis, the bounding TPBAR mass of 2.3 lbs. listed in Lopez (2002) for the Sequoyah Units and Lopez (2003) for Watts Bar should be referenced.

Table 1. Reactor Data

Reactor Data from Lopez 2002, 2003	
Parameter	**Value**
Mass of U, kg/assembly	462
Number of assemblies	193
Reactor Power, MW	3,459
Irradiation Time, d	510
Maximum Assembly Burnup, MWd/MTU	29,700
Assumptions	
U-235 enrichment, wt%	3.000
U-234 content is small and can be treated as if it is U-238.	
Reactor is at full power throughout the cycle.	
Calculated Numbers	
Mass U-235, g/MTU	30000
Mass U-238, g/MTU	970000
Specific Power for Assembly, MW/MTU	58.24
Radial Assembly Peaking Factor	1.50

ORIGEN2 was executed for the following 3 cases:

- complete TPBAR
- hold-down assembly (without thimble plugs)
- single thimble plug (SS-304)

The hold-down assembly and the thimble plugs are located above the active core. Therefore, the results must be modified by conservative "scaling factors" to account for the fact that these components are located outside the active region of the core.

The various components, their masses determined for radiological source analysis, and appropriate scaling factors are summarized in Table 2. Note that the average scaling factor for a thimble plug is 0.2 for radionuclide concentrations and decay heat. Since the thimble plug will activate more at the end closer to the core, where the scaling factor is estimated to be 0.5 (Guenther et al. 1988), the scaling factor for the thimble plug photon source term is assumed to be 0.5 to be conservative.

The scaling factor for the hold-down assembly was applied to the output from the ORIGEN2 calculation. The calculation for the thimble plug was made as one gram of material. The output from each calculation was multiplied by the mass of the thimble plug (150 grams) and the appropriate scaling factors.

Table 2. Summary of ORIGEN2 Cases

Component	Material	Mass (g)	Scaling Factor
Complete TPBAR	SS-316, Lithium Aluminate, Nickel, Aluminum, Zircaloy	1245	1.0 (no scaling factor) Note: Mass is valid only for radiological source calculations. Bounding mechanical and shielding mass of 2.3 lbs. is listed in Lopez (2002) and Lopez (2003).
Hold-Down Assembly (no thimble plugs)	SS-304 and Inconel	2815	0.1 (Migliore et al. 1994)
Single Thimble Plug	SS-304	150	0.2 for radionuclide concentrations and decay heat (Luksic 1989, averaged over whole thimble plug) 0.5 for source terms (Guenther et al. 1988)

ORIGEN2 input for each of these cases is given in Appendix B.

ORIGEN2 output does not report a complete list of radionuclides generated by irradiation as this list would be quite long. Rather the code provides a threshold value below which concentrations are not reported. For the above cases the threshold is set at a value such that any radionuclide whose value is nine orders of magnitude below the total for the item is not reported. In most cases this is sufficient to identify important radionuclides of concern. However, parent-daughter products (such as Sr-90 and Y-90) may not both be displayed if one of the radionuclides does not meet the threshold. Appendix D provides a listing of radionuclide concentrations for the TPBAR where the threshold has been lowered to report any concentration greater than 1 picocurie.

2.2 MCNP Methodology

Dose rates were estimated for the unshielded TPBAR and hold-down assembly using the MCNP code (RSICC 2000). MCNP is a general-purpose particle transport code commonly used for shielding applications. MCNP allows the user to model the problem geometry in as much detail as the user demands. Input includes the problem geometry, materials, and source term.

TPBAR Geometry. The TPBAR was modeled in a simplified manner as a piece of bare cladding using smeared geometry (but not smeared compositions) as described in Love (2003). Smeared geometry was used because the source term was calculated for the entire TPBAR, not for individual TPBAR components. To add conservatism the source (Table 5) is uniformly distributed throughout the smeared cladding region (i.e., no source in the inner region of the TPBAR). This assumption was made because the largest contributor to the dose rate is from cobalt activation in the cladding. Even more conservatism could be added by using unsmeared cladding dimensions because this would concentrate the source closer to the surface, but this level of conservatism is unwarranted because there will be a contribution to the dose rate from the TPBAR internals, which is approximately modeled by using smeared cladding dimensions. The entire length of the TPBAR was modeled. No shielding material was used in the model and the TPBAR is detached from the hold-down assembly.

Hold-Down Assembly Geometry. The geometry of the hold-down assembly was modeled in a simplified manner. All dimensions used in the model are approximate and sufficient to describe the hold-down assembly for the purpose of dose rate analyses. Dimensions are assumed and were chosen based upon the approximate cross sectional area of a fuel assembly and from personal communication with Westinghouse.

The TPBARs will be removed from the hold-down assembly prior to extraction, leaving only the thimble plugs. It was assumed that a hold-down assembly would contain at least 4 TPBARs, leaving 20 thimble plugs on the hold-down assembly. Figure 1 shows the assumed loading pattern. Each thimble plug was modeled as a cylinder with a radius of 0.5 cm and a length of 16 cm. The hold-down assembly itself was modeled as a cylindrical plate 0.7 cm thick with a radius of 12 cm. (Note: The entire mass and source term of the hold-down assembly is modeled as a single plate.) The steel composition was modeled as pure iron with an assumed density of 8 g/cc (approximate density of steel from Livingston 2001). No shielding material was used in the model.

The source term for the hold-down assembly (Table 8) is distributed uniformly throughout the plate. The source term for a thimble plug (Table 11) is distributed uniformly throughout each thimble plug. Note that the average scaling factor for a thimble plug is 0.2 for radionuclide concentrations (see Table 2). Because the thimble plug will activate more at the end closer to the core, where the scaling factor is estimated to be 0.5, to be conservative the source strength for a thimble plus is assumed to be 0.5 in the MCNP calculations.

Flux-to-dose rate conversion factors are used by MCNP to estimate dose rates. The conversion factors used are the ANSI/ANS-6.1.1-1977 standard

(Battat 1977). A 1991 standard is also available, but the 1977 standard is still in wide use and gives more conservative results than the 1991 standard.

The dose rates for both the TPBAR and hold-down assembly are computed for decay times of 7 days, 90 days, 180 days, 1 year, and 5 years. For the TPBAR, dose rates are calculated at the surface and at a distance of lm along the entire length. Dose rates at lm (radial) are also given for the centermost lm (axial) and represent an average over this axial region. For the hold-down assembly, dose rates are calculated at the top of the assembly, bottom of the thimble plugs, and around the sides of the assembly (at a radial distance of 12 cm from the centerline). All dose rates are averaged over surface areas.

Select MCNP input files are included in Appendix C.

3.0 ORIGEN2 RESULTS FOR RADIONUCLIDE CONCENTRATIONS, DECAY HEAT, AND PHOTON SOURCE TERMS; MCNP RESULTS FOR DOSE RATES

Complete results for TPBAR radionuclide concentrations, decay heat, and source terms are presented in Tables 3 through 5, respectively, for various decay times. The tritium results for the complete TPBAR have been forced to match the functional requirement of 1.2 g tritium maximum per TPBAR (e.g., the ORIGEN2 results for tritium are not reported in Tables 3 and 4). Similar results for the hold-down assembly are presented in Tables 6 through 8 and results for the thimble plug are given in Tables 9 through 11.

Complete results for the dose rates for a TPBAR and hold-down assembly are presented in Tables 12 and 13, respectively.

The source term was axially distributed uniformly throughout the TPBAR, i.e., core axial peaking was ignored in both the source term and dose rate analyses. Sufficient conservatism exists in the calculation that treating the axial peaking explicitly was unwarranted. The components were also modeled as existing in a vacuum and having no air attenuation, back-scattering, or other buildup factors included in the dose rates.

The relative axial profile of power per unit length for the TPBAR (without the bottom end plug) is shown in Figure 2. The peak-to-average ratio for this profile is 1.15. The bottom end plug is not shown as it represents 6.8% of the total power of the TPBAR. The remainder of the power is distributed as shown in Figure 2. This axial power distribution accounts for axial distribution of neutron fluence as deduced from the end of life axial distribution of tritium production, and also accounts for the higher mass/unit length in the bottom spacer region, which is the cause of the rise at the bottom end. This profile is provided for reference but was not used in these calculations.

The calculations in this document are conservative based upon the input assumptions and the calculational approach. The major assumptions are:

- Cobalt-60 is the major contributor to the dose rates. 500 ppm of cobalt was assumed for the calculations, which is the highest allowed by the stainless steel specification. The actual cobalt concentration could be a factor of 2 lower, which would cause the actual dose rates to be a factor of 2 lower than those calculated.

- Experimental data shows that ORIGEN2 tends to calculate cobalt-60 approximately 50% higher than expected (Migliore et. al. 1994).

- The flux-to-dose-rate conversion factors used in MCNP are a conservative set. The dose rates would decrease if a less conservative set of factors were used.

- The hold-down assembly was modeled as a plate. The actual hold-down assembly extends above the bottom plate, which would spread the source over a larger volume. The dose rate at the top of the hold-down assembly should decrease if a more detailed model were employed.

Table 3. Radionuclide Concentrations in a TPBAR (Ci/TPBAR)

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
H-3[1]	1.16E+04	1.15E+04	1.14E+04	1.13E+04	1.10E+04	8.76E+03	6.61E+03
C 14	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03
NA 24	1.98E-02	1.65E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P 32	1.03E+00	3.38E-01	1.84E-02	2.35E-04	3.02E-08	5.78E-10	5.75E-10
S 35	1.37E-02	1.15E-02	7.15E-03	3.52E-03	8.18E-04	8.22E-09	4.65E-15
AR 37	3.79E-01	2.40E-01	7.32E-02	1.23E-02	3.15E-04	8.74E-17	1.76E-32
AR 39	9.49E-03	9.49E-03	9.48E-03	9.48E-03	9.46E-03	9.37E-03	9.25E-03
K 42	2.18E-04	8.34E-12	8.31E-12	8.27E-12	8.18E-12	7.52E-12	6.77E-12
CA 41	7.51E-05	7.51E-05	7.51E-05	7.51E-05	7.51E-05	7.51E-05	7.51E-05
CA 45	3.13E-01	2.84E-01	2.20E-01	1.50E-01	6.82E-02	1.37E-04	5.78E-08
CA 47	1.57E-04	4.66E-06	4.86E-10	5.17E-16	2.62E-28	0.00E+00	0.00E+00
SC 46	8.20E-03	6.78E-03	4.13E-03	1.96E-03	4.24E-04	2.39E-09	6.57E-16
SC 47	5.68E-04	1.76E-05	1.86E-09	1.98E-15	1.00E-27	0.00E+00	0.00E+00
CR 51	9.67E+02	5.44E+02	1.21E+02	1.28E+01	1.24E-01	1.66E-17	2.38E-37
MN 54	4.19E+01	3.98E+01	3.48E+01	2.85E+01	1.89E+01	7.41E-01	1.29E-02
FE 55	2.15E+02	2.12E+02	2.03E+02	1.90E+02	1.66E+02	5.71E+01	1.51E+01
FE 59	1.98E+01	1.39E+01	5.52E+00	1.38E+00	7.96E-02	1.34E-11	8.14E-24
CO 58	2.69E+02	2.15E+02	1.19E+02	4.95E+01	8.06E+00	4.92E-06	8.41E-14
CO 60	3.60E+01	3.57E+01	3.49E+01	3.38E+01	3.16E+01	1.87E+01	9.68E+00
NI 59	1.68E-01	1.68E-01	1.68E-01	1.68E-01	1.68E-01	1.68E-01	1.68E-01

1 The ORIGEN2 values for H-3 are not reported. The values given for H-3 are based on a maximum of 1.2 g of tritium per TPBAR at discharge, as specified in the Functional Requirements document (Lopez 2003). There is 9664 Ci per gram of tritium, and the half-life of tritium is 12.33 years. The value of 1.2 g at discharge is decayed appropriately for the various decay times.

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
NI 63	2.29E+01	2.29E+01	2.28E+01	2.28E+01	2.27E+01	2.20E+01	2.12E+01
NI 66	1.52E-04	1.38E-07	1.59E-15	1.97E-27	0.00E+00	0.00E+00	0.00E+00
CU 64	1.27E-03	1.04E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CU 66	1.52E-04	1.38E-07	1.59E-15	1.97E-27	0.00E+00	0.00E+00	0.00E+00
ZN 65	4.13E-03	3.87E-03	3.26E-03	2.52E-03	1.49E-03	2.34E-05	1.31E-07
AS 76	8.74E-01	4.25E-07	1.44E-23	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SE 75	8.88E-01	7.77E-01	5.49E-01	3.26E-01	1.12E-01	2.38E-05	6.13E-10
BR 82	1.14E-03	2.25E-08	1.18E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR 89	7.51E-02	5.48E-02	2.40E-02	6.99E-03	5.49E-04	1.07E-12	1.39E-23
Y 89M	5.48E-04	4.18E-06	1.24E-11	6.39E-20	0.00E+00	0.00E+00	0.00E+00
Y 90	5.14E-01	1.30E-03	1.38E-06	1.37E-06	1.36E-06	1.23E-06	1.09E-06
Y 91	1.92E-01	1.46E-01	7.19E-02	2.47E-02	2.76E-03	8.38E-11	3.36E-20
ZR 89	5.49E-04	4.18E-06	1.25E-11	6.40E-20	5.60E-37	0.00E+00	0.00E+00
ZR 93	1.13E-04	1.13E-04	1.13E-04	1.13E-04	1.13E-04	1.13E-04	1.13E-04
ZR 95	6.57E+01	5.12E+01	2.67E+01	1.01E+01	1.36E+00	1.81E-07	4.63E-16
ZR 97	1.12E-01	1.65E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NB 92	3.04E-01	6.34E-02	1.06E-03	2.28E-06	7.41E-12	0.00E+00	0.00E+00
NB 93M	3.68E-06	4.02E-06	4.87E-06	6.15E-06	8.73E-06	2.69E-05	4.49E-05
NB 94	4.76E-04	4.76E-04	4.76E-04	4.76E-04	4.76E-04	4.76E-04	4.76E-04
NB 95	6.93E+01	6.50E+01	4.45E+01	1.99E+01	2.94E+00	4.02E-07	1.03E-15
NB 95M	4.80E-01	3.80E-01	1.98E-01	7.48E-02	1.01E-02	1.34E-09	3.44E-18
NB 96	1.20E-03	9.19E-11	2.51E-29	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NB 97	1.13E-01	1.78E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NB 97M	1.06E-01	1.57E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MO 93	1.04E-03	1.04E-03	1.04E-03	1.04E-03	1.04E-03	1.04E-03	1.04E-03
MO 99	1.68E+01	5.11E-02	1.38E-08	1.94E-18	0.00E+00	0.00E+00	0.00E+00
TC 99	4.35E-05	4.36E-05	4.36E-05	4.36E-05	4.36E-05	4.36E-05	4.36E-05
RU103	3.21E-03	2.14E-03	7.41E-04	1.52E-04	5.76E-06	3.67E-17	3.71E-31
CD115	2.91E-04	2.27E-07	1.78E-15	1.23E-27	0.00E+00	0.00E+00	0.00E+00
CD115M	1.84E-04	1.28E-04	5.05E-05	1.25E-05	7.00E-07	9.62E-17	4.52E-29
IN113M	1.31E+00	1.14E+00	7.94E-01	4.62E-01	1.51E-01	2.28E-05	3.83E-10
IN114	1.26E-01	9.13E-02	3.94E-02	1.12E-02	8.36E-04	1.10E-12	8.64E-24
IN114M	1.32E-01	9.54E-02	4.12E-02	1.17E-02	8.73E-04	1.15E-12	9.03E-24
SN113	1.31E+00	1.14E+00	7.93E-01	4.61E-01	1.51E-01	2.28E-05	3.82E-10
SN117M	8.21E+00	2.63E+00	1.35E-01	1.57E-03	1.64E-07	0.00E+00	0.00E+00
SN119M	8.42E+00	7.89E+00	6.66E+00	5.16E+00	3.06E+00	4.90E-02	2.80E-04
SN121	7.39E-02	4.66E-08	3.12E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SN121M	5.54E-04	5.53E-04	5.52E-04	5.50E-04	5.46E-04	5.17E-04	4.82E-04
SN123	4.78E-01	4.22E-01	3.06E-01	1.89E-01	6.99E-02	2.75E-05	1.52E-09
SN125	2.20E+00	4.21E-01	5.63E-03	8.71E-06	1.43E-11	0.00E+00	0.00E+00
SB122	1.10E-01	2.99E-04	6.12E-11	5.66E-21	0.00E+00	0.00E+00	0.00E+00
SB124	1.86E-02	1.43E-02	7.16E-03	2.54E-03	3.01E-04	1.49E-11	1.10E-20
SB125	1.67E+00	1.66E+00	1.60E+00	1.50E+00	1.32E+00	4.87E-01	1.39E-01

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
SB126	5.64E-02	1.56E-02	5.45E-04	3.55E-06	1.13E-10	0.00E+00	0.00E+00
TE123M	3.02E-03	2.65E-03	1.87E-03	1.11E-03	3.80E-04	8.02E-08	2.05E-12
TE 125M	3.26E-01	3.40E-01	3.58E-01	3.56E-01	3.22E-01	1.19E-01	3.40E-02
CS131	5.10E-02	2.34E-02	1.17E-03	7.33E-06	1.50E-10	0.00E+00	0.00E+00
BA131	3.68E-02	9.53E-03	2.81E-04	1.43E-06	2.69E-11	0.00E+00	0.00E+00
BA133	7.43E-04	7.40E-04	7.32E-04	7.20E-04	697E-04	5.38E-04	3.90E-04
BA133M	3.65E-05	1.95E-09	1.39E-20	2.26E-37	0.00E+00	0.00E+00	0.00E+00
BA135M	2.77E-04	4.49E-10	3.51E-25	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA140	3.92E-04	1.86E-07	6.07E-09	4.62E-11	2.02E-15	0.00E+00	0.00E+00
LU177	2.13E-03	1.99E-04	1.57E-06	7.79E-07	3.40E-07	4.95E-10	1.40E-13
HF175	3.25E-02	2.59E-02	1.43E-02	5.86E-03	9.37E-04	4.88E-10	6.84E-18
HF181	8.82E-01	6.06E-01	2.27E-01	5.22E-02	2.52E-03	1.07E-13	1.15E-26
TA182	1.07E+01	9.33E+00	6.50E+00	3.78E+00	1.24E+00	1.85E-04	3.84E-09
TA183	2.54E+01	1.12E+00	3.21E-04	1.56E-09	1.82E-20	0.00E+00	0.00E+00
W181	5.88E-03	5.16E-03	3.66E-03	2.19E-03	7.58E-04	1.78E-07	5.17E-12
W185	2.09E-01	1.69E-01	9.69E-02	4.22E-02	7.64E-03	1.06E-08	5.09E-16
W187	2.68E-02	2.99E-09	2.18E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00
W188	1.65E-02	1.31E-02	7.22E-03	2.94E-03	4.62E-04	2.12E-10	2.54E-18
RE186	3.18E-02	4.66E-04	7.70E-09	5.16E-16	8.85E-31	0.00E+00	0.00E+00
RE188	1.79E-02	1.33E-02	7.29E-03	2.97E-03	4.67E-04	2.15E-10	2.57E-18
OS191	4.87E-05	1.73E-05	1.16E-06	2.03E-08	4.86E-12	0.00E+00	0.00E+00
TOTAL	1.34E+04	1.28E+04	1.21E+04	1.17E+04	1.12E+04	8.86E+03	6.66E+03

Table 4. Decay Heat in a TPBAR (Watts/TPBAR)

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
H-3[2]	3.90E-01	3.89E-01	3.85E-01	3.80E-01	3.69E-01	2.95E-01	2.23E-01
P 32	1.04E-02	3.42E-03	1.87E-04	2.38E-06	3.06E-10	5.86E-12	5.83E-12
CR 51	2.07E-01	1.17E-01	2.60E-02	2.74E-03	2.66E-05	3.57E-21	5.10E-41
MN 54	2.09E-01	1.98E-01	1.73E-01	1.42E-01	9.42E-02	3.69E-03	6.42E-05
FE 55	7.28E-03	7.15E-03	6.85E-03	6.41E-03	5.60E-03	1.93E-03	5.08E-04
FE 59	1.54E-01	1.08E-01	4.28E-02	1.07E-02	6.16E-04	1.04E-13	6.30E-26
CO 58	1.61E+00	1.29E+00	7.14E-01	2.96E-01	4.82E-02	2.94E-08	5.03E-16
CO 60	5.55E-01	5.50E-01	5.39E-01	5.21E-01	4.88E-01	2.88E-01	1.49E-01
NI 63	2.30E-03	2.30E-03	2.30E-03	2.30E-03	2.29E-03	2.22E-03	2.14E-03
AS 76	7.74E-03	3.76E-09	1.28E-25	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ZR 95	3.33E-01	2.60E-01	1.36E-01	5.11E-02	6.87E-03	9.18E-10	2.35E-18
NB 95	3.32E-01	3.12E-01	2.13E-01	9.53E-02	1.41E-02	1.93E-09	4.93E-18

2 The ORIGEN2 values for H-3 are not reported. The values given for H-3 are based on a maximum of 1.2 g of tritium per TPBAR at discharge, as specified in the Functional Requirements document (Lopez 2003). There is 0.325 W per gram of tritium, and the half-life of tritium is 12.33 years. The value of 1.2 g at discharge is decayed appropriately for the various decay times.

MO 99	5.40E-02	1.64E-04	4.44E-11	6.24E-21	0.00E+00	0.00E+00	0.00E+00
SN117M	1.52E-02	4.88E-03	2.50E-04	2.91E-06	3.03E-10	0.00E+00	0.00E+00
SN119M	4.35E-03	4.08E-03	3.44E-03	2.67E-03	1.58E-03	2.53E-05	1.45E-07
SN125	1.46E-02	2.79E-03	3.73E-05	5.77E-08	9.47E-14	0.00E+00	0.00E+00
SB125	5.23E-03	5.20E-03	5.00E-03	4.70E-03	4.14E-03	1.52E-03	4.35E-04
TA182	9.55E-02	8.31E-02	5.79E-02	3.36E-02	1.10E-02	1.65E-06	3.42E-11
TA183	1.61E-01	7.08E-03	2.03E-06	9.91E-12	1.15E-22	0.00E+00	0.00E+00
Total	4.19E+00	3.35E+00	2.31E+00	1.55E+00	1.05E+00	5.92E-01	3.75E-01

Table 5. Source Term in a TPBAR (Photons/s/TPBAR)

Energy (MeV)	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
1.00E-02	7.73E+12	5.07E+12	2.33E+12	1.14E+12	6.01E+11	3.17E+11	2.28E+11
2.50E-02	6.71E+11	4.15E+11	2.59E+11	1.76E+11	1.03E+11	1.95E+10	7.02E+09
3.75E-02	1.80E+11	1.08E+11	6.65E+10	3.72E+10	1.85E+10	6.83E+09	2.84E+09
5.75E-02	5.80E+11	4.44E+11	2.90E+11	1.60E+11	5.27E+10	4.20E+09	2.15E+09
8.50E-02	1.52E+11	9.81E+10	5.86E+10	2.93E+10	9.11E+09	1.66E+09	8.49E+08
1.25E-01	2.24E+11	1.41E+11	8.80E+10	4.66E+10	1.45E+10	7.08E+08	3.45E+08
2.25E-01	4.52E+11	2.38E+11	1.20E+11	6.46E+10	2.15E+10	1.30E+09	4.20E+08
3.75E-01	3.06E+12	1.73E+12	4.10E+11	6.55E+10	1.94E+10	6.57E+09	1.90E+09
5.75E-01	2.75E+12	2.17E+12	1.21E+12	5.16E+11	1.02E+11	8.36E+09	2.39E+09
8.50E-01	1.56E+13	1.29E+13	7.83E+12	3.77E+12	1.11E+12	2.70E+10	5.28E+08
1.25E+00	3.05E+12	2.96E+12	2.81E+12	2.63E+12	2.38E+12	1.38E+12	7.16E+11
1.75E+00	5.01E+10	3.96E+10	2.20E+10	9.10E+09	1.48E+09	9.09E+02	5.52E+00
2.25E+00	2.12E+09	3.75E+08	3.27E+07	1.84E+07	1.30E+07	7.33E+06	3.80E+06
2.75E+00	7.48E+08	6.48E+04	5.30E+04	4.48E+04	3.88E+04	2.27E+04	1.18E+04
3.50E+00	5.05E+05	1.88E+00	6.13E-02	4.70E-04	3.16E-06	2.87E-06	2.58E-06
5.00E+00	5.21E+03	5.25E-08	6.64E-09	4.23E-09	1.67E-09	1.11E-12	1.93E-15
7.00E+00	6.37E-10	5.81E-10	4.31E-10	2.75E-10	1.09E-10	7.23E-14	1.25E-16
9.50E+00	4.03E-11	3.68E-11	2.72E-11	1.74E-11	6.87E-12	4.57E-15	7.93E-18
TOTAL	3.45E+13	2.63E+13	1.55E+13	8.65E+12	4.44E+12	1.78E+12	9.63E+11

Table 6. Radionuclide Concentrations in a Hold-Down Assembly, no thimble plugs (Ci/HDA) (scaling factor of 0.1 applied)

Isotope	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
H 3	8.61E-07	8.58E-07	8.50E-07	8.39E-07	8.15E-07	6.51E-07	4.92E-07
C 14	3.10E-08	3.10E-08	3.10E-08	3.10E-08	3.10E-08	3.10E-08	3.10E-08
NA 24	1.11E-05	9.27E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P 32	6.41E-01	2.10E-01	1.15E-02	1.46E-04	1.87E-08	2.15E-10	2.14E-10
P 33	2.92E-05	1.54E-05	2.92E-06	2.41E-07	1.42E-09	3.63E-27	0.00E+00
S 35	1.88E-02	1.57E-02	9.77E-03	4.81E-03	1.12E-03	1.12E-08	6.36E-15
CA 45	4.18E-04	3.79E-04	2.94E-04	2.00E-04	9.11E-05	1.83E-07	7.73E-11
CA 47	1.94E-06	5.77E-08	6.01E-12	6.40E-18	3.25E-30	0.00E+00	0.00E+00
SC 46	5.68E-02	4.69E-02	2.86E-02	1.36E-02	2.93E-03	1.65E-08	4.55E-15
SC 47	2.39E-02	2.05E-04	8.57E-10	3.13E-17	1.24E-29	0.00E+00	0.00E+00
SC 48	6.64E-04	1.07E-07	1.36E-17	1.95E-32	0.00E+00	0.00E+00	0.00E+00
CR 51	5.23E+02	2.94E+02	6.56E+01	6.90E+00	6.71E-02	8.99E-18	1.30E-37

Isotope	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
MN 54	1.96E+01	1.87E+01	1.63E+01	1.34E+01	8.87E+00	3.47E-01	6.04E-03
FE 55	9.65E+01	9.49E+01	9.08E+01	8.50E+01	7.43E+01	2.56E+01	6.74E+00
FE 59	9.09E+00	6.38E+00	2.53E+00	6.33E-01	3.65E-02	6.15E-12	3.73E-24
CO 58	4.10E+01	3.27E+01	1.82E+01	7.53E+00	1.23E+00	7.49E-07	1.28E-14
CO 60	5.41E+01	5.37E+01	5.25E+01	5.09E+01	4.76E+01	2.81E+01	1.46E+01
NI 59	2.56E-02	2.56E-02	2.56E-02	2.56E-02	2.56E-02	2.56E-02	2.56E-02
NI 63	3.48E+00	3.48E+00	3.48E+00	3.47E+00	3.46E+00	3.35E+00	3.23E+00
NI 66	2.31E-05	2.10E-08	2.42E-16	3.00E-28	0.00E+00	0.00E+00	0.00E+00
CU 64	9.68E-04	7.98E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CU 66	2.32E-05	2.10E-08	2.43E-16	3.01E-28	0.00E+00	0.00E+00	0.00E+00
CU 67	1.03E-06	2.11E-09	2.08E-16	6.40E-27	0.00E+00	0.00E+00	0.00E+00
ZN65	3.18E-03	2.98E-03	2.51E-03	1.95E-03	1.15E-03	1.81E-05	1.01E-07
Y 89M	3.13E-05	2.38E-07	7.10E-13	3.65E-21	0.00E+00	0.00E+00	0.00E+00
Y 90	1.44E-04	3.64E-07	4.92E-11	4.88E-11	4.82E-11	4.38E-11	3.89E-11
ZR 89	3.13E-05	2.39E-07	7.11E-13	3.65E-21	3.36E-38	0.00E+00	0.00E+00
ZR 95	4.18E-04	3.26E-04	1.70E-04	6.41E-05	8.62E-06	1.15E-12	2.95E-21
NB 92	3.04E-02	6.32E-03	1.06E-04	2.27E-07	7.38E-13	0.00E+00	0.00E+00
NB 94	7.76E-04	7.76E-04	7.76E-04	7.76E-04	7.76E-04	7.76E-04	7.76E-04
NB 95	1.38E+00	8.78E-01	2.69E-01	4.57E-02	1.20E-03	2.56E-12	6.54E-21
NB 95M	3.05E-06	2.42E-06	1.26E-06	4.76E-07	6.40E-08	8.55E-15	2.19E-23
NB 96	3.16E-05	2.42E-12	6.60E-31	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MO 93	5.92E-05	5.92E-05	5.92E-05	5.92E-05	5.91E-05	5.91E-05	5.90E-05
MO 99	9.60E-01	2.91E-03	7.87E-10	1.11E-19	0.00E+00	0.00E+00	0.00E+00
TC 99	2.48E-06	2.49E-06	2.49E-06	2.49E-06	2.49E-06	2.49E-06	2.49E-06
RU103	1.83E-04	1.22E-04	4.23E-05	8.64E-06	3.29E-07	2.09E-18	2.12E-32
TOTAL	7.50E+02	5.05E+02	2.50E+02	1.68E+02	1.36E+02	5.74E+01	2.46E+01

Table 7. Decay Heat in a Hold-Down Assembly, no thimble plugs (Watts/HDA)
(scaling factor of 0.1 applied)

Isotope	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
P 32	6.50E-03	2.13E-03	1.16E-04	1.48E-06	1.89E-10	2.18E-12	2.17E-12
CR 51	1.12E-01	6.31E-02	1.41E-02	1.48E-03	1.44E-05	1.93E-21	2.78E-41
MN 54	9.77E-02	9.28E-02	8.13E-02	6.66E-02	4.41E-02	1.73E-03	3.01E-05
FE 55	3.26E-03	3.21E-03	3.07E-03	2.87E-03	2.51E-03	8.64E-04	2.28E-04
FE 59	7.04E-02	4.94E-02	1.96E-02	4.90E-03	2.83E-04	4.76E-14	2.89E-26
CO 58	2.45E-01	1.96E-01	1.09E-01	4.50E-02	7.34E-03	4.48E-09	7.65E-17
CO 60	8.35E-01	8.28E-01	8.10E-01	7.84E-01	7.34E-01	4.34E-01	2.25E-01
NI 63	3.51E-04	3.51E-04	3.50E-04	3.50E-04	3.48E-04	3.38E-04	3.25E-04
NB 95	6.63E-03	4.21E-03	1.29E-03	2.19E-04	5.76E-06	1.23E-14	3.14E-23
MO 99	3.08E-03	9.35E-06	2.53E-12	3.56E-22	0.00E+00	0.00E+00	0.00E+00
TOTAL	1.38E+00	1.24E+00	1.04E+00	9.06E-01	7.88E-01	4.36E-01	2.25E-01

Table 8. Source Term for Hold-Down Assembly, no thimble plugs (Photons/s/HDA) (scaling factor of 0.1 applied)

Energy (MeV)	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
1.00E-02	2.76E+12	1.71E+12	6.17E+11	2.62E+11	1.50E+11	5.76E+10	2.93E+10
2.50E-02	4.42E+10	3.60E+10	2.69E+10	2.08E+10	1.67E+10	9.57E+09	4.98E+09
3.75E-02	2.73E+10	2.18E+10	1.60E+10	1.21E+10	9.57E+09	5.45E+09	2.83E+09
5.75E-02	3.48E+10	2.77E+10	1.97E+10	1.44E+10	1.09E+10	6.14E+09	3.18E+09
8.50E-02	1.80E+10	1.39E+10	9.34E+09	6.30E+09	4.39E+09	2.41E+09	1.25E+09
1.25E-01	1.21E+10	7.62E+09	4.79E+09	2.91E+09	1.77E+09	9.27E+08	4.80E+08
2.25E-01	1.31E+10	7.87E+09	4.41E+09	2.12E+09	7.69E+08	3.05E+08	1.58E+08
3.75E-01	1.62E+12	9.13E+11	2.04E+11	2.21E+10	4.49E+08	8.55E+07	4.43E+07
5.75E-01	4.05E+11	3.23E+11	1.80E+11	7.44E+10	1.21E+10	4.93E+06	2.54E+06
8.50E-01	2.21E+12	1.86E+12	1.25E+12	7.54E+11	3.66E+11	1.27E+10	3.13E+08
1.25E+00	4.01E+12	3.97E+12	3.89E+12	3.76E+12	3.52E+12	2.08E+12	1.08E+12
1.75E+00	7.50E+09	5.99E+09	3.33E+09	1.38E+09	2.25E+08	1.37E+02	2.00E-04
2.25E+00	2.12E+07	2.11E+07	2.06E+07	1.99E+07	1.87E+07	1.10E+07	5.71E+06
2.75E+00	4.76E+05	6.51E+04	6.37E+04	6.17E+04	5.77E+04	3.41E+04	1.77E+04
3.50E+00	2.81E+02	4.06E-09	1.53E-09	1.29E-09	9.14E-10	6.44E-11	7.67E-12
5.00E+00	2.92E+00	2.44E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TOTAL	1.12E+13	8.91E+12	6.22E+12	4.94E+12	4.09E+12	2.18E+12	1.12E+12

Table 9. Radionuclide Concentrations for Single Thimble Plug (Ci/thimble plug) (scaling factor of 0.2 and mass of 150g applied)

Isotope	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
H 3	9.18E-08	9.15E-08	9.07E-08	8.94E-08	8.69E-08	6.94E-08	5.24E-08
C 14	3.31E-09	3.31E-09	3.31E-09	3.31E-09	3.31E-09	3.31E-09	3.31E-09
P 32	7.69E-02	2.52E-02	1.38E-03	1.75E-05	2.23E-09	2.53E-11	2.51E-11
P 33	3.41E-06	1.80E-06	3.41E-07	2.81E-08	1.65E-10	4.23E-28	0.00E+00
S 35	2.19E-03	1.83E-03	1.14E-03	5.60E-04	1.30E-04	1.31E-09	7.41E-16
SC 47	3.40E-07	2.93E-09	1.34E-14	1.73E-21	8.28E-34	0.00E+00	0.00E+00
SC 48	1.11E-07	1.78E-11	2.26E-21	3.01E-36	0.00E+00	0.00E+00	0.00E+00
CR 51	5.69E+01	3.20E+01	7.13E+00	7.50E-01	7.29E-03	9.77E-19	0.00E+00
MN 54	2.35E+00	2.24E+00	1.96E+00	1.60E+00	1.06E+00	4.16E-02	7.25E-04
FE 55	1.15E+01	1.13E+01	1.08E+01	1.01E+01	8.82E+00	3.04E+00	8.01E-01
FE 59	1.09E+00	7.61E-01	3.02E-01	7.55E-02	4.36E-03	7.34E-13	4.46E-25
CO 58	2.65E+00	2.12E+00	1.18E+00	4.87E-01	7.94E-02	4.85E-08	8.28E-16
CO 60	1.69E+00	1.68E+00	1.64E+00	1.59E+00	1.49E+00	8.79E-01	4.55E-01
NI 59	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03
NI 63	2.25E-01	2.25E-01	2.25E-01	2.24E-01	2.24E-01	2.17E-01	2.09E-01
NI 66	1.49E-06	1.35E-09	1.56E-17	1.94E-29	0.00E+00	0.00E+00	0.00E+00

Isotope	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
CU 64	1.45E-07	1.20E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CU 66	1.50E-06	1.36E-09	1.57E-17	1.94E-29	0.00E+00	0.00E+00	0.00E+00
ZN 65	1.01E-07	9.44E-08	7.96E-08	6.16E-08	3.64E-08	5.72E-10	3.19E-12
Y 89M	3.83E-06	2.92E-08	8.69E-14	4.47E-22	0.00E+00	0.00E+00	0.00E+00
Y 90	9.39E-07	2.38E-09	1.21E-12	1.21E-12	1.19E-12	1.08E-12	9.61E-13
ZR 89	3.84E-06	2.92E-08	8.70E-14	4.47E-22	0.00E+00	0.00E+00	0.00E+00
ZR 95	5.12E-05	3.99E-05	2.08E-05	7.85E-06	1.06E-06	1.41E-13	3.61E-22
NB 92	2.16E-03	4.49E-04	7.49E-06	1.62E-08	5.25E-14	0.00E+00	0.00E+00
NB 94	5.04E-06	5.04E-06	5.04E-06	5.04E-06	5.04E-06	5.04E-06	5.04E-06
NB 95	9.08E-03	5.78E-03	1.79E-03	3.13E-04	1.00E-05	3.13E-13	8.01E-22
NB 95M	3.74E-07	2.96E-07	1.55E-07	5.83E-08	7.83E-09	1.05E-15	2.68E-24
NB 96	1.02E-06	7.79E-14	2.12E-32	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MO 93	7.25E-06	7.25E-06	7.25E-06	7.25E-06	7.24E-06	7.24E-06	7.23E-06
MO 99	1.18E-01	3.57E-04	9.65E-11	1.36E-20	0.00E+00	0.00E+00	0.00E+00
TC 99	3.04E-07	3.05E-07	3.05E-07	3.05E-07	3.05E-07	3.05E-07	3.05E-07
RU103	2.24E-05	1.49E-05	5.18E-06	1.06E-06	4.03E-08	2.57E-19	2.60E-33
TOTAL	7.65E+01	5.03E+01	2.32E+01	1.48E+01	1.17E+01	4.18E+00	1.47E+00

Table 10. Decay Heat in a Single Thimble Plug (Watts/thimble plug)
(scaling factor of 0.2 and mass of 150g applied)

Isotope	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
P 32	7.79E-04	2.56E-04	1.39E-05	1.78E-07	2.26E-11	2.56E-13	2.55E-13
CR 51	1.22E-02	6.86E-03	1.53E-03	1.61E-04	1.56E-06	2.10E-22	0.00E+00
MN 54	1.17E-02	1.11E-02	9.75E-03	7.99E-03	5.30E-03	2.07E-04	3.61E-06
FE 55	3.87E-04	3.81E-04	3.65E-04	3.41E-04	2.98E-04	1.03E-04	2.71E-05
FE 59	8.40E-03	5.90E-03	2.34E-03	5.85E-04	3.37E-05	5.68E-15	3.45E-27
CO 58	1.59E-02	1.27E-02	7.04E-03	2.91E-03	4.75E-04	2.90E-10	4.95E-18
CO 60	2.61E-02	2.59E-02	2.53E-02	2.45E-02	2.29E-02	1.36E-02	7.02E-03
NI 63	2.27E-05	2.27E-05	2.27E-05	2.26E-05	2.25E-05	2.19E-05	2.11E-05
MO 99	3.77E-04	1.15E-06	3.10E-13	4.36E-23	0.00E+00	0.00E+00	0.00E+00
TOTAL	7.59E-02	6.31E-02	4.64E-02	3.65E-02	2.91E-02	1.39E-02	7.07E-03

Table 11. Source Term for a Single Thimble Plug (Photons/s/thimble plug)
(scaling factor of 0.5 and mass of 150g applied)

Energy (Mev)	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
1.00E-02	6.95E+11	4.18E+11	1.34E+11	4.68E+10	2.27E+10	4.95E+09	2.35E+09
2.50E-02	6.68E+09	4.76E+09	3.01E+09	1.96E+09	1.36E+09	7.52E+08	3.92E+08
3.75E-02	4.25E+09	2.93E+09	1.83E+09	1.16E+09	7.80E+08	4.27E+08	2.22E+08
5.75E-02	5.49E+09	3.85E+09	2.34E+09	1.42E+09	8.96E+08	4.80E+08	2.49E+08
8.50E-02	2.97E+09	2.03E+09	1.18E+09	6.66E+08	3.69E+08	1.89E+08	9.77E+07
1.25E-01	2.36E+09	1.17E+09	6.53E+08	3.36E+08	1.55E+08	7.24E+07	3.75E+07

Energy (Mev)	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
2.25E-01	2.53E+09	1.30E+09	6.81E+08	3.00E+08	8.15E+07	2.38E+07	1.23E+07
3.75E-01	4.40E+11	2.48E+11	5.54E+10	5.91E+09	8.33E+07	6.68E+06	3.46E+06
5.75E-01	6.56E+10	5.23E+10	2.90E+10	1.20E+10	1.96E+09	3.85E+05	1.99E+05
8.50E-01	4.50E+11	3.91E+11	2.82E+11	1.89E+11	1.04E+11	3.79E+09	6.98E+07
1.25E+00	3.13E+11	3.11E+11	3.04E+11	2.94E+11	2.75E+11	1.63E+11	8.42E+10
1.75E+00	1.21E+09	9.69E+08	5.38E+08	2.23E+08	3.63E+07	2.22E+01	1.32E-05
2.25E+00	1.66E+06	1.65E+06	1.61E+06	1.56E+06	1.46E+06	8.62E+05	4.46E+05
2.75E+00	5.13E+03	5.09E+03	4.98E+03	4.82E+03	4.51E+03	2.67E+03	1.38E+03
3.50E+00	1.32E-05	5.11E-10	4.56E-10	3.86E-10	2.75E-10	1.75E-11	5.16E-13
5.00E+00	1.38E-07	1.15E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TOTAL	1.99E+12	1.44E+12	8.14E+11	5.54E+11	4.07E+11	1.73E+11	8.77E+10

Table 12. Dose Rates for the TPBAR (rem/hr)[3]

	7 days	90 days	180 days	1 year	5 years
Surface, Entire Length	77, 000	42,000	25,000	14,000	6200
1m from TPBAR, Entire Length	160	86	52	29	13
1m from TPBAR, 1m In Center (average)	180	97	59	33	14

Table 13. Surface Dose Rates for the Hold-Down Assembly (rem/hr) (including 20 thimble plugs)[3]

	7 days	90 days	180 days	1 year	5 years
Top of Assembly	51,000	38,000	32,000	27,000	15,000
Bottom of Assembly	34,000	22,000	18,000	14,000	6800
Side of Assembly	28,000	19,000	16,000	13,000	6400

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RSIC Computer Code Collection. 1996. *ORIGEN2.1: Isotope Generation and Depletion Code - Matrix Exponential Method.* CCC-371, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

RSICC Computer Code Collection. 2000. *MCNP4C – Monte Carlo N-Particle Transport Code System.* CCC-700. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

RSICC Computer Code Collection. 2002. *ORIGEN2.2: Isotope Generation and Depletion Code - Matrix Exponential Method.* CCC-371, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Special Metals. 2003. http://www.magellanmetals.com/inconel_X750.htm

Walker FW, JR Parrington, and F Feiner. 1989. *Chart of the Nuclides 14th Edition.* General Electric Co., San Jose, California.

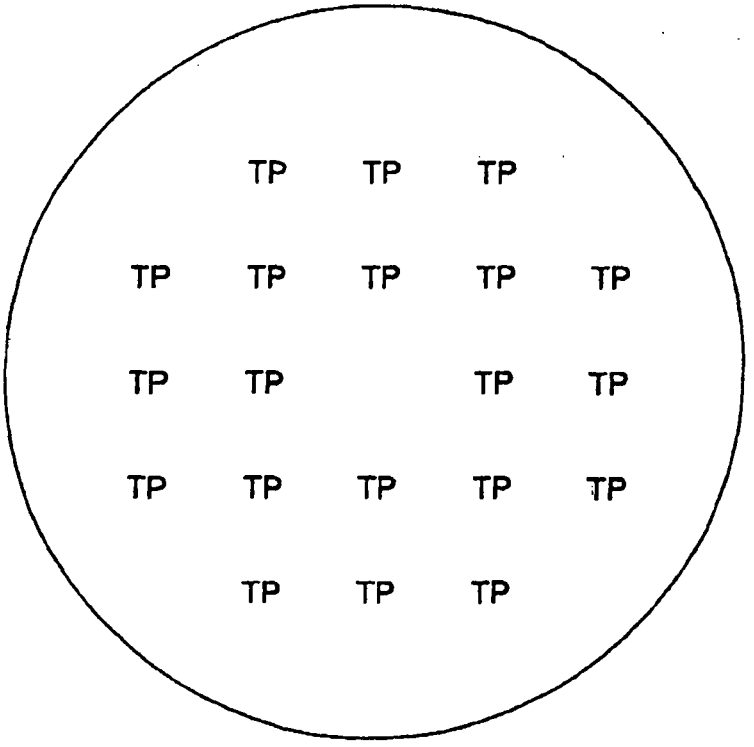

Figure 1. Assumed Hold-Down Assembly Thimble Plug (TP) Loading Pattern

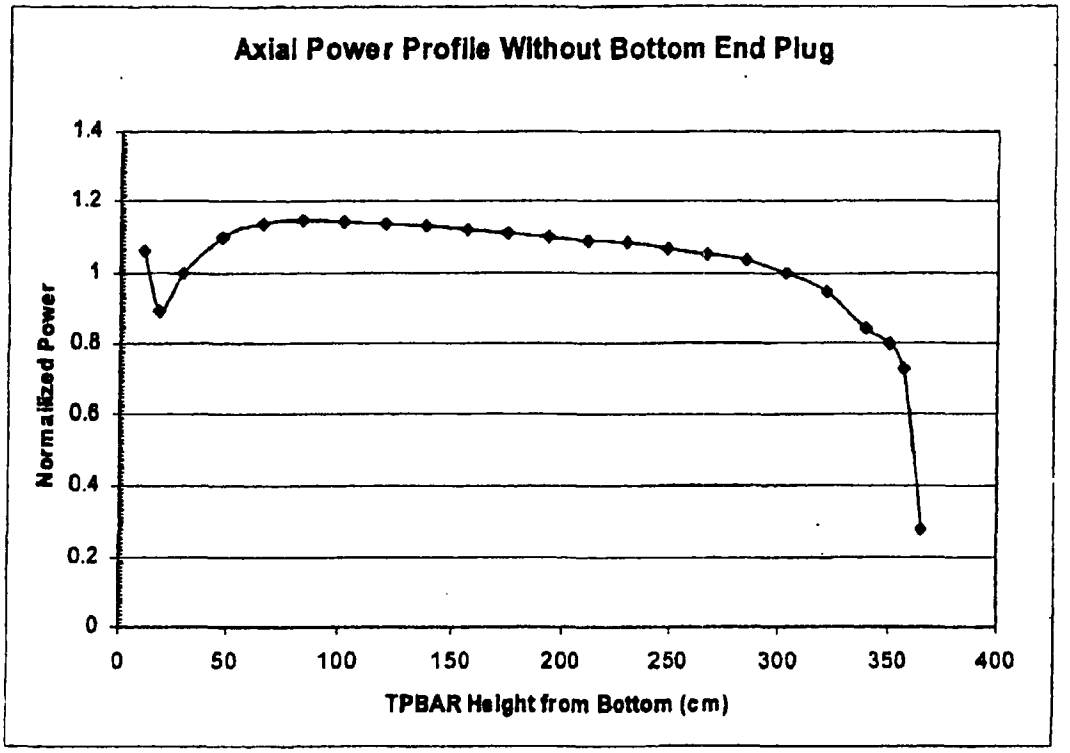

Figure 2. Axial Power Profile without Bottom End Plug

APPENDIX A

TPBAR Constituents

Masses for the elements present in a TPBAR were obtained from various sources as referenced on pages 20-22. All material in the TPBAR was accounted for including the aluminide barrier and the nickel plating on the getters. The bounding masses derived here are for radiological source assessment and not mechanical analysis or radiological shielding (self-shielding) analysis. Bounding mechanical and shielding masses are 2.3 lbs. from Lopez (2002) for the Sequoyah Units and Lopez (2003) for Watts Bar.

Compositions of the Zircaloy and SS-316 were taken from Livingston (2001).

Composition of the pellet was taken from Gates (2001).

Composition of the Inconel was taken from Special Metals (2003).

Composition of the SS-304 was taken primarily from ASTM A 213. Because this ASTM standard does not contain values for cobalt, niobium, and molybdenum, the weight percent of cobalt was assumed, while the weight percent of the molybdenum and niobium were taken from Migliore (1998b).

Table A-1. Data for Developing the TPBAR Constituents

Parameter	Value	Reference
Mass of hold-down assembly (SS304)	5.29 lb	PNNL-TTQP-1-702 R9
Mass of inconel in HDA	0.5 lb	PNNL-TTQP-1-702 R9
Mass of thimble plug (SS304)	0.3 lb	PNNL-TTQP-1-702 R9
Atomic Weight of Ni	58.69 g/mole	Chart of the Nuclides
Atomic Weight of Li-6	6.015 g/mole	Chart of the Nuclides
Atomic Weight of Li-7	7.016 g/mole	Chart of the Nuclides
Atomic Weight Al	26.9815 g/mole	Chart of the Nuclides
Atomic Weight of O	15.9994 g/mole	Chart of the Nuclides
Avogrado's No.	6.022E+23 a/mole	Chart of the Nuclides
Li Nominal Enrichment	33.7% atom%	PNNL-TTQP-1-702 R9
Assumptions		
Assumed Mass of Stainless Steel (total)	565 g	PNNL-TTQP-1-726 R3
Assumed Mass Zircaloy-4	215 g	PNNL-TTQP-1-726 R3
Assumed Mass LiA1O2	210 g	PNNL-TTQP-1-726 R3
Assumed Mass of Nickel Plating	255 g	PNNL-TTQP-1-726 R3
Cobalt Concentration	500 ppm	For SS-304
Add the pellet impurities to the given pellet mass. The resulting mass will be larger than the value given above, bringing the total to 217g.		
Fe+Cr+Ni impurity in the pellet is split equally.		
U in the Zircaloy-4 and F, Cl, I, & Br in the pellet have a negligible contribution and will not be included in the ORIGEN2 model.		
Calculated Values		
Mass of hold-down assembly (SS304)	2815 g	Bounding Value
Mass of inconel in HDA	365 g	Bounding Value
Mass of thimble plug (SS304)	150 g	Bounding Value
Atomic Weight of Enriched Li	6.679 g/mole	
Molecular Weight of LiA1O2	65.66 g/mole	
Mass of Li-6	6.48 g	
Mass of Li-7	14.88 g	
Mass of Al	86.30 g	
Mass of O	102.34 g	

Table A-2. Material Impurities, wt%

Element	Zircaloy-4	316-SS	Pellet	304-SS	Inconel X
	TTQP-7-008 R3	TTQP-7-008 R3	TTQP-1-076 R4	ASTM A 213	Special Metals
Fe	0.24	Remainder		Remainder	9.0
Cr	0.13	18.0		20	17.0
Ni	0.0070	14.0		11	Remainder
Zr	Remainder				
Fe+Cr+Ni			0.6		
F+Cl+I+Br			0.06		
Al	0.0075	0.05			1.0
As		0.03	0.05		
B	0.00005	0.002			
Ba			0.08		
C	0.027	0.06	0.15	0.08	0.08
Ca			0.4		
Cd	0.00005				
Co	0.0020	0.050		0.05[4]	1.0
Cu	0.0050	0.04			0.5
H	0.0025				
Hf	0.010				
K			0.5		
Mg	0.0020		0.2		
Mn	0.0050	2.00		2	1.0
Mo	0.0050	3.00		0.3965	
N	0.0080	0.01			
Na			0.5		
Nb		0.05		0.01[5]	1.2
P		0.04		0.04	
Pb			0.04		
S		0.01		0.03	0.01
Se			0.035		
Si	0.0120	0.75	1.0	0.75	0.5
Sn	1.70				
Ta		0.02			
Ti	0.0050				2.75
V		0.05			
W	0.010				
Zr					
U	0.00035				
Total	2.18	38.16	3.62	34.36	34.04
Calculated Numbers, wt%					
Fe		61.84		65.64	
Zr	97.82				
Ni					65.96

4 Assumed.
5 From Migliore 1998b

Table A-3. Nuclide Mass Values, g

							pounds	g
					SS in holddown		5.401	2450
ORIGEN2 Mass Input					Inconel in holddown		0.805	365
Mass(g) =		215.0	565.0	210.0		1.0	1.0	
Nuclide	ORIGEN2 ID	Zircaloy-4	316-SS	Pellet	TPBAR (with Ni)	304-SS	Inconel X	HDA
Li-6	30060			6.48E+00	6.48E+00			
Li-7	30070			1.49E+01	1.49E+01			
Fe	260000	5.16E-01	3.49E+02	4.20E-01	3.50E+02	6.56E-01	9.00E-02	1.64E+03
Cr	240000	2.80E-01	1.02E+02	4.20E-01	1.02E+02	2.00E-01	1.70E-01	5.52E+02
Ni[6]	280000	1.51E-02	7.91E+01	4.20E-01	3.35E+02	1.10E-01	6.60E-01	5.10E+02
O	80000			1.02E+02	1.02E+02			
Al	130000	1.61E-02	2.83E-01	8.63E+01	8.66E+01		1.00E-02	3.65E+00
As	330000		1.70E-01	1.05E-01	2.75E-01			
B	50000	1.08E-04	1.13E-02		1.14E-02			
Ba	560000			1.68E-01	1.68E-01			
C	60000	5.81E-02	3.39E-01	3.15E-01	7.12E-01	8.00E-04	8.00E-04	2.25E+00
Ca	200000			8.40E-01	8.40E-01			
Cd	480000	1.08E-04			1.08E-04			
Co	270000	4.30E-03	2.83E-01		2.87E-01	5.00E-04	1.00E-02	4.88E+00
Cu	290000	1.08E-02	2.26E-01		2.37E-01		5.00E-03	1.83E+00
H	10000	5.38E-03			5.38E-03			
Hf	720000	2.15E-02			2.15E-02			
K	190000			1.05E+00	1.05E+00			
Mg	120000	4.30E-03		4.20E-01	4.24E-01			
Mn	250000	1.08E-02	1.13E+01		1.13E+01	2.00E-02	1.00E-02	5.27E+01
Mo	420000	1.08E-02	1.70E+01		1.70E+01	3.96E-03		9.70E+00
N	70000	1.72E-02	5.65E-02		7.37E-02			
Na	110000			1.05E+00	1.05E+00			
Nb	410000		2.83E-01		2.83E-01	1.00E-04	1.20E-02	4.63E+00
P	150000		2.26E-01		2.26E-01	4.00E-04		9.80E-01
Pb	820000			8.40E-02	8.40E-02			
S	160000		5.65E-02		5.65E-02	3.00E-04	1.00E-04	7.72E-01
Se	340000			7.35E-02	7.35E-02			
Si	140000	2.58E-02	4.24E+00	2.10E+00	6.36E+00	7.50E-03	5.00E-03	2.02E+01
Sn	500000	3.66E+00			3.66E+00			
Ta	730000		1.13E-01		1.13E-01			
Ti	220000	1.08E-02			1.08E-02		2.75E-02	1.00E+01
V	230000		2.83E-01		2.83E-01			
W	740000	2.15E-02			2.15E-02			
Zr	400000	2.10E+02			2.10E+02			
U	920000	7.53E-04			7.53E-04			
Total		2.15E+02	5.65E+02	2.17E+02	1.25E+03	1.00E+00	1.00E+00	2.82E+03

6 The total value for nickel in column 6 includes the assumed 255g of nickel plating.

APPENDIX B

ORIGEN2 Input and Output

The ORIGEN2 input files are listed on the following pages. They are:

- TPBAR.INP- One TPBAR
- HDA.INP- One hold-down assembly (no thimble plugs)
- SS304.INP-One gram of SS304 (thimble plug)

The PWRU library was used for the calculations because its enrichment (3.1%) most closely matches the assumed assembly enrichment (3.0%).

ORIGEN2 was executed on a Dell OptiPlex Gx1 Pentium-II with Windows 98, which has been approved for Commercial Nuclear Related calculations.

TPBAR.INP

```
-1
-1
-1
TIT     Prod.  Reactor Target Rod Waste Eval.:  TPBAR
RDA     PD = 58.24 MW/MTU   E = 3.0
BAS     1 TPBAR
LIB     0 1 2 3 204 205 206 9 3 0 1 1
PHO     101 102 103 10
LIP     0 0 0
INP     1 1 -1 -1 1 1
BUP
IRP      50.  58.24     1  2  4  2
IRP     100.  58.24     2  3  4  0
IRP     150.  58.24     3  4  4  0
IRP     200.  58.24     4  5  4  0
IRP     250.  58.24     5  6  4  0
IRP     300.  58.24     6  7  4  0
IRP     350.  58.24     7  8  4  0
IRP     400.  58.24     8  9  4  0
IRP     450.  58.24     9 10  4  0
IRP     500.  58.24    10 11  4  0
IRP     510.  58.24    11  1  4  0
BUP
DEC       7.             1  2  4  2
DEC      30.             2  3  4  0
DEC      90.             3  4  4  0
DEC     180.             4  5  4  0
DEC       1.             5  6  5  0
DEC       5.             6  7  5  0
DEC      10.             7  8  5  0
HED     1   Discharge
HED     2     7 Days
HED     3    30 Days
HED     4    90 Days
HED     5   180 Days
HED     6     1 Year
HED     7     5 Years
HED     8    10 Years
OPTL    8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTA    8 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTF    8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
CUT     7 1.0E-9 -1
OUT     8  1  0  -1
STP     4
1        30060 6.48E+00     30070 1.49E+01         0       0.0
2       922350  30000.0    922380 970000.0         0       0.0
4       260000 3.50E+02    240000 1.02E+02    280000 3.35E+02     80000 1.02E+02
4       130000 8.66E+01    330000 2.75E-01     50000 1.14E-02    560000 1.68E-01
4        60000 7.12E-01    200000 8.40E-01    480000 1.08E-04    270000 2.87E-01
4       290000 2.37E-01     10000 5.38E-03    720000 2.15E-02    190000 1.05E+00
4       120000 4.24E-01    250000 1.13E+01    420000 1.70E+01     70000 7.37E-02
4       110000 1.05E+00    410000 2.83E-01    150000 2.26E-01    820000 8.40E-02
4       160000 5.65E-02    340000 7.35E-02    140000 6.36E+00    500000 3.66E+00
```

```
4       730000 1.13E-01   220000 1.08E-02   230000 2.83E-01   740000 2.15E-02
4       400000 2.10E+02        0      0.0
0
END
```

HDA.INP

```
-1
-1
-1
TIT     Prod.  Reactor Target Rod Waste Eval.:  HDA
RDA     PD = 58.24 MW/MTU   E = 3.0
BAS     1 hold-down assembly, no thimble plugs
LIB     0 1 2 3 204 205 206 9 3 0 1 1
PHO     101 102 103 10
LIP     0 0 0
INP     1 1 -1 -1 1 1
BUP
IRP      50.  58.24    1  2  4  2
IRP     100.  58.24    2  3  4  0
IRP     150.  58.24    3  4  4  0
IRP     200.  58.24    4  5  4  0
IRP     250.  58.24    5  6  4  0
IRP     300.  58.24    6  7  4  0
IRP     350.  58.24    7  8  4  0
IRP     400.  58.24    8  9  4  0
IRP     450.  58.24    9 10  4  0
IRP     500.  58.24   10 11  4  0
IRP     510.  58.24   11  1  4  0
BUP
DEC       7.            1  2  4  2
DEC      30.            2  3  4  0
DEC      90.            3  4  4  0
DEC     180.            4  5  4  0
DEC       1.            5  6  5  0
DEC       5.            6  7  5  0
DEC      10.            7  8  5  0
HED     1   Discharge
HED     2    7 Days
HED     3   30 Days
HED     4   90 Days
HED     5  180 Days
HED     6    1 Year
HED     7    5 Years
HED     8   10 Years
OPTL    8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTA    8 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTF    8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
CUT     7 1.0E-9 -1
OUT     8  1  0  -1
STP     4
1        30060 0.00E+00    30070 0.00E+00        0      0.0
2       922350  30000.0   922380 970000.0        0      0.0
4       260000 1.64E+03   240000 5.52E+02   280000 5.10E+02    80000 0.00E+00
```

```
4        130000 3.65E+00   330000 0.00E+00    50000 0.00E+00   560000 0.00E+00
4         60000 2.25E+00   200000 0.00E+00   480000 0.00E+00   270000 4.88E+00
4        290000 1.83E+00    10000 0.00E+00   720000 0.00E+00   190000 0.00E+00
4        120000 0.00E+00   250000 5.27E+01   420000 9.70E+00    70000 0.00E+00
4        110000 0.00E+00   410000 4.63E+00   150000 9.80E-01   820000 0.00E+00
4        160000 7.72E-01   340000 0.00E+00   140000 2.02E+01   500000 0.00E+00
4        730000 0.00E+00   220000 1.00E+01   230000 0.00E+00   740000 0.00E+00
4        400000 0.00E+00        0       0.0
0
END
```

SS304.INP

```
-1
-1
-1
TIT     Prod.  Reactor Target Rod Waste Eval.:  ss304
RDA     PD = 58.24 MW/MTU   E = 3.0
BAS     1g of ss304
LIB     0 1 2 3 204 205 206 9 3 0 1 1
PHO     101 102 103 10
LIP     0 0 0
INP     1 1 -1 -1 1 1
BUP
IRP      50.   58.24     1  2  4  2
IRP     100.   58.24     2  3  4  0
IRP     150.   58.24     3  4  4  0
IRP     200.   58.24     4  5  4  0
IRP     250.   58.24     5  6  4  0
IRP     300.   58.24     6  7  4  0
IRP     350.   58.24     7  8  4  0
IRP     400.   58.24     8  9  4  0
IRP     450.   58.24     9 10  4  0
IRP     500.   58.24    10 11  4  0
IRP     510    58.24    11  1  4  0
BUP
DEC       7.             1  2  4  2
DEC      30.             2  3  4  0
DEC      90.             3  4  4  0
DEC     180.             4  5  4  0
DEC       1.             5  6  5  0
DEC       5.             6  7  5  0
DEC      10.             7  8  5  0
HED     1   Discharge
HED     2     7 Days
HED     3    30 Days
HED     4    90 Days
HED     5   180 Days
HED     6     1 Year
HED     7     5 Years
HED     8    10 Years
OPTL    8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTA    8 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
```

```
OPTF     8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
CUT      7 1.0E-9 -1
OUT      8  1  0  -1
STP      4
1         30060 0.00E+00    30070 0.00E+00        0       0.0
2        922350  30000.0   922380 970000.0        0       0.0
4        260000 6.56E-01   240000 2.00E-01   280000 1.10E-01    80000 0.00E+00
4        130000 0.00E+00   330000 0.00E+00    50000 0.00E+00   560000 0.00E+00
4         60000 8.00E-04   200000 0.00E+00   480000 0.00E+00   270000 5.00E-04
4        290000 0.00E+00    10000 0.00E+00   720000 0.00E+00   190000 0.00E+00
4        120000 0.00E+00   250000 2.00E-02   420000 3.96E-03    70000 0.00E+00
4        110000 0.00E+00   410000 1.00E-04   150000 4.00E-04   820000 0.00E+00
4        160000 3.00E-04   340000 0.00E+00   140000 7.50E-03   500000 0.00E+00
4        730000 0.00E+00   220000 0.00E+00   230000 0.00E+00   740000 0.00E+00
4        400000 0.00E+00      0.0         0
0
END
```

APPENDIX C

MCNP Input

The MCNP input files are:

TPBAR7.I	TPBAR dose rates, 7 day decay time
TPBAR90.I	TPBAR dose rates, 90 day decay time
TPBAR180.I	TPBAR dose rates, 180 day decay time
TPBAR1.I	TPBAR dose rates, 1 year decay time
TPBAR5.I	TPBAR dose rates, 5 year decay time
HDA7.I	HDA dose rates, 7 day decay time
HDA90.I	HDA dose rates, 90 day decay time
HDA180.I	HDA dose rates, 180 day decay time
HDA1.I	HDA dose rates, 1 year decay time
HAD5.I	HDA dose rates, 5 year decay time

Because many of these input files are similar, only the files TPBAR7.I and HDA7.I are presented.

TPBAR7.I

```
Dose rate, TPBAR, 7 day decay time
999    0        -14:13:12          imp:p=0
10     0         14 -13 -11        imp:p=1
11     1 -8.0    14 -13  11 -10    imp:p=1
12     0         14 -13  10 -12    imp:p=1

10     cz   0.4839    $ cladding OR
11     cz   0.3848    $ cladding IR
12     cz   100.4839 $ 1m tally surface
13     pz   193       $ top of TPBAR
14     pz  -193       $ bottom of TPBAR
20     pz   50        $ tally cutting surface
21     pz  -50        $ tally cutting surface

print    -85
c
c      tallies
c
fc12     Contact dose rate, entire length
f12:p    10
fs12     13 -14
sd12     1174 2r
c
fc22     Contact dose rate, middle 1m
f22:p    10
fs22     20 -21
sd22     304 2r
c
fc32     1m from side, entire length
f32:p    12
fs32     13 -14
sd32     2.437e5 2r
c
fc42     1m from side, middle 1m
f42:p    12
fs42     20 -21
sd42     63136  2r
c
mode    p
prdmp    j j 1 2
nps     1000000
sdef      cel=11 erg=d1 pos=0 0 0 rad=d2
          ext=d3 axs=0 0 1 wgt=3.45e13
si2       0.3848 0.4839
si3       193
c
m1      26000 1
c
c      Photon source
c
c         E, MeV    photons/s
#            si1    sp1
             1        d
```

```
                0.01     7.73E+12
               0.025     6.71E+11
              0.0375     1.80E+11
              0.0575     5.80E+11
               0.085     1.52E+11
               0.125     2.24E+11
               0.225     4.52E+11
               0.375     3.06E+12
               0.575     2.75E+12
                0.85     1.56E+13
                1.25     3.05E+12
                1.75     5.01E+10
                2.25     2.12E+09
                2.75     7.48E+08
                 3.5     5.05E+05
                 5.0     5.21E+03
                 7.0     6.37E-10
                 9.5     4.03E-11
c       TOTAL    3.45E+13
c
c       Flux to Dose conversion from MCNP Manual
c       ANSI/ANS-6.1.1-1977
c
c       E, MeV      (rem/hr)/(photons/cm2/s)
#         de0          df0
          0.01        3.96e-6
          0.03        5.82e-7
          0.05        2.90e-7
          0.07        2.58e-7
          0.1         2.83e-7
          0.15        3.79e-7
          0.2         5.01e-7
          0.25        6.31e-7
          0.3         7.59e-7
          0.35        8.78e-7
          0.4         9.85e-7
          0.45        1.08e-6
          0.5         1.17e-6
          0.55        1.27e-6
          0.6         1.36e-6
          0.65        1.44e-6
          0.7         1.52e-6
          0.8         1.68e-6
          1.0         1.98e-6
          1.4         2.51e-6
          1.8         2.99e-6
          2.2         3.42e-6
          2.6         3.82e-6
          2.8         4.01e-6
          3.25        4.41e-6
          3.75        4.83e-6
          4.25        5.23e-6
          4.75        5.60e-6
          5.0         5.80e-6
          5.25        6.01e-6
```

```
          5.75        6.37e-6
          6.25        6.74e-6
          6.75        7.11e-6
          7.5         7.66e-6
          9.0         8.77e-6
          11.0        1.03e-5
          13.0        1.18e-5
          15.0        1.33e-5
```

HDA7.I

```
Dose rate, entire hold-down assembly, 7 day decay time
999    0          -40:42:35     imp:p=0
10     1 -8.0     41 -42 -35    imp:p=1  $ plate
20     1 -8.0    -41  40 -10    imp:p=1  $ thimble plug
22     1 -8.0    -41  40 -11    imp:p=1  $ thimble plug
24     1 -8.0    -41  40 -12    imp:p=1  $ thimble plug
26     0          40 -41 -13    imp:p=1  $ void
27     0          40 -41 -14    imp:p=1  $ void
28     1 -8.0    -41  40 -15    imp:p=1  $ thimble plug
30     1 -8.0    -41  40 -16    imp:p=1  $ thimble plug
32     1 -8.0    -41  40 -17    imp:p=1  $ thimble plug
34     1 -8.0    -41  40 -18    imp:p=1  $ thimble plug
36     1 -8.0    -41  40 -19    imp:p=1  $ thimble plug
38     1 -8.0    -41  40 -20    imp:p=1  $ thimble plug
40     1 -8.0    -41  40 -21    imp:p=1  $ thimble plug
43     0          40 -41 -22    imp:p=1  $ center void
44     1 -8.0    -41  40 -23    imp:p=1  $ thimble plug
46     1 -8.0    -41  40 -24    imp:p=1  $ thimble plug
48     1 -8.0    -41  40 -25    imp:p=1  $ thimble plug
50     1 -8.0    -41  40 -26    imp:p=1  $ thimble plug
52     1 -8.0    -41  40 -27    imp:p=1  $ thimble plug
54     1 -8.0    -41  40 -28    imp:p=1  $ thimble plug
56     1 -8.0    -41  40 -29    imp:p=1  $ thimble plug
58     0          40 -41 -30    imp:p=1  $ void
59     0          40 -41 -31    imp:p=1  $ void
60     1 -8.0    -41  40 -32    imp:p=1  $ thimble plug
62     1 -8.0    -41  40 -33    imp:p=1  $ thimble plug
64     1 -8.0    -41  40 -34    imp:p=1  $ thimble plug
66     0          10 11 12 13 14 15 16 17  $ void between plugs
                  18 19 20 21 22 23 24 25
                  26 27 28 29 30 31 32 33
                  34
                 -35 40 -41 imp:p=1

c      20 thimble plugs, 4 TPBAR voids, 1 instrument tube void
10     c/z -3.78  7.56 0.5
11     c/z  0     7.56 0.5
12     c/z  3.78  7.56 0.5
13     c/z -6.3   6.3  0.5  $ TPBAR void
14     c/z  6.3   6.3  0.5  $ TPBAR void
15     c/z -7.56  3.78 0.5
16     c/z -3.78  3.78 0.5
17     c/z  0     3.78 0.5
18     c/z  3.78  3.78 0.5
```

```
19     c/z  7.56 -3.78 0.5
20     c/z -7.56  0    0.5
21     c/z -3.78  0    0.5
22     cz              0.5  $ instrument tube void
23     c/z  3.78  0    0.5
24     c/z  7.56  0    0.5
25     c/z -7.56 -3.78 0.5
26     c/z -3.78 -3.78 0.5
27     c/z  0    -3.78 0.5
28     c/z  3.78 -3.78 0.5
29     c/z  7.56 -3.78 0.5
30     c/z -6.3  -6.3  0.5  TPBAR void
31     c/z  6.3  -6.3  0.5  TPBAR void
32     c/z -3.78 -7.56 0.5
33     c/z  0    -7.56 0.5
34     c/z  3.78 -7.56 0.5
c      hold-down plate
35     cz    12
c
40     pz   -16   $ bottom of thimble plug
41     pz    0    $ bottom of plate
42     pz    0.7  $ top of plate

c
m1      26000  1
c
print    -85
c
c       tallies
c
fc12     Top of Plate
f12:p    42
fs12     -35
sd12     452.4 1r
c
fc22     Bottom of Assembly
f22:p    40
fs22     -35
sd22     452.4 1r
c
fc32     Side of Assembly
f32:p    35
fs32     42 -40
sd32     1259 2r
c
mode    p
prdmp    j j 1 2
nps     1000000
sdef      cel=d10 erg=fcel=d20 pos=fcel=d30 rad=fcel=d40
          ext=fcel=d50 axs=0 0 1  wgt=5.1e13
si10     1 10                          $ plate
           20 22 24 28 30 32 34 36     $ thimble plugs
           38 40 44 46 48 50 52 54
           56 60 62 64
sp10      1.13e13 1.99e12 19r
```

```
ds20      s 21 22 19r
ds30      l   0  0  0.35
             -3.78  7.56 -8       0  7.56 -8
              3.78  7.56 -8   -7.56  3.78 -8
             -3.78  3.78 -8       0  3.78 -8
              3.78  3.78 -8    7.56  3.78 -8
             -7.56     0 -8   -3.78     0 -8
              3.78     0 -8    7.56     0 -8
             -7.56 -3.78 -8   -3.78 -3.78 -8
                 0 -3.78 -8    3.78 -3.78 -8
              7.56 -3.78 -8   -3.78 -7.56 -8
                 0 -7.56 -8    3.78 -7.56 -8
ds40     s 41 42 19r
si41       12
si42       0.5
ds50     s 51 52 19r
si51       0.35
si52       8
c
c       Photon source
c         Plate                        Thimble Plugs
c         E, MeV    photons/s          E, MeV    photons/s
#            si21     sp21                si22      sp22
                l        d                   l         d
            0.01   2.76E+12            0.01   6.95E+11
           0.025   4.42E+10           0.025   6.68E+09
          0.0375   2.73E+10          0.0375   4.25E+09
          0.0575   3.48E+10          0.0575   5.49E+09
           0.085   1.80E+10           0.085   2.97E+09
           0.125   1.21E+10           0.125   2.36E+09
           0.225   1.31E+10           0.225   2.53E+09
           0.375   1.62E+12           0.375   4.40E+11
           0.575   4.05E+11           0.575   6.56E+10
            0.85   2.21E+12            0.85   4.50E+11
            1.25   4.01E+12            1.25   3.13E+11
            1.75   7.50E+09            1.75   1.21E+09
            2.25   2.12E+07            2.25   1.66E+06
            2.75   4.76E+05            2.75   5.13E+03
             3.5   2.81E+02             3.5   1.32E-05
               5   2.92E+00               5   1.38E-07
               7   0.00E+00               7   0.00E+00
             9.5   0.00E+00             9.5   0.00E+00
c       TOTAL      1.12E+13                   1.99E+12
c       Grand      5.10E+13
c        Flux to Dose conversion from MCNP Manual
c        ANSI/ANS-6.1.1-1977
c
c        E, MeV      (rem/hr)/(photons/cm2/s)
#          de0         df0
          0.01        3.96e-6
          0.03        5.82e-7
          0.05        2.90e-7
          0.07        2.58e-7
          0.1         2.83e-7
          0.15        3.79e-7
```

0.2	5.01e-7
0.25	6.31e-7
0.3	7.59e-7
0.35	8.78e-7
0.4	9.85e-7
0.45	1.08e-6
0.5	1.17e-6
0.55	1.27e-6
0.6	1.36e-6
0.65	1.44e-6
0.7	1.52e-6
0.8	1.68e-6
1.0	1.98e-6
1.4	2.51e-6
1.8	2.99e-6
2.2	3.42e-6
2.6	3.82e-6
2.8	4.01e-6
3.25	4.41e-6
3.75	4.83e-6
4.25	5.23e-6
4.75	5.60e-6
5.0	5.80e-6
5.25	6.01e-6
5.75	6.37e-6
6.25	6.74e-6
6.75	7.11e-6
7.5	7.66e-6
9.0	8.77e-6
11.0	1.03e-5
13.0	1.18e-5
15.0	1.33e-5

APPENDIX D

Trace Isotope Concentrations

ORIGEN2 output does not report a complete list of radionuclides generated by irradiation as this list would be quite long. Rather, the code provides a threshold value below which concentrations are not reported. For the standard cases, the threshold is set at a value such that any radionuclide whose value is nine orders of magnitude below the total for the TPBAR, Hold-Down Assembly, or Single Thimble Plug is not reported. In most cases this is sufficient to identify important radionuclides of concern. However, parent-daughter products (such as Sr-90 and Y-90) may not both be displayed if one of the radionuclides does not meet the threshold requirements.

Additionally, the calculated ORIGEN2 cases (described in Appendix B) use the power irradiation option to generate the irradiation profile of the components. Power irradiation assumes uranium isotopes to be contained in fuel pins, not trace uranium contained in the metal components of a TPBAR, Hold-Down Assembly, or Single Thimble Plug. Therefore, fission products generated in the ORIGEN2 output for these cases are for fuel pins. Based upon the threshold output value for these standard cases it would not be expected to see the fission products from uranium impurities in the TPBAR, Hold-Down Assembly, or Single Thimble Plug, so the absence from the standard calculations is of no concern.

There are applications, however, where it is necessary to know the concentrations of trace radionuclides generated either from irradiation or from fission of uranium in metal components. A trace radionuclide is defined for the purposes of this calculation as a concentration greater than one picocurie. Table D1 provides a list of these trace radionuclides for the TPBAR excluding tritium.

Table D1. Trace Radionuclide Concentrations in a TPBAR (Ci/TPBAR)

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
BE 10	3.76E-09	3.76E-09	3.76E-09	3.76E-09	3.76E-09	3.76E-09	3.76E-09
C 14	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03
NA 24	1.71E-02	1.43E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MG 28	1.53E-10	1.73E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AL 28	1.53E-10	1.73E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI 32	5.76E-10	5.76E-10	5.76E-10	5.76E-10	5.76E-10	5.73E-10	5.70E-10
P 32	9.13E-01	2.99E-01	1.63E-02	2.08E-04	2.68E-08	5.73E-10	5.70E-10
P 33	1.90E-05	1.01E-05	1.90E-06	1.57E-07	9.23E-10	2.36E-27	0.00E+00
S 35	2.77E-01	2.31E-01	1.44E-01	7.08E-02	1.65E-02	1.65E-07	9.36E-14
CL 36	7.09E-05	7.09E-05	7.09E-05	7.09E-05	7.09E-05	7.09E-05	7.09E-05
AR 37	3.40E-01	2.15E-01	6.57E-02	1.11E-02	2.83E-04	7.84E-17	1.57E-32
AR 39	9.48E-03	9.48E-03	9.47E-03	9.47E-03	9.46E-03	9.36E-03	9.24E-03
AR 42	7.78E-12	7.77E-12	7.74E-12	7.70E-12	7.62E-12	7.01E-12	6.31E-12
K 40	3.03E-08	3.03E-08	3.03E-08	3.03E-08	3.03E-08	3.03E-08	3.03E-08
K 42	1.89E-04	7.77E-12	7.74E-12	7.70E-12	7.62E-12	7.01E-12	6.31E-12
K 43	1.37E-06	6.08E-14	4.01E-33	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
CA 41	7.50E-05	7.50E-05	7.50E-05	7.50E-05	7.50E-05	7.50E-05	7.50E-05
CA 45	2.99E-01	2.71E-01	2.10E-01	1.43E-01	6.52E-02	1.30E-04	5.52E-08
CA 47	1.36E-04	4.05E-06	4.23E-10	4.50E-16	2.28E-28	0.00E+00	0.00E+00
SC 46	7.79E-03	6.44E-03	3.92E-03	1.86E-03	4.02E-04	2.27E-09	6.24E-16
SC 47	4.93E-04	1.53E-05	1.62E-09	1.72E-15	8.74E-28	0.00E+00	0.00E+00
SC 48	1.13E-05	1.83E-09	2.32E-19	3.33E-34	0.00E+00	0.00E+00	0.00E+00
CR 51	8.61E+02	4.84E+02	1.08E+02	1.14E+01	1.10E-01	1.48E-17	2.11E-37
MN 54	4.09E+01	3.88E+01	3.40E+01	2.78E+01	1.85E+01	7.22E-01	1.26E-02
FE 55	2.13E+02	2.10E+02	2.01E+02	1.88E+02	1.64E+02	5.65E+01	1.49E+01
FE 59	1.79E+01	1.26E+01	5.00E+00	1.25E+00	7.20E-02	1.21E-11	7.36E-24
CO 58	2.57E+02	2.05E+02	1.14E+02	4.73E+01	7.70E+00	4.70E-06	8.03E-14
CO 60	3.58E+01	3.55E+01	3.48E+01	3.37E+01	3.15E+01	1.86E+01	9.64E+00
NI 59	1.68E-01	1.68E-01	1.68E-01	1.68E-01	1.68E-01	1.68E-01	1.68E-01
NI 63	2.28E+01	2.28E+01	2.28E+01	2.27E+01	2.27E+01	2.20E+01	2.12E+01
NI 66	1.14E-04	1.03E-07	1.19E-15	1.48E-27	0.00E+00	0.00E+00	0.00E+00
CU 64	1.10E-03	9.03E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CU 66	1.14E-04	1.03E-07	1.19E-15	1.48E-27	0.00E+00	0.00E+00	0.00E+00
CU 67	1.12E-06	2.30E-09	2.26E-16	6.98E-27	0.00E+00	0.00E+00	0.00E+00
ZN 65	4.00E-03	3.75E-03	3.16E-03	2.45E-03	1.45E-03	2.27E-05	1.27E-07
ZN 69	1.09E-12	9.19E-25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ZN 69M	1.02E-12	8.56E-25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ZN 72	5.87E-09	1.57E-12	7.46E-22	7.75E-36	0.00E+00	0.00E+00	0.00E+00
GA 72	8.45E-09	2.25E-12	1.07E-21	1.12E-35	0.00E+00	0.00E+00	0.00E+00
GA 73	5.74E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
GE 73M	5.74E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
GE 77	2.47E-11	4.88E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AS 76	7.57E-01	3.68E-07	1.25E-23	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AS 77	1.11E-07	5.82E-12	3.93E-23	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SE 75	8.38E-01	7.33E-01	5.18E-01	3.08E-01	1.05E-01	2.25E-05	5.78E-10
SE 77M	2.76E-10	1.44E-14	9.75E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SE 79	8.52E-06	8.52E-06	8.52E-06	8.52E-06	8.52E-06	8.52E-06	8.52E-06
BR 80	6.00E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BR 80M	5.61E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BR 82	1.75E-01	3.43E-06	1.81E-18	7.47E-37	0.00E+00	0.00E+00	0.00E+00
KR 79	4.01E-07	6.94E-12	2.63E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KR 81	1.60E-06	1.60E-06	1.60E-06	1.60E-06	1.60E-06	1.60E-06	1.60E-06
KR 85	9.11E-06	9.07E-06	8.97E-06	8.83E-06	8.55E-06	6.60E-06	4.78E-06
KR 85M	7.87E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB 86	7.35E-07	3.13E-07	3.37E-08	1.19E-09	1.22E-12	0.00E+00	0.00E+00
RB 87	6.12E-15	6.12E-15	6.12E-15	6.12E-15	6.12E-15	6.12E-15	6.12E-15
SR 89	6.86E-02	5.01E-02	2.20E-02	6.39E-03	5.02E-04	9.81E-13	1.27E-23
SR 90	2.22E-05	2.22E-05	2.21E-05	2.20E-05	2.17E-05	1.97E-05	1.75E-05
SR 91	7.17E-08	2.31E-25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y 89M	4.76E-04	3.62E-06	1.08E-11	5.55E-20	0.00E+00	0.00E+00	0.00E+00
Y 90	4.45E-01	1.15E-03	2.21E-05	2.20E-05	2.17E-05	1.98E-05	1.75E-05

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
Y 91	1.76E-01	1.34E-01	6.59E-02	2.27E-02	2.53E-03	7.68E-11	3.08E-20
Y 91M	2.05E-09	6.61E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y 92	1.72E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y 93	1.02E-08	3.61E-25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ZR 89	4.77E-04	3.63E-06	1.08E-11	5.56E-20	5.04E-37	0.00E+00	0.00E+00
ZR 93	1.13E-04	1.13E-04	1.13E-04	1.13E-04	1.13E-04	1.13E-04	1.13E-04
ZR 95	6.03E+01	4.70E+01	2.45E+01	9.25E+00	1.24E+00	1.66E-07	4.25E-16
ZR 97	9.67E-02	1.42E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NB 92	2.67E-01	5.56E-02	9.27E-04	2.00E-06	6.49E-12	0.00E+00	0.00E+00
NB 93M	3.83E-06	4.16E-06	5.02E-06	6.29E-06	8.85E-06	2.69E-05	4.49E-05
NB 94	4.75E-04	4.75E-04	4.75E-04	4.75E-04	4.75E-04	4.75E-04	4.75E-04
NB 95	6.51E+01	6.07E+01	4.11E+01	1.83E+01	2.70E+00	3.69E-07	9.43E-16
NB 95M	4.41E-01	3.49E-01	1.82E-01	6.86E-02	9.23E-03	1.23E-09	3.15E-18
NB 96	9.87E-04	7.55E-11	2.06E-29	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NB 97	9.75E-02	1.53E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NB 97M	9.19E-02	1.35E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MO 93M	5.03E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MO 93	1.04E-03	1.04E-03	1.04E-03	1.04E-03	1.04E-03	1.03E-03	1.03E-03
MO 99	1.46E+01	4.43E-02	1.20E-08	1.68E-18	0.00E+00	0.00E+00	0.00E+00
TC 98	1.58E-11	1.58E-11	1.58E-11	1.58E-11	1.58E-11	1.58E-11	1.58E-11
TC 99	4.34E-05	4.35E-05	4.35E-05	4.35E-05	4.35E-05	4.35E-05	4.35E-05
TC 99M	2.36E-04	7.16E-07	1.94E-13	2.73E-23	0.00E+00	0.00E+00	0.00E+00
RU103	4.22E-03	2.81E-03	9.75E-04	1.99E-04	7.58E-06	4.83E-17	4.88E-31
RU105	4.83E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RU106	4.61E-04	4.41E-04	3.94E-04	3.33E-04	2.35E-04	1.50E-05	4.81E-07
RH102	5.31E-10	5.23E-10	5.03E-10	4.74E-10	4.20E-10	1.61E-10	4.89E-11
RH103M	1.16E-03	7.76E-04	2.69E-04	5.50E-05	2.09E-06	1.33E-17	1.35E-31
RH105	4.29E-05	8.58E-10	4.73E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RH105M	1.36E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RH106	4.61E-04	4.41E-04	3.94E-04	3.33E-04	2.35E-04	1.50E-05	4.81E-07
PD107	7.55E-11	7.55E-11	7.55E-11	7.55E-11	7.55E-11	7.55E-11	7.55E-11
PD109	6.72E-08	3.04E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD111	5.74E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD111M	7.87E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD112	1.28E-07	6.92E-16	2.19E-37	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AG106	5.17E-11	7.92E-12	5.94E-14	3.86E-17	1.06E-23	0.00E+00	0.00E+00
AG108	3.03E-11	3.03E-11	3.02E-11	3.02E-11	3.01E-11	2.95E-11	2.87E-11
AG108M	3.40E-10	3.40E-10	3.40E-10	3.39E-10	3.38E-10	3.31E-10	3.22E-10
AG109M	5.98E-06	5.72E-06	5.23E-06	4.57E-06	3.47E-06	3.91E-07	2.55E-08
AG110	4.41E-08	4.14E-08	3.50E-08	2.73E-08	1.63E-08	2.84E-10	1.79E-12
AG110M	3.32E-06	3.11E-06	2.63E-06	2.05E-06	1.23E-06	2.13E-08	1.35E-10
AG111	4.30E-05	5.06E-06	1.90E-08	4.40E-12	1.44E-19	0.00E+00	0.00E+00
AG111M	8.24E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AG112	1.52E-07	8.20E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AG113	8.48E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
CD109	5.92E-06	5.72E-06	5.23E-06	4.57E-06	3.47E-06	3.91E-07	2.55E-08
CD113M	3.55E-08	3.54E-08	3.51E-08	3.47E-08	3.39E-08	2.80E-08	2.21E-08
CD115	2.55E-04	1.99E-07	1.56E-15	1.08E-27	0.00E+00	0.00E+00	0.00E+00
CD115M	1.68E-04	1.18E-04	4.62E-05	1.14E-05	6.41E-07	8.81E-17	4.14E-29
IN113M	1.23E+00	1.07E+00	7.48E-01	4.35E-01	1.43E-01	2.15E-05	3.61E-10
IN114	1.17E-01	8.46E-02	3.65E-02	1.04E-02	7.75E-04	1.02E-12	8.01E-24
IN114M	1.22E-01	8.84E-02	3.82E-02	1.08E-02	8.09E-04	1.06E-12	8.37E-24
IN115	1.03E-20	1.04E-20	1.06E-20	1.07E-20	1.07E-20	1.07E-20	1.07E-20
IN115M	2.51E-06	2.04E-09	3.35E-11	8.27E-12	4.65E-13	6.38E-23	2.96E-35
SN113	1.23E+00	1.07E+00	7.48E-01	4.35E-01	1.43E-01	2.15E-05	3.60E-10
SN117M	7.22E+00	2.31E+00	1.19E-01	1.38E-03	1.44E-07	0.00E+00	0.00E+00
SN119M	8.16E+00	7.65E+00	6.45E+00	5.00E+00	2.96E+00	4.75E-02	2.71E-04
SN121	6.40E-02	4.03E-08	2.70E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SN121M	5.52E-04	5.52E-04	5.51E-04	5.49E-04	5.45E-04	5.15E-04	4.81E-04
SN123	4.53E-01	4.00E-01	2.90E-01	1.79E-01	6.62E-02	2.61E-05	1.44E-09
SN125	1.93E+00	3.69E-01	4.93E-03	7.65E-06	1.26E-11	0.00E+00	0.00E+00
SN126	4.33E-10	4.33E-10	4.33E-10	4.33E-10	4.33E-10	4.33E-10	4.33E-10
SB122	9.51E-02	2.59E-04	5.31E-11	4.91E-21	0.00E+00	0.00E+00	0.00E+00
SB124	1.75E-02	1.35E-02	6.74E-03	2.39E-03	2.83E-04	1.40E-11	1.03E-20
SB125	1.66E+00	1.65E+00	1.59E+00	1.49E+00	1.31E+00	4.82E-01	1.38E-01
SB126	4.95E-02	1.37E-02	4.78E-04	3.12E-06	1.59E-10	6.06E-11	6.06E-11
SB126M	4.33E-10	4.33E-10	4.33E-10	4.33E-10	4.33E-10	4.33E-10	4.33E-10
SB127	3.14E-05	5.00E-07	1.02E-11	9.31E-19	3.04E-33	0.00E+00	0.00E+00
SB128	3.80E-11	1.38E-29	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB129	5.98E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TE123M	2.88E-03	2.52E-03	1.78E-03	1.06E-03	3.61E-04	7.64E-08	1.95E-12
TE125M	3.30E-01	3.42E-01	3.57E-01	3.53E-01	3.19E-01	1.18E-01	3.37E-02
TE127	6.64E-05	3.20E-05	2.15E-05	1.21E-05	3.74E-06	3.45E-10	3.12E-15
TE127M	3.71E-05	3.22E-05	2.20E-05	1.24E-05	3.82E-06	3.52E-10	3.19E-15
TE129	5.02E-05	3.13E-05	9.07E-06	1.42E-06	3.10E-08	2.52E-21	0.00E+00
TE129M	7.72E-05	4.80E-05	1.39E-05	2.18E-06	4.76E-08	3.88E-21	1.69E-37
TE131	5.95E-07	1.72E-12	6.11E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TE131M	2.64E-06	7.64E-12	2.71E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TE132	2.63E-04	1.97E-06	5.64E-12	2.73E-20	2.25E-37	0.00E+00	0.00E+00
I129	6.19E-11	6.21E-11	6.23E-11	6.23E-11	6.23E-11	6.23E-11	6.23E-11
I130	9.21E-09	3.32E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I131	4.73E-04	6.52E-05	3.70E-07	1.58E-10	1.83E-17	0.00E+00	0.00E+00
I132	2.71E-04	2.03E-06	5.81E-12	2.81E-20	0.00E+00	0.00E+00	0.00E+00
I133	6.06E-06	6.22E-14	8.98E-35	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I135	3.37E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
XE127	7.86E-05	5.08E-05	1.62E-05	2.92E-06	8.59E-08	7.17E-20	5.72E-35
XE129M	5.31E-03	7.23E-04	4.00E-06	1.64E-09	1.76E-16	0.00E+00	0.00E+00
XE131M	1.21E-05	4.52E-06	1.74E-07	9.62E-10	1.99E-14	0.00E+00	0.00E+00
XE133	7.57E-04	3.66E-05	1.32E-08	9.01E-14	2.10E-24	0.00E+00	0.00E+00
XE133M	8.53E-06	5.96E-09	3.37E-17	1.43E-29	0.00E+00	0.00E+00	0.00E+00

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
XE135	1.16E-08	6.10E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
XE135M	5.40E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CS131	4.51E-02	2.06E-02	1.02E-03	6.44E-06	1.32E-10	0.00E+00	0.00E+00
CS132	1.03E-07	8.78E-09	1.43E-11	9.32E-16	2.27E-24	0.00E+00	0.00E+00
CS134	6.66E-05	6.52E-05	6.17E-05	5.68E-05	4.79E-05	1.25E-05	2.32E-06
CS135	9.73E-11	9.73E-11	9.73E-11	9.73E-11	9.73E-11	9.73E-11	9.73E-11
CS136	2.01E-05	5.96E-06	2.49E-07	2.13E-09	1.18E-13	0.00E+00	0.00E+00
CS137	4.19E-05	4.19E-05	4.17E-05	4.15E-05	4.10E-05	3.74E-05	3.33E-05
BA131	3.23E-02	8.36E-03	2.47E-04	1.25E-06	2.37E-11	0.00E+00	0.00E+00
BA133	7.40E-04	7.37E-04	7.29E-04	7.18E-04	6.94E-04	5.36E-04	3.89E-04
BA133M	3.16E-05	1.69E-09	1.20E-20	2.26E-37	0.00E+00	0.00E+00	0.00E+00
BA135M	2.40E-04	3.88E-10	3.04E-25	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA136M	3.31E-06	9.82E-07	4.11E-08	3.51E-10	1.95E-14	0.00E+00	0.00E+00
BA137M	3.97E-05	3.96E-05	3.95E-05	3.92E-05	3.88E-05	3.53E-05	3.15E-05
BA140	9.03E-04	2.60E-04	1.01E-05	7.65E-08	3.34E-12	0.00E+00	0.00E+00
LA138	2.71E-20	2.71E-20	2.71E-20	2.71E-20	2.71E-20	2.71E-20	2.71E-20
LA140	1.37E-03	2.99E-04	1.16E-05	8.81E-08	3.84E-12	0.00E+00	0.00E+00
LA141	1.84E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CE141	1.08E-03	6.63E-04	1.84E-04	2.71E-05	5.21E-07	1.55E-20	1.91E-37
CE142	9.97E-15	9.97E-15	9.97E-15	9.97E-15	9.97E-15	9.97E-15	9.97E-15
CE143	3.24E-05	2.99E-10	2.18E-23	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CE144	6.43E-04	6.08E-04	5.25E-04	4.22E-04	2.68E-04	7.61E-06	8.86E-08
PR142	9.80E-08	2.02E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR143	8.34E-04	2.59E-04	1.21E-05	1.21E-07	9.40E-12	0.00E+00	0.00E+00
PR144	6.43E-04	6.08E-04	5.25E-04	4.22E-04	2.68E-04	7.61E-06	8.86E-08
PR144M	7.72E-06	7.29E-06	6.30E-06	5.06E-06	3.22E-06	9.14E-08	1.06E-09
ND144	2.84E-19	2.97E-19	3.28E-19	3.66E-19	4.23E-19	5.20E-19	5.22E-19
PR145	2.70E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PM146	1.19E-09	1.18E-09	1.16E-09	1.12E-09	1.05E-09	6.35E-10	3.38E-10
SM146	2.82E-17	2.85E-17	2.92E-17	3.02E-17	3.22E-17	4.43E-17	5.30E-17
ND147	3.27E-04	7.73E-05	1.80E-06	6.39E-09	5.80E-14	0.00E+00	0.00E+00
PM147	6.65E-05	6.83E-05	6.62E-05	6.21E-05	5.43E-05	1.89E-05	5.04E-06
SM147	2.95E-16	3.23E-16	3.95E-16	4.97E-16	6.88E-16	1.56E-15	1.90E-15
PM148	7.20E-05	4.16E-06	1.85E-07	4.03E-08	1.80E-09	4.03E-20	1.96E-33
PM148M	1.31E-05	8.88E-06	3.24E-06	7.16E-07	3.20E-08	7.15E-19	3.48E-32
SM148	1.45E-20	1.46E-20	1.47E-20	1.48E-20	1.48E-20	1.48E-20	1.48E-20
PM149	5.60E-05	4.15E-08	2.83E-16	1.60E-28	0.00E+00	0.00E+00	0.00E+00
EU150	3.42E-15	3.41E-15	3.40E-15	3.39E-15	3.35E-15	3.10E-15	2.82E-15
PM151	3.06E-06	4.29E-12	2.31E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SM151	1.94E-07	1.94E-07	1.94E-07	1.94E-07	1.93E-07	1.87E-07	1.80E-07
EU152	1.88E-09	1.88E-09	1.86E-09	1.84E-09	1.79E-09	1.46E-09	1.13E-09
EU152M	2.02E-13	2.99E-31	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SM153	3.02E-05	8.35E-09	4.35E-18	5.17E-32	0.00E+00	0.00E+00	0.00E+00
GD153	1.46E-08	1.37E-08	1.16E-08	8.92E-09	5.25E-09	7.99E-11	4.28E-13
EU154	4.56E-06	4.53E-06	4.48E-06	4.39E-06	4.21E-06	3.05E-06	2.04E-06

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
EU155	3.08E-06	3.05E-06	2.98E-06	2.88E-06	2.68E-06	1.53E-06	7.62E-07
SM156	1.14E-10	2.40E-28	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EU156	1.02E-04	3.58E-05	2.32E-06	3.81E-08	8.09E-12	0.00E+00	0.00E+00
EU157	1.38E-08	1.61E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
GD159	1.40E-08	1.63E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TB160	7.71E-07	6.19E-07	3.48E-07	1.47E-07	2.49E-08	2.06E-14	5.12E-22
TB161	8.00E-07	7.99E-08	1.96E-10	2.39E-14	2.09E-22	0.00E+00	0.00E+00
DY166	8.97E-09	8.20E-11	3.94E-16	4.14E-24	0.00E+00	0.00E+00	0.00E+00
HO166	1.47E-08	1.22E-10	5.86E-16	6.17E-24	0.00E+00	0.00E+00	0.00E+00
HO166M	1.53E-12	1.53E-12	1.53E-12	1.53E-12	1.53E-12	1.52E-12	1.52E-12
ER169	1.58E-10	2.90E-11	3.48E-13	4.57E-16	5.34E-22	0.00E+00	0.00E+00
TM170	3.20E-11	2.82E-11	2.04E-11	1.26E-11	4.63E-12	1.76E-15	9.34E-20
TM171	5.22E-13	5.10E-13	4.81E-13	4.40E-13	3.66E-13	8.64E-14	1.42E-14
TM172	6.04E-10	1.47E-12	2.25E-19	1.34E-29	0.00E+00	0.00E+00	0.00E+00
YB175	4.08E-12	9.08E-14	4.44E-18	1.52E-24	8.74E-38	0.00E+00	0.00E+00
LU177	1.88E-03	1.76E-04	1.47E-06	7.45E-07	3.25E-07	4.73E-10	1.34E-13
LU177M	7.02E-06	6.33E-06	4.84E-06	3.24E-06	1.41E-06	2.06E-09	5.84E-13
HF175	2.98E-02	2.37E-02	1.31E-02	5.37E-03	8.58E-04	4.47E-10	6.26E-18
HF180M	3.08E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
HF181	7.98E-01	5.48E-01	2.06E-01	4.72E-02	2.28E-03	9.65E-14	1.04E-26
HF182	7.65E-10	7.65E-10	7.65E-10	7.65E-10	7.65E-10	7.65E-10	7.65E-10
TA182	1.05E+01	9.16E+00	6.38E+00	3.71E+00	1.21E+00	1.82E-04	3.78E-09
TA183	2.17E+01	9.53E-01	2.74E-04	1.34E-09	1.55E-20	0.00E+00	0.00E+00
W181	5.56E-03	4.87E-03	3.46E-03	2.07E-03	7.16E-04	1.68E-07	4.88E-12
W185	1.94E-01	1.57E-01	9.00E-02	3.92E-02	7.09E-03	9.88E-09	4.72E-16
W187	2.33E-02	2.59E-09	1.89E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00
W188	1.40E-02	1.11E-02	6.12E-03	2.49E-03	3.91E-04	1.80E-10	2.16E-18
RE186	2.86E-02	4.19E-04	6.92E-09	4.64E-16	7.95E-31	0.00E+00	0.00E+00
RE187	6.01E-11	6.01E-11	6.01E-11	6.01E-11	6.01E-11	6.01E-11	6.01E-11
RE188	1.52E-02	1.13E-02	6.18E-03	2.52E-03	3.96E-04	1.82E-10	2.18E-18
RE189	5.96E-08	8.65E-15	1.25E-32	0.00E+00	0.00E+00	0.00E+00	0.00E+00
OS191	4.34E-05	1.54E-05	1.04E-06	1.81E-08	4.34E-12	0.00E+00	0.00E+00
OS191M	6.15E-09	1.02E-21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
OS193	1.23E-11	5.34E-17	5.55E-31	0.00E+00	0.00E+00	0.00E+00	0.00E+00
IR192	9.83E-06	7.92E-06	4.52E-06	1.95E-06	3.43E-07	8.05E-12	7.55E-12
IR192M	7.76E-12	7.76E-12	7.76E-12	7.75E-12	7.74E-12	7.65E-12	7.54E-12
IR194	1.52E-09	1.34E-13	1.31E-13	1.28E-13	1.20E-13	7.57E-14	4.25E-14
PT193	3.08E-11	3.09E-11	3.09E-11	3.09E-11	3.09E-11	3.07E-11	3.05E-11
PT193M	5.54E-09	1.36E-10	8.57E-15	4.29E-21	4.61E-34	0.00E+00	0.00E+00
PT195M	6.53E-12	4.07E-14	7.21E-20	1.70E-28	0.00E+00	0.00E+00	0.00E+00
TL207	1.08E-17	1.32E-17	1.78E-17	2.70E-17	4.38E-17	1.86E-16	3.83E-16
TL208	4.94E-14	5.77E-14	8.54E-14	1.31E-13	2.47E-13	1.40E-12	2.25E-12
TL209	6.95E-19	4.78E-19	1.62E-19	1.71E-19	1.62E-19	1.87E-19	2.35E-19
PB205	1.47E-10	1.47E-10	1.47E-10	1.47E-10	1.47E-10	1.47E-10	1.47E-10
PB209	3.22E-17	2.21E-17	7.50E-18	7.91E-18	7.48E-18	8.64E-18	1.09E-17

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
PB210	2.15E-19	2.32E-19	2.47E-19	2.55E-19	2.74E-19	1.03E-18	4.77E-18
PB211	1.08E-17	1.32E-17	1.79E-17	2.70E-17	4.39E-17	1.86E-16	3.84E-16
PB212	1.38E-13	1.61E-13	2.38E-13	3.65E-13	6.86E-13	3.90E-12	6.27E-12
PB214	6.58E-19	6.58E-19	9.11E-19	1.18E-18	1.87E-18	1.33E-17	4.30E-17
BI210	2.90E-09	1.21E-10	3.00E-14	3.73E-19	2.74E-19	1.03E-18	4.77E-18
BI211	1.08E-17	1.32E-17	1.79E-17	2.70E-17	4.39E-17	1.86E-16	3.84E-16
BI212	1.38E-13	1.61E-13	2.38E-13	3.65E-13	6.86E-13	3.90E-12	6.27E-12
BI213	3.22E-17	2.21E-17	7.50E-18	7.91E-18	7.48E-18	8.64E-18	1.09E-17
BI214	6.58E-19	6.58E-19	9.11E-19	1.18E-18	1.87E-18	1.33E-17	4.30E-17
PO210	4.83E-09	4.40E-09	3.26E-09	2.08E-09	8.22E-10	5.47E-13	6.68E-17
PO211	3.02E-20	3.69E-20	5.00E-20	7.57E-20	1.23E-19	5.21E-19	1.08E-18
PO212	8.81E-14	1.03E-13	1.52E-13	2.34E-13	4.40E-13	2.50E-12	4.02E-12
PO213	3.15E-17	2.16E-17	7.34E-18	7.74E-18	7.32E-18	8.45E-18	1.07E-17
PO214	1.26E-17	6.05E-18	1.62E-18	1.20E-18	1.87E-18	1.33E-17	4.30E-17
PO215	1.08E-17	1.32E-17	1.79E-17	2.70E-17	4.39E-17	1.86E-16	3.84E-16
PO216	1.38E-13	1.61E-13	2.38E-13	3.65E-13	6.86E-13	3.90E-12	6.27E-12
PO218	6.58E-19	6.58E-19	9.11E-19	1.18E-18	1.87E-18	1.33E-17	4.30E-17
AT217	3.22E-17	2.21E-17	7.50E-18	7.91E-18	7.48E-18	8.64E-18	1.09E-17
RN218	1.20E-17	5.39E-18	7.10E-19	1.75E-20	0.00E+00	0.00E+00	0.00E+00
RN219	1.08E-17	1.32E-17	1.79E-17	2.70E-17	4.39E-17	1.86E-16	3.84E-16
RN220	1.38E-13	1.61E-13	2.38E-13	3.65E-13	6.86E-13	3.90E-12	6.27E-12
RN222	6.58E-19	6.58E-19	9.11E-19	1.18E-18	1.87E-18	1.33E-17	4.30E-17
FR221	3.22E-17	2.21E-17	7.50E-18	7.91E-18	7.48E-18	8.64E-18	1.09E-17
FR223	2.09E-19	2.36E-19	3.08E-19	4.16E-19	6.42E-19	2.57E-18	5.29E-18
RA222	1.20E-17	5.39E-18	7.10E-19	1.75E-20	0.00E+00	0.00E+00	0.00E+00
RA223	1.08E-17	1.32E-17	1.79E-17	2.70E-17	4.39E-17	1.86E-16	3.84E-16
RA224	1.38E-13	1.61E-13	2.38E-13	3.65E-13	6.86E-13	3.90E-12	6.27E-12
RA225	2.88E-17	1.48E-17	7.21E-18	7.21E-18	7.48E-18	8.64E-18	1.09E-17
RA226	6.95E-19	7.52E-19	9.11E-19	1.18E-18	1.87E-18	1.33E-17	4.30E-17
RA228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E-21
AC225	3.22E-17	2.21E-17	7.50E-18	7.91E-18	7.48E-18	8.64E-18	1.09E-17
AC227	1.51E-17	1.71E-17	2.23E-17	3.01E-17	4.65E-17	1.86E-16	3.84E-16
AC228	1.98E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E-21
TH226	1.20E-17	5.39E-18	7.10E-19	1.75E-20	0.00E+00	0.00E+00	0.00E+00
TH227	1.23E-17	1.46E-17	1.97E-17	2.74E-17	4.32E-17	1.83E-16	3.79E-16
TH228	1.42E-13	1.66E-13	2.37E-13	3.63E-13	6.84E-13	3.89E-12	6.27E-12
TH229	7.28E-18	7.29E-18	7.32E-18	7.37E-18	7.48E-18	8.64E-18	1.09E-17
TH230	2.02E-15	2.12E-15	2.37E-15	2.74E-15	3.50E-15	9.71E-15	1.79E-14
TH231	4.18E-12	3.30E-12	3.30E-12	3.30E-12	3.30E-12	3.30E-12	3.30E-12
TH232	1.81E-21	1.94E-21	2.28E-21	2.79E-21	3.84E-21	1.21E-20	2.25E-20
TH234	2.46E-10	2.46E-10	2.46E-10	2.46E-10	2.46E-10	2.46E-10	2.46E-10
PA231	1.00E-15	1.01E-15	1.02E-15	1.03E-15	1.07E-15	1.35E-15	1.70E-15
PA232	1.25E-12	6.49E-18	1.06E-31	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PA233	7.53E-11	7.89E-11	8.28E-11	8.38E-11	8.39E-11	8.45E-11	8.62E-11
PA234M	2.46E-10	2.46E-10	2.46E-10	2.46E-10	2.46E-10	2.46E-10	2.46E-10

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
PA234	3.20E-13	3.20E-13	3.20E-13	3.20E-13	3.20E-13	3.20E-13	3.20E-13
U230	1.16E-17	5.24E-18	3.50E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U231	1.20E-15	2.55E-17	1.28E-21	4.53E-28	0.00E+00	0.00E+00	0.00E+00
U232	1.15E-12	1.26E-12	1.52E-12	1.90E-12	2.61E-12	5.86E-12	7.00E-12
U233	1.98E-15	2.00E-15	2.06E-15	2.15E-15	2.33E-15	3.81E-15	5.67E-15
U234	1.67E-10	1.67E-10	1.67E-10	1.68E-10	1.69E-10	1.77E-10	1.86E-10
U235	3.30E-12	3.30E-12	3.30E-12	3.30E-12	3.30E-12	3.30E-12	3.30E-12
U236	4.20E-11	4.20E-11	4.20E-11	4.20E-11	4.20E-11	4.20E-11	4.21E-11
U237	1.52E-04	1.43E-05	3.26E-08	2.39E-09	2.33E-09	1.92E-09	1.51E-09
U238	2.46E-10	2.46E-10	2.46E-10	2.46E-10	2.46E-10	2.46E-10	2.46E-10
U240	2.35E-11	3.66E-16	3.66E-16	3.66E-16	3.66E-16	3.66E-16	3.66E-16
NP235	1.77E-12	1.70E-12	1.53E-12	1.31E-12	9.46E-13	7.34E-14	3.00E-15
NP236M	1.83E-11	7.52E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NP236	1.45E-15	1.45E-15	1.45E-15	1.45E-15	1.45E-15	1.45E-15	1.45E-15
NP237	8.25E-11	8.37E-11	8.39E-11	8.39E-11	8.39E-11	8.45E-11	8.62E-11
NP238	1.32E-05	7.10E-09	1.68E-11	1.67E-11	1.67E-11	1.64E-11	1.60E-11
NP239	2.96E-03	3.41E-06	1.24E-08	1.24E-08	1.24E-08	1.24E-08	1.24E-08
NP240M	2.37E-11	3.66E-16	3.66E-16	3.66E-16	3.66E-16	3.66E-16	3.66E-16
PU236	1.76E-10	1.73E-10	1.67E-10	1.57E-10	1.39E-10	5.25E-11	1.56E-11
PU237	2.01E-10	1.42E-10	5.69E-11	1.45E-11	8.68E-13	1.97E-22	1.73E-34
PU238	6.11E-07	6.23E-07	6.46E-07	6.71E-07	6.99E-07	7.03E-07	6.76E-07
PU239	2.33E-07	2.34E-07	2.34E-07	2.34E-07	2.34E-07	2.34E-07	2.34E-07
PU240	3.24E-07	3.24E-07	3.24E-07	3.24E-07	3.24E-07	3.24E-07	3.24E-07
PU241	9.95E-05	9.92E-05	9.84E-05	9.73E-05	9.49E-05	7.83E-05	6.16E-05
PU242	1.34E-09	1.34E-09	1.34E-09	1.34E-09	1.34E-09	1.34E-09	1.34E-09
PU243	2.42E-14	4.01E-17	4.01E-17	4.01E-17	4.01E-17	4.01E-17	4.01E-17
PU244	3.67E-16	3.67E-16	3.67E-16	3.67E-16	3.67E-16	3.67E-16	3.67E-16
PU245	1.44E-14	3.04E-30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PU246	2.40E-13	5.52E-14	1.20E-15	3.21E-18	2.41E-23	8.12E-25	8.12E-25
AM239	4.75E-17	5.16E-31	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AM240	1.82E-11	9.73E-15	2.86E-23	4.58E-36	0.00E+00	0.00E+00	0.00E+00
AM241	5.71E-08	6.71E-08	9.31E-08	1.32E-07	2.10E-07	7.61E-07	1.31E-06
AM242M	3.35E-09	3.35E-09	3.35E-09	3.35E-09	3.34E-09	3.28E-09	3.21E-09
AM242	4.56E-08	3.34E-09	3.33E-09	3.33E-09	3.32E-09	3.26E-09	3.19E-09
AM243	1.24E-08	1.24E-08	1.24E-08	1.24E-08	1.24E-08	1.24E-08	1.24E-08
AM244	5.33E-11	1.88E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AM245	1.79E-14	3.77E-18	3.31E-18	2.73E-18	1.83E-18	7.71E-20	1.48E-21
AM246	2.40E-13	5.53E-14	1.20E-15	3.81E-18	2.41E-23	8.12E-25	8.12E-25
CM241	9.17E-12	5.89E-12	1.85E-12	3.28E-13	9.26E-15	5.62E-27	0.00E+00
CM242	2.33E-05	2.11E-05	1.64E-05	1.12E-05	5.09E-06	1.30E-08	2.64E-09
CM243	8.85E-09	8.83E-09	8.80E-09	8.75E-09	8.64E-09	7.84E-09	6.94E-09
CM244	1.26E-06	1.26E-06	1.25E-06	1.24E-06	1.21E-06	1.04E-06	8.60E-07
CM245	8.80E-11	8.80E-11	8.80E-11	8.80E-11	8.80E-11	8.80E-11	8.80E-11
CM246	1.65E-11	1.65E-11	1.65E-11	1.65E-11	1.65E-11	1.65E-11	1.65E-11
CM247	4.01E-17	4.01E-17	4.01E-17	4.01E-17	4.01E-17	4.01E-17	4.01E-17

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
CM248	8.05E-17	8.05E-17	8.05E-17	8.05E-17	8.05E-17	8.05E-17	8.05E-17
CM249	8.38E-19	3.42E-19	3.47E-20	1.69E-21	1.26E-24	0.00E+00	0.00E+00
BK249	2.74E-13	2.60E-13	2.29E-13	1.88E-13	1.26E-13	5.32E-15	1.02E-16
BK250	1.83E-18	1.73E-18	1.49E-18	1.17E-18	7.29E-19	4.14E-20	1.47E-20
CF249	6.32E-17	9.65E-17	1.76E-16	2.77E-16	4.32E-16	7.28E-16	7.34E-16
CF250	3.75E-15	3.74E-15	3.70E-15	3.66E-15	3.56E-15	2.88E-15	2.21E-15
CF251	1.99E-17	1.99E-17	1.99E-17	1.99E-17	1.99E-17	1.98E-17	1.97E-17
CF252	3.45E-15	3.39E-15	3.25E-15	3.05E-15	2.67E-15	9.32E-16	2.51E-16
CF253	2.70E-16	1.10E-16	1.12E-17	5.45E-19	4.04E-22	0.00E+00	0.00E+00
CF254	4.35E-18	3.21E-18	1.76E-18	5.59E-19	2.14E-19	1.15E-26	9.40E-36
ES253	2.06E-16	1.85E-16	5.00E-17	3.95E-18	4.73E-19	0.00E+00	0.00E+00
ES254M	5.27E-18	3.12E-22	2.91E-33	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ES254	1.83E-18	1.73E-18	1.47E-18	1.13E-18	7.29E-19	4.14E-20	1.47E-20
TOTAL	1.65E+03	1.15E+03	6.03E+02	3.72E+02	2.55E+02	9.87E+01	4.61E+01

In order to provide the results in Table D1 it was necessary to convert the ORIGEN2 case from a power irradiation to a flux irradiation for the TPBAR. The output file from the input file shown in Appendix B provides an equivalent flux irradiation to the specified power irradiation in the input file. Using this information, it is possible to include the trace uranium in the metal components to generate a complete listing of radionuclides. Table D1 contains a summation of the activation products, the actinides and daughters, and the fission products. A listing of the input file is provided below.

Small_Origen.inp

```
-1
-1
-1
TIT     Prod.  Reactor Target Rod Waste Eval.:  TPBAR
RDA     FLUX=5.16435E14
BAS     1 TPBAR
LIB     0 1 2 3 204 205 206 9 3 0 1 1
PHO     101 102 103 10
LIP     0 0 0
INP     1 1 -1 -1 1 1
BUP
IRF      50.  5.16435E14  1  2  4  2
IRF     100.  5.16435E14  2  3  4  0
IRF     150.  5.16435E14  3  4  4  0
IRF     200.  5.16435E14  4  5  4  0
IRF     250.  5.16435E14  5  6  4  0
IRF     300.  5.16435E14  6  7  4  0
IRF     350.  5.16435E14  7  8  4  0
IRF     400.  5.16435E14  8  9  4  0
IRF     450.  5.16435E14  9 10  4  0
IRF     500.  5.16435E14 10 11  4  0
IRF     510.  5.16435E14 11  1  4  0
BUP
DEC       7.             1  2  4  2
```

```
DEC      30.              2  3  4  0
DEC      90.              3  4  4  0
DEC     180.              4  5  4  0
DEC       1.              5  6  5  0
DEC       5.              6  7  5  0
DEC      10.              7  8  5  0
HED      1   Discharge
HED      2    7 Days
HED      3   30 Days
HED      4   90 Days
HED      5  180 Days
HED      6    1 Year
HED      7    5 Years
HED      8   10 Years
OPTL     8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTA     8 8 8 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTF     8 8 8 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
CUT      7 3.0E-17 -1
OUT      8  1  0  -1
STP      4
1         30060 6.48E+00    30070 1.49E+01        0       0.0
2        922340 4.14E-08   922350 5.42E-06   922380 7.48E-04        0       0.0
4        260000 3.50E+02   240000 1.02E+02   280000 3.35E+02    80000 1.02E+02
4        130000 8.66E+01   330000 2.75E-01    50000 1.14E-02   560000 1.68E-01
4         60000 7.12E-01   200000 8.40E-01   480000 1.08E-04   270000 2.87E-01
4        290000 2.37E-01    10000 5.38E-03   720000 2.15E-02   190000 1.05E+00
4        120000 4.24E-01   250000 1.13E+01   420000 1.70E+01    70000 7.37E-02
4        110000 1.05E+00   410000 2.83E-01   150000 2.26E-01   820000 8.40E-02
4        160000 5.65E-02   340000 7.35E-02   140000 6.36E+00   500000 3.66E+00
4        730000 1.13E-01   220000 1.08E-02   230000 2.83E-01   740000 2.15E-02
4        400000 2.10E+02    90000 3.15E-02   170000 3.15E-02   530000 3.15E-02
4        350000 3.15E-02        0       0.0
0
END
```

APPENDIX 1-D

DOE Drawing H-3-307845, "Production TPBAR Reactor Interface Dimensions Watts Bar," Revision 10, Sheet 1 of 2

UNCLASSIFIED

UNCLASSIFIED

Security-Related Information
Figure Withheld Under 10 CFR 2.390

U. S. DEPARTMENT OF ENERGY
PACIFIC NORTHWEST NATIONAL LABORATORY
PRODUCTION TPBAR REACTOR
INTERFACE DIMENSIONS WATTS BAR
H-3-307845 10

UNCLASSIFIED

APPENDIX 1-E

DOE Drawing H-3-308875, "Production TPBAR Reactor Interface Dimensions Sequoyah," Revision 5, Sheet 1 of 2

UNCLASSIFIED

UNCLASSIFIED

Security-Related Information
Figure Withheld Under 10 CFR 2.390

U. S. DEPARTMENT OF ENERGY

PACIFIC NORTHWEST NATIONAL LABORATORY

PRODUCTION TPBAR REACTOR
INTERFACE DIMENSIONS SEQUOYAH

H-3-308875

UNCLASSIFIED

APPENDIX 1-F

DOE Drawing H-3-310568, "Mark 8 Multi-Pencil TPBAR – Watts Bar Reactor Interface," Revision 0, Sheet 1 of 2

UNCLASSIFIED

Security-Related Information
Figure Withheld Under 10 CFR 2.390

U. S. DEPARTMENT OF ENERGY
PACIFIC NORTHWEST SITE OFFICE
Battelle
MARK 8 MULTI PENCIL
TPBAR - WATTS BAR
REACTOR INTERFACE
TRITIUM TECHNOLOGY PROGRAM
D | 5003 | H-3-310568 | 0
SCALE 6" = 1" | SHEET 1 OF 2

UNCLASSIFIED

2/2

APPENDIX 1-G

PNNL Letter, TTP-06-056, Subject: Exposure of Shipping Casks to Tritium, February 21, 2006

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

February 21, 2006 TTP-06-056

Ms. Nanette D. Founds
Tritium Readiness Subprogram
Office of Stockpile Technology (NA-123)
Department of Energy/NNSA
PO Box 5400
Albuquerque, NM 87185-5400

Dear Ms. Founds:

EXPOSURE OF SHIPPING CASKS TO TRITIUM

Pacific Northwest National Laboratory was assigned a Tritium Readiness Subprogram Action Item to "Draft position on NRC tritium cask exposure issue" (AI 43). Attached is a white paper summarizing the conclusions we presented during the teleconference with NAC International, Inc.; U.S. Nuclear Regulatory Commission; and National Nuclear Security Administration to complete this action.

If you have any questions regarding the information in this paper, please contact me or Bruce Reid at (509) 372-4135.

Sincerely,
Cheryl K. Thornhill
Cheryl K. Thornhill, Manager
Tritium Technology Program

/bjk
Enclosure

ecc: J. R. Chapman, SAIC
C. J. Rogers, SAIC
M. Holloway, SAIC
cc: J. Adam, NAC
B. G. McLeod, DOE-PNSO
NA-123 RMS/SS (05-10)

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Nuclear Regulatory Commission Concerns Regarding Shipping Tritium Producing Burnable Absorber Rods in the NAC-LWT Cask

Background

In conversations with NAC licensing personnel in preparation for their submittal of a license amendment request for the NAC-LWT cask to handle future shipments of tritium producing burnable absorber rods (TPBARs), staff from the U.S. Nuclear Regulatory Commission (NRC) expressed some concerns regarding the potential for residual tritium contamination in the crystalline structure of the stainless steel to be an issue for subsequent cask users. While the NRC had no firm calculations, some "back-of-the-envelope" calculations by an NRC materials expert indicated that residual tritium could be an issue of concern for the subsequent cask users who were not expecting tritium contamination.

A conference call was held on January 26, 2006 with representatives of NRC, NNSA, Westinghouse Savannah River Company (WSRC), NAC and Pacific Northwest National Laboratory (PNNL) participating. At the conclusion of the call, NRC was satisfied with the responses received and requested that NAC provide, in Chapter 7 of the NAC-LWT Safety Analysis Report, a discussion of the procedures to be followed when unloading TPBARs and before sending the empty cask back to NAC.

During the conference call, PNNL staff discussed the experience with shipping TPBARs to date and the potential for tritium to permeate from the irradiated TPBARs into the Stainless Steel cask wall.

Transportation Experience

The NRC has licensed the NAC-LWT cask to ship up to 300 TPBARs including 2 pre-failed TPBARs. To date, there have been 9 shipments of TPBARs to various locations as noted below:

- 4 shipments of 8 TPBARs each from Watts Bar Nuclear Plant (WBN) to Idaho National Laboratory (INL) (1999)
- 1 shipment of 3 sectioned TPBARs (12 sections) from INL to PNNL (2000)
- 1 shipment of 6 TPBARs from WBN to INL (2005)
- 1 shipment of 3 TPBARs from INL to PNNL (2005)
- 1 shipment of 215 TPBARs from WBN to the Savannah River Site Tritium Extraction Facility (TEF) (2005)
- 1 shipment of 19 TPBARs from WBN to TEF (2005)

The last two shipments will remain stored at TEF in the NAC-LWT shipping casks until the TEF is ready to process the tritium.

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Discussion

Prior to opening the casks bearing TPBARs, both INL and PNNL have sampled the gas in the cask cavity to assure that there would not be a tritium release to the environment or to facility personnel. In all cases, the gas samples have tested at negligible levels for tritium (~1E-6 μCi/cc). Also, prior to sending the empty cask back to NAC for use by others, "swipes" of the internal surfaces have been taken to assure that contamination was not present. Samples taken on the consolidation container and the basket within the cask cavity showed tritium levels ranging from ~25 to ~1050 disintegrations per minute per 100 cm^2, well below any levels of concern for contamination. A similar procedure will be followed at TEF when they open and return the NAC-LWT casks. The TPBARs are contained in the stainless steel consolidation container and the basket holds the consolidation container. Both are between the TPBARs and the cask inner wall, thus if contamination is present, it would be noticed first on the consolidation container and basket before it would affect the cask wall.

When the TPBARs at INL were punctured, the gas pressure inside the rod was measured and the gas analyzed. The tritium partial pressure in the gas was below 5 $X10^{-3}$ Pa of T_2 which is ~5 X 10^{-8} atmospheres, i.e., equivalent to a very good vacuum with respect to tritium. Hence, there is little driving force for permeation of the tritium out of the unbreached TPBARs during storage and shipment. With no driving force, there is no mechanism for the tritium to permeate from the TPBARs into the cask inner wall. As noted above, there have been no shipments to date at the licensed limit (300) for TPBARs; however the number of TPBARs in the cask will not change the tritium partial pressure inside the individual TPBAR. The number of TPBARs in the shipment does affect the temperature in the cask cavity (at 30 days after discharge from the reactor, each TPBAR produces ~3.3 watts of decay heat). The temperature that will exist when shipping 300 TPBARs is well below the temperature required to drive the tritium out of the TPBARs to any significant degree within the time frame of expected residence in the cask.

With regard to the two (2) pre-failed TPBARs in a shipment, which is part of the licensing basis for the cask, it is assumed that the failure occurs near the end of the plant operating cycle when the TPBAR has generated the maximum amount of tritium. The isotopic exchange that takes place between the tritium in the TPBAR and the hydrogen in the reactor coolant system (and the spent fuel pool after the TPBARs are discharged from the reactor) is expected to remove essentially all of the tritium from the TPBAR, thus the tritium available to "leak" from the TPBAR to the cask wall is still expected to be negligible. The failed TPBARs will have no internal pressure and any residual tritium would first contact the consolidation container and basket before the cask inner wall is exposed. Another scenario would be damage to two TPBARs during handling in the spent fuel pool while removing the TPBAR base plate from the fuel assembly. In this case, TVA procedures will have the breached TPBAR placed in another tube which can be sealed to prevent further tritium contamination of the spent fuel pool. During the time

it will take to remove the TPBAR from the baseplate, get the secondary tube, and place the TPBAR in the tube, a significant amount of the tritium will have been released to the spent fuel pool through isotopic exchange. Because of the precautions to be taken and the low driving force to move tritium from the TPBAR, contamination of the cask cavity is not expected to be a significant issue. In this scenario, the TPBAR will be enclosed in a secondary tube contained in the consolidation container, so an additional barrier will exist between the TPBAR and the cask wall.

If the tritium partial pressure in the cask did rise to some higher level (we have not performed calculations to determine what pressure would be required) then tritium surface contamination would be expected. Experiments performed by Hirayabashi and Saeki (JNM 120 (1984) 309-315) examined stainless steel coupons after exposing the coupons to relatively high pressure tritium gas (13,300 Pa compared to the $<5X10^{-3}$ Pa found inside of TPBARs at INL). They did find subsurface tritium in the steel after exposure at this pressure. However, it is significant to note that they also found surface concentrations of tritium in the sample almost 2 orders of magnitude greater than the levels in the bulk (i.e. beneath the surface). Hence, extrapolation of these results to the NAC-LWT cask situation would indicate that highly contaminated surface smears would identify that subsurface tritium concentrations of lower levels (~2 orders of magnitude lower) existed. At some level of surface contamination, it is evident from the literature that the surface contamination would indicate there had been enough tritium permeate into the cask wall that subsequent leaching of tritium from the bulk could present a concern for subsequent users. No work has been done to determine what this level of surface contamination is. However, at the low tritium partial pressure in the TPBARs, the risk of achieving a high level of surface contamination is small and, as noted above, there are other stainless steel surfaces between the TPBARs and the cask wall. If an abnormally high level of surface contamination is found, this issue will need to be addressed.

Conclusion

Based on past experience and the above discussion, it is concluded that the potential for tritium contamination of the NAC-LWT cask inner wall is minimal. The steps that will be taken to monitor the cask gas prior to opening the cask and the taking of smears on the internal surfaces will provide assurance that residual tritium contamination is not an issue of concern for subsequent users.